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The Effects of Coal Upgrading and Blending on the Combustion Performance Characteristics of Low-Rank Philippine Coals

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Coal is one of the most abundant sources of energy in the Philippines. About 90% of the Philippine's most economically recoverable reserves of coal is subbituminous (60%) and lignite (30%), which are usually referred to as low-rank coals. Most low-rank Philippine coals are usually low-grade with poor consistency and poor combustion characteristics. Their utilization is restricted by their high moisture content, low heating value, and high ash content. Due to these problems, some big coal users in the country like the cement industries and thermal power plants have opted to use high-grade imported coals mainly from Australia and Indonesia.

To increase the local coal percentage in the domestic coal usage, it is necessary to attract the big coal users to increase their utilization of local low-rank coals. This can be done by upgrading the quality of the local low-rank coals to meet the requirements of these coal users. Local coals are cheaper, readily available, and its acquisition does not involve foreign currencies. The utilization of more local coals would therefore mean not only possible reduction in the operating costs of the coal-fired plants, but also lower import bills for the country.

There are various methods of upgrading low-grade coals. Two of these methods are ***coal cleaning*** and ***coal blending***. This study was conducted to determine the effects of coal upgrading and blending on the properties of low-rank Philippine coals. Characterization tests on the different raw run-of-mine and cleaned low-rank Philippine coals and blends of low-rank Philippine and high-rank Australian coals were conducted to determine the fuel and ash performance characteristics. Comparative analyses were conducted on the fuel and ash properties of the raw, cleaned, and blended coals, and the coal quality requirements of the industries.

Methodology

Low-rank Philippine coals from the southern, central and northern parts of Cebu, Surigao and Semirara were studied. Coal samples were brought by the author to the University of New South Wales (UNSW) in Sydney, Australia for

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testing and analysis. A series of standard ASTM coal analyses and some bench scale tests were performed on these coal samples at different laboratories. The following coal characterization tests were conducted: proximate analysis, ultimate analysis, heating value determination, ash fusion test, x-ray fluorescent tests, crucible free swelling index tests, and Hardgove grindability index test.

The apparent ranks of the different coal samples were determined based on their properties. Two of these coal samples, Surigao and Central Cebu (Uling) coals, which were classified under the low-rank category based on their ash compositions, were subjected to upgrading processes by coal cleaning and coal blending. Coal upgrading was conducted on raw run-of-mine Surigao and Central Cebu coals by applying the standard coal cleaning techniques like the heavy medium separation method and the use of shaking and pneumatic tables and jigs. The cleaned Surigao and Uling coals were also subjected to a series of coal characterization tests. The slagging, fouling and other indices of the baseline and cleaned Surigao and Uling coals were determined using the results of the laboratory and bench scale tests.

Raw low-rank Surigao and Central Cebu coal samples were also upgraded by blending these with high-grade Australian coals in varying proportions. The fuel and ash properties of the resulting coal blends were determined. The slagging and fouling potentials of the different coal blends were also determined. The fuel and ash properties of the raw, cleaned, and blended coals were compared with the coal quality requirements of the cement plants, power plants and other industries to determine their suitability.

Results and Discussion

A. Standard Coal Analyses

The results of the standard coal laboratory analysis for the different raw Philippine coals are summarized in Table 1. Of the four samples tested in the laboratory Danao coal has the highest gross specific energy (gross heating value) of 26.19 MJ/Kg (11,260 Btu/lb), air-dry basis (ad), with the Uling coal having the lowest at 18.24 MJ/Kg (7,837 Btu/LB), (ad). The sulfur contents of the samples are fairly low with the highest value being only 1.1 percent by weight for Surigao coal, air-dry basis. Southern Cebu coal has the lowest sulfur content with only 0.57% (ad). Surigao and Uling coals have high ash content with 21 percent by weight for Surigao and 20.2 percent for Uling, air-dry basis. As expected, coals with higher carbon content have also high gross specific energy (heating value). All the coals tested have relatively low volatile matter content ranging from only 33.6 percent (ad) for Uling coal to 38.3 percent (ad) for Danao coal. This is significant considering that fuels with low volatile matter contents could pose some combustion problems especially on flame stability. Danao coal with the highest gross specific energy has also the highest carbon content at 61.64% by weight (ad). Uling coal with the lowest gross specific energy has also the lowest carbon content at 45.77% (ad).

Table 2 shows the ash fusion characteristics, the crucible swelling indices and the ash analyses of the different coal samples. Semirara coal has the highest silica (SiO2) content with 45.1% followed by Uling (Central Cebu) coal with 42.29%. Danao coal has the lowest silica content with only 33.25%. Southern Cebu coal has the highest aluminum (Al2O3) content with 23.0% by weight followed by Semirara coal with 21.3%. Based on their ash analyses Surigao, Semirara, Southern Cebu and Uling coals could be classified as low-rank (sub-bituminous and lignite) coals since their dolomite (CaO + MgO) contents are greater than their iron oxide (Fe2O3) contents. Considering this, Surigao coal could then be considered as subbituminous because of its calorific value. Applying the PARR formula, Uling coal will also classify as subbituminous. Semirara coal has the highest ash fluid temperature at 1404°C followed by Southern Cebu coal with 1348°C. Surigao coal has the lowest ash fluid temperature at 1186°C. It could be noted that Semirara and Southern Cebu coals have high combined silica and aluminum (SiO2 + Al2O3) contents.

Table 1
Laboratory Analyses of Philippine Coals
(Air-Dry Basis)

	Surigao	Southern Cebu	Danao	Uling	Semirara
PROXIMATE (wt.%)					
Moisture	3.6	5.5	7.0	12.2	15.2
Ash	21.0	8.0	11.7	20.2	14.2
Volatile Matter	36.8	37.6	38.3	33.6	35.7
Fixed Carbon	38.6	38.9	43.0	34.0	34.9
ULTIMATE (wt.%)					
Carbon	56.2	57.18	61.64	45.77	53.2
Hydrogen	4.23	4.65	4.86	3.72	3.8
Nitrogen	1.0	1.27	1.58	1.07	1.0
Sulfur	1.1	0.57	1.02	0.84	0.64
Oxygen	12.87	12.83	12.2	16.30	11.96
GROSS SPECIFIC ENERGY					
MJ/kg	23.9	23.06	26.19	18.24	19.98
Btu/lb	10,312	9,918	11,260	7,837	8,592
Kcal/kg	5,729	5,509	6,257	4,357	4,773

B. Coal Cleaning Results

Two of the low-rank Philippine coal samples with high ash contents were subjected to coal cleaning. These are Uling coal with 20.2% ash content and Surigao coal with 21.0%, air-dry basis. The results of the laboratory and bench scale tests for the baseline and cleaned Surigao subbituminous coal are summarized in Table 3. Data on baseline Surigao are typical of a low-rank subbituminous Philippine coal. The table shows that coal cleaning reduces the ash content. From a baseline ash content of 21.78% by weight dry basis (d), the ash content was reduced to 14.28 % by weight; (d). In terms of heat value, from a baseline ash content of 0.0088 Kg ash/MJ (d), coal cleaning reduced this to 0.0052 Kg ash/MJ (db) for the cleaned coal. This is an ash reduction of more than 30%. The sulfur content was reduced from 1.14% by weight (db) to 1.05% (db) or a reduction of about 8%. The gross specific energy or heating value increased from 10,660 Btu/lb (d) to 11,810 Btu/lb (d). Coal cleaning reduced the silica content in the baseline ash from 42.70% to 31.41% in the cleaned coal ash. The aluminum content was also reduced from 10.32% in the baseline ash to 9.06% in the cleaned coal ash. The iron, calcium and magnesium contents increased with coal cleaning. The reduction in the silica and aluminum contents and the increase in iron, calcium and magnesium contents could be attributed to the removal of the coarse quartz particles and fine clay minerals during cleaning. Coal cleaning re-

Table 2

Ash Fusion Characteristics, Swelling Properties and Ash Analyses of Philippine Coals

	Surigao	Southern Cebu	Danao	Uling	Semirara
ASH FUSIBILITY TEST (deg C)					
Initial Deformation Temperature	1170	1295	1188	1245	1248
Softening Temperature	1176	1320	1202	1264	1303
Hemispherical Temperature	1180	1330	1205	1275	1316
Fluid Temperature	1186	1348	1235	1302	1404
CRUCIBLE SWELLING NUMBER	1.5	1	1	1	1
HARDGROVE INDEX	48	55	52	58	42
ASH ANALYSIS (wt. %)					
SiO2	40.85	37.18	33.25	42.29	45.1
Al2O3	9.88	23.0	11.36	19.45	21.3
Fe2O3	10.35	11.59	21.35	10.32	7.1
TiO3	0.56	1.33	0.75	0.78	0.8
CaO	20.35	11.66	16.91	8.42	8.0
MgO	2.09	1.59	1.77	2.99	5.0
Na2O2	0.47	0.95	1.14	3.27	3.6
K2O	0.53	0.21	0.65	1.28	0.2
P2O5	0.04	0.9	0.04	0.06	0.21
Mn3O4	0.04	0.12	1.15	0.10	0.07
SO3	10.52	8.48	7.89	7.24	7.2
(CaO + MgO)/Fe2O3	2.17	1.34	0.87	1.11	1.83

Table 3

Fuel Analyses of Surigao Subbituminous *

	Baseline		Cleaned	
PROXIMATE (wt.%)				
Ash	21.74		14.28	
Volatile Matter	38.18		40.69	
Fixed Carbon	40.04		45.03	
ULTIMATE (wt.%)				
Carbon	58.30		63.88	
Hydrogen	4.39		4.06	
Nitrogen	1.04		1.04	
Sulfur	1.14		1.05	
Oxygen	13.35		15.69	
Ash	21.78		14.28	
SPECIFIC ENERGY				
Btu/lb	10,660		11,810	
MJ/kg	24.29		27.47	
Kcal/kg	5,929		6,569	
Kg Ash/MJ	0.0088		0.0052	
ASH FUSION TEMPERATURES (°C)				
Initial Deformation Temperature	1170		1130	
Softening Temperature	1176		1145	
Hemispherical Temperature	1180		1150	
Fluid Temperature	1186		1165	
ASH COMPOSITION (wt. %)	Ash Basis	Coal Basis	Ash Basis	Coal Basis
SiO2	42.70	9.30	31.41	4.49
Al2O3	10.32	2.25	9.06	1.29
Fe2O3	10.82	2.36	12.02	1.72
TiO2	0.59	0.13	0.71	0.10
CaO	21.27	4.63	27.56	3.94
MgO	2.18	0.48	3.02	0.43
Na2O	0.49	0.10	0.51	0.07
K2O	0.56	0.12	0.32	0.05
P2O5	0.04	0.01	0.04	0.01
Mn3O4	0.05	0.01	0.05	0.01
SO3	10.98	2.39	15.30	2.18
Total	100.00	21.78	100.00	14.28

*dry basis

Table 4

Fuel Analyses of Uling Subbituminous *

	Baseline		Cleaned	
PROXIMATE (wt.%)				
Ash	22.89		16.38	
Volatile Matter	38.38		40.74	
Fixed Carbon	38.73		42.88	
ULTIMATE (wt.%)				
Carbon	52.13		56.35	
Hydrogen	4.24		3.93	
Nitrogen	1.22		1.22	
Sulfur	0.96		0.87	
Oxygen	18.56		21.25	
Ash	22.89		16.38	
SPECIFIC ENERGY				
Btu/lb	8,930		9,894	
MJ/kg	20.77		23.01	
Kcal/kg	4,965		5,503	
ASH FUSIBILITY TEST (deg C)				
Initial Deformation Temperature	1245		1230	
Softening Temperature	1264		1245	
Hemispherical Temperature	1275		1260	
Fluid Temperature	1302		1280	
Kg Ash/MJ	0.011		0.0071	
ASH COMPOSITION (wt. %)	Ash Basis	Coal Basis	Ash Basis	Coal Basis
SiO2	43.97	10.07	33.16	5.43
Al2O3	20.23	4.63	18.56	3.04
Fe2O3	10.73	2.45	13.24	2.17
TiO2	0.79	0.18	1.22	0.20
CaO	8.75	2.01	12.04	1.97
MgO	3.11	0.72	4.34	0.71
Na2O	3.40	0.78	4.06	0.67
K2O	1.33	0.30	0.76	0.12
P2O5	0.06	0.01	0.06	0.01
Mn3O4	0.10	0.02	0.10	0.02
SO3	7.52	1.72	12.45	2.04
Total	100.00	22.89	100.00	16.38

* dry basis

duced the ash fusion temperatures which means that the cleaned coal ash has higher basic constituents compared to the baseline coal.

Table 4 shows the laboratory and bench scale test results for the baseline and cleaned Uling coal. The specific energy increased from 8,930 Btu/lb (d) for baseline coal to 9,894 Btu/lb (d) for cleaned coal. The ash content was reduced from 0.011 Kg ash/MJ (d) for the baseline coal to 0.0071 Kg ash/MJ (d) for the cleaned coal. Sulfur content was likewise reduced from 0.96% by weight (d) for the baseline coal to 0.87% (d) for the cleaned coal.. Coal cleaning reduced the SiO_2 and Al_2O_3 contents of the ash while the Fe_2O_3, CaO and MgO contents were increased. These could be attributed to the removal of the coarse quartz particles and fine clay minerals. The ash fusion temperatures were also reduced with the application of coal cleaning. For the Uling coal the ash fluid temperature was reduced from 1302 °C or the baseline coal to 1280 °C for the cleaned coal. The reduction in the ash fusion temperature is an indication that the cleaned coal has higher basic constituents.

The slagging, fouling, ash deposit-forming propensity and erosion indices and potentials of the Surigao and Uling coals were evaluated using the data obtained from the laboratory and bench scale tests. The results are summarized in Table 5. Baseline Surigao has a medium to high slagging potential while cleaned Surigao has a medium to severe slagging potential. On the overall, both baseline and cleaned Uling have medium slagging potentials. Baseline Surigao has medium or moderate fouling potential while cleaned Surigao has a high fouling potential. Both baseline and cleaned Uling have high to severe fouling potential. The ash deposit-forming propensity and erosion potentials of baseline and cleaned Surigao are low. The ash deposit-forming propensity for both baseline and cleaned Uling are severe. For the erosion potential, which is a function of the abrasiveness of the coal ash measured in terms of the silica and aluminum content, baseline and cleaned Surigao have low potentials. The erosion potential is severe for baseline and intermediate for cleaned Central Cebu (Uling) coals.

C. Coal Blending Results

Two low-rank Philippine (Surigao and Central Cebu) subbituminous coals were blended with two high-rank Australian (Hunter Valley and Katoomba) bituminous coals. The following blend proportions in weight percent were made: 75% Philippine coal - 25% Australian coal; 50% Philippine and 50% Australian and 25% Philippine and 75% Australian coal. These blend proportions were applied for the Surigao and Hunter Valley coals and also for the Central Cebu (Uling) and Katoomba coals. The fuel and ash characteristics of these original (100%) coals and the resulting coal blends are shown in Table 7. At 25% Surigao and 75% Hunter Valley (25%S:75%HV) blend proportion, the resulting blend (Blend No.3) has an ash content of 15.38% and a gross heating value of 11,783 Btu/lb which is higher than that of the original Surigao (100%S) coal. At 50%S:50%HV blend proportion, the resulting ash content of the blend (Blend No.2) is 17.25% by weight which is lower than the ash content of the original

Surigao coal. The gross heating value of the blend, which is 11,291 Btu/lb, is higher than that of the 100% Surigao coal.

The slagging and fouling factors of the resulting two S and HV blends (No.2 and No.3) are low which means that the slagging and fouling potentials are lower compared to the medium slagging and fouling potentials for the original Surigao coal. The alkali content, which is an indication of the ash-forming propensity of coal, is low for both the original Surigao and the resulting coal blends. For a 50% Uling and 50% Katoomba (50%U:50%K) blend proportion, the ash content of the resulting blend (Blend No.2) is 16.69% which is lower than 20.1% ash content for the original Uling coal. The gross heating value for the blend is 10,131 Btu/lb, which is higher than 7,844 Btu/lb for the original Uling (100%U) coal. The fouling potential and alkali content have improved from severe for the original Uling coal to medium potential for the resulting blend (Blend No.2). At 25%U:75%K the fouling potential and alkali content are further improved to low fouling potential and low alkali content for the resulting blend (Blend No.3). The ash content of only 14.99% for the resulting blend is lower than the ash content of 20.1% for the original Uling coal. The gross heating value has improved to 11, 274 Btu/lb for resulting Blend No.3 compared to only 7,844 for the 100% Uling coal.

D. Comparison with the Coal Quality Requirements of the Industries

Table 6 shows the coal quality requirements of the cement plants, power plants and other industries in the Philippines. The comparison of these requirements with the fuel and ash properties of the upgraded (cleaned and blended) low-rank coals shows that coal cleaning and blending could improve the quality of these coals to meet the industrial coal specifications.

Cleaned Surigao Coal

The fuel and ash properties of the cleaned Surigao coal on a dry basis (d) are shown in Table 3. Converting these to the air dried (ad) basis with 3.6% moisture, the following are obtained: ash, 13.77% ad; volatile matter, 39.22% ad; fixed carbon, 43.41% ad; sulfur, 0.92% ad; gross heating value, 11,380 Btu/lb ad. The ash content of 13.77% ad is lower than 15% maximum for the power plants, 18% maximum for the cement plants and 17% average for most of other industries using coal as fuel. The sulfur content of 0.92% air dried, is lower than that of the power plants (3% maximum), cement plants (3% maximum), other industries (1.5% average) and the Philippine government regulation that restricts coal sulfur content to 1.0 % (by weight) in and outside Metro Manila.

Cleaned Uling Coal

Table 4 shows the fuel and ash properties on the dry basis (d) of the cleaned Uling coal. Converting these to an air dried basis with 12.2% moisture ad, the following are obtained: ash, 14.38% ad; volatile matter, 35.77% ad; calorific value, 8,680 Btu/lb ad; sulfur content, 0.76% ad. Just like the cleaned Surigao coal, cleaned Uling easily satisfies the coal quality requirements of the industries. The ash content, the volatile matter content, the sulfur content and the heating value satisfy the specifications of the power plants and other industries. The heating value of 8,680 Btu/lb ad of the cleaned Uling however could not satisfy the requirements of all the cements plants which ranges from a low of 8,500 Btu/lb minimum for some to a high of 9,000 minimum for other industries. All the other properties however are well within the specifications of the cement plants.

Table 5
Slagging and Fouling Indices of Baseline and Cleaned Surigao and Uling Coals

	Baseline		Cleaned	
	Index	Potential	Index	Potential
SURIGAO COAL				
Slagging Indicators				
Fusion Slagging Index, C	1172	High	1134	Severe
Base/Acid Ratio Index	0.75	Medium	1.11	Medium
Ash Fluid Temperature, C	1186	High	1165	Severe
Fouling Indicators				
Base/Acid Ratio Index	0.32	Medium	0.54	High
Sodium Oxide Content Index	0.47	Medium	4.06	High
Ash Deposit-Forming Propensity Indicator				
Alkali	0.16	Low	0.10	Low
Erosion Potential Indicator				
Silica+Alumina Content	0.0005	Low	0.0021	Low
ULING COAL				
Slagging Indicators				
Fusion Slagging Index, C	1251	Medium	1236	Medium
Base/Acid Ratio Index	0.40	Low	0.57	Low
Ash Fluid Temperature, C	1302	Medium - High	1280	Medium-High
Fouling Indicators				
Base/Acid Ratio Index	1.37	Severe	2.64	Severe
Sodium Oxide Content Index	3.40	High	4.06	High
Ash Deposit-Forming Propensity Indicator				
Alkali	0.77	Severe	0.61	Severe
Erosion Potential Indicator				
Silica+Alumina Content	0.0071	Severe	0.0037	Intermediate

Table 6

Coal Quality Requirements of Industries*

	Cement Plants	Power Plants	Other Industries +
Moisture, % air-dry	10% max	10% max	15% ave
Ash, % air-dry	10% ave 18% max	15% max	17% ave
Volatile matter, % air-dry	20% min	33.5% min	20 to 30 min
Heating Value, Btu/lb air-dry	9000 ave	7500 to 8500 min	8600 ave
Sulfur, % air-dry	3% max	3% ave	1.5% ave

* Reference (4)
+ Includes alcohol, fertilizer, tobacco, sugar, textile and other processing industries.

Blends of Low-Rank Philippine and High-Rank Australian Coals

Surigao and Hunter Valley Coal Blends

Table 7 shows the fuel and ash properties of the Surigao Subbituminous and Hunter Valley Bituminous Coal Blends. A coal blend with a composition by weight of 50% Surigao and 50% Hunter Valley (50%S:50%HV) could easily satisfy the coal quality requirements of the cement plants and other industries. A coal blend of 25%S:75%HV has 17.5% ash, 35.4% volatile matter, 0.8% sulfur and a gross specific energy (heating value) of 11,291 Btu/lb. This blend would satisfy the quality requirements of not only the cement plants and other industries but also the specifications of the power plants.

Uling and Katoomba Coal Blends

The fuel and ash properties of the different blends of Uling subbituminous and Katoomba bituminous coals are shown in Table 7. A blend proportion containing 50% Uling and 50% Katoomba by weight has an ash content of 16.69%, volatile matter of 30.3%, sulfur content of 0.59% and a gross heating value of 10,131 Btu/lb. This coal blend can satisfy the specifications of the cement plants and most other industries. For the power plants, a blend proportion of 25%U:75%K would be sufficient. The ash (14.15% ad), volatile matter (28.7% ad) and sulfur (0.46% ad) contents as well as the gross heating value (11,274 Btu/lb ad) are well within the coal quality requirements of the power plants.

Table 7

Properties of Low-Rank Philippine and High Rank Australian Coal Blends

SURIGAO AND HUNTER VALLEY COAL BLENDS

	Surigao (*S*)	Hunter Valley (*HV*)	Blend No. 1	Blend No. 2	Blend No. 3
Coal Composition (wt%)	100%	100%*HV*	75%*S* 25%*HV*	50%*S* 50%*HV*	25%*S* 75%*HV*
Proximate Analysis (wt% ad*)					
Moisture	3.6	2.5	3.3	3.0	2.8
Ash	21.0	13.45	19.12	17.25	15.38
Volatile Matter	36.8	34.0	36.1	35.4	34.8
Fixed Carbon	38.6	50.0	41.5	44.3	47.1
Gross Heating Value, Btu/lb	10312	12275	10799	11291	11783
Sulfur, % air-dry	1.10	0.51	0.95	0.80	0.65
As Fusion Temperature, C					
Initial Deformation Temp.	1420	1170	1500	1250	1340
Softening Temperature	1176	1540	1260	1360	1450
Hemispherical Temp.	1180	1560	1280	1370	1470
Fluid Temperature	1190	> 1560	>1280	> 1370	> 1470
Crucible Swelling No.	1.5	2.0	1.5	2.0	2.0
Slagging Factor	0.75 Medium	0.03 Low	0.48 Low	0.28 Low	0.13 Low
Fouling Factor	0.31 Medium	0.03 Low	0.23 Medium	0.16 Low	0.09 Low
Alkali	0.16 Low	0.15 Low	0.16 low	0.16 low	0.16 Low

CENTRAL CEBU (ULING) AND KATOOMBA COAL BLENDS

	Uling (*U*)	Katoomba (*K*)	Blend #1	Blend #2	Blend #3
Coal Composition (wt%)	100%*U*	100%*K*	75%*U* 25%*K*	50%*U* 50%*K*	25%*U* 75%*K*
Proximate Analysis (wt% ad*)					
Moisture	12.2	2.2	9.7	7.2	4.7
Ash	20.1	13.3	18.42	16.69	14.99
Volatile Matter	33.7	27.0	32.0	30.3	28.7
Fixed Carbon	34.0	57.5	39.9	45.8	51.6
Gross Heating Value, Btu/lb	7844	12424	8988	10131	11274
Sulfur, % air-dry	0.84	0.34	0.71	0.59	0.46
As Fusion Temperature, C					
Initial Deformation Temp.	1242	1440	1290	1340	1390
Softening Temperature	1264	1552	> 1330	>1360	>1480
Hemispherical Temp.	1275	1555	> 1340	>1410	>1480
Fluid Temperature	1302	> 1560	> 1360	>1430	>1490
Crucible Swelling No.	1.0	1.0	1.0	1.0	1.0
Slagging Factor	0.40 Low	0.01 Low	0.25 Low	0.14 Low	0.06 Low
Fouling Factor	0.37 Severe	0.04 Low	0.86 High	0.44 Medium	0.14 Low
Alkali	0.77 Severe	0.04 Low	0.59 High	0.41 Medium	0.22 Low

Conclusions

The results of this study showed that the coals tested have generally low volatile matter, fixed carbon and sulfur contents. This study has also shown that the quality of low-rank Philippine coals could be improved by coal cleaning and blending. Coal upgrading by cleaning and blending could produce cleaned coals and coal blends with fuel and ash properties that satisfy the coal quality requirements of the industries. The following are the specific conclusions drawn from this study:

- The Philippine coals tested have generally low volatile matter, low fixed carbon and low sulfur contents. These accounted for the low heating values of these coals. Except for one, all the coals under study have a dolomite to iron oxide ratio which is higher than one ranging from 1.11 to 2.17 which placed them under the low-rank category. The low volatile matter and fixed carbon contents and high ash content could pose some combustion problems like poor flame stability.

- Coal cleaning significantly increased the coal calorific value and reduced the ash content due to the removal of the mineral matters. This means that for the same quantity of energy used, there will be less coal and ash passing through the plant equipment like the coal pulverizer and the boiler. From a baseline value of 0.0088 Kg ash/MJ for Surigao coal cleaning reduced this to 0.0052 Kg ash/MJ. For Uling coal a baseline value of 0.011 ash/MJ was reduced to 0.0071 Kg ash/MJ after coal cleaning. This could mean better plant operating performance and availability. Removal of the mineral matters would result to lower abrasive components, which means that there will be less erosion potential. Cleaning also increased the volatile matter content of coal, which would mean less flame stability problem.

- The blending of the low-rank coal with the high-rank coal produced a coal blend with fuel and ash properties better than that of the original low-rank coal. By choosing the right proportion of coal mix the fuel and ash properties of the coal blend could be adjusted. The calorific value and the volatile matter content could be increased and the ash and sulfur contents could be reduced by coal blending.

- The two coal upgrading methods, cleaning and blending, are viable methods which could be used to improve the fuel and ash properties of low-rank coals, which could also improve the performance and availability of the coal-fired plants. Results of cleaning and blending of the low-rank coals showed that the calorific value, the volatile matter content, the ash content and the sulfur content can be adjusted to satisfy the coal specifications of the cement plants, the power plants and other coal-fired plants.

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