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AN ASSESSMENT OF THE EFFECT OF COAL BLENDING ON HARDGROVE GRINDABILITY INDEX

Niaz Muhammad Shahani

School of Mines, China University of Mining & Technology, Xuzhou, 221116, China

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Abstract

Hardgrove Grindability Index (HGI) is a determining factor of energy consumption during grinding. The current study is aimed at investigating the influence of the blending behavior on HGIs of two dissimilar coal samples.

In this study, one local coal sample is taken from Lakhra coal deposits and second sample is extracted from Indonesian coal reserves for empirical experiment and analysis. The total number of nine blends with different blending ratios based on the Net Calorific Value (NCV) was made. In addition, the samples were further tested for proximate and ultimate analysis, Gross Calorific Values and HGI respectively. The ASTM D409-D409M standard Hardgrove grindability tester was used for the determination of HGI of cited two coal samples. The main purpose of this study is to determine the blends that specify the optimum results those are appropriate for power sectors and cement industries. According to the above study, the blend no 2 and 3 demonstrate the optimum results for cement factories with approximately HGI 46 and 49 with sulphur content 1.01 and 1.17, whereas blend no 4 and 5 are appropriate for power sectors with approximately HGI 52 and 54 with sulphur content 1.37 and 1.58.

Furthermore, the value of the blends for HGI and moisture content shows the inverse relation, as the moisture content increases HGI value decreases. Similarly, research results also determine that there is also inverse relationship between the blend value of volatile matter and total carbon with HGI. Additionally, the GCV also exhibits inverse relationship while ash and fixed carbon reveal direct relationship with the value of blends for HGI. In the same manner, sulfur also exhibits direct relation with HGI value..

***Keywords**: Coal blending; Gross calorific value; Hardgrove grindability index; proximate analysis; Ultimate analysis.*

1. Introduction

Among fuel, coal has the key standing in meeting the energy needs around the globe. It's extensively leading source of energy accessible to world economy nowadays [1].

The HGI is intended to conclude ease through which coal can be ground. It evaluates the grindability of coal and is a confidential measure of coal. It delivers the knowledge of grinding power consumption and comminuting extents. HGI of coal can be contingent on the composition of coal. It's extensively utilized by the industries so as to measure power need throughout the process of comminution [2-5]. Typically, harder coals have low HGI and softer coals have higher HGI contents [6-10]. A number of the physical properties of coal like stiffness, tenacity, and rupture are often indicated by it as similarly [11-13].

Generally, coal grindability is classified into two terms: first is work index that measures overall energy consumption for obtaining product quality fineness is determined; second is grindability index through that fineness of absolute product is measured for same grinding work of standard samples. As work index is time and labor cost consuming factor, therefore, Hardgrove grindability index (HGI) is mostly preferred for projecting the behavior of coal and energy consumptions requirements of mill [14]. It is very important to discuss that multiple physical and chemical properties of coal put impact on the value and measurement of HGI, including particulars of moisture, ash, volatile matter and fixed carbon. In addition to that, presence and exact proportion of multiple macerals and microlithotypes and composition and supply of mineral substance. Coal blending is also a compulsory parameter that affects the HGI grindability of assumed coal. Usually, coal blending doesn't indicate any additive relation among the Hardgrave grindability index results of separate constituent coals [15].

This study deals with the assessment of HGI of two dissimilar coal blends related to their chemical properties.

Various countries around the globe depend on different sectors that play role in the strength of economy. Some countries rely on agriculture and other on their mineral resources. The Pakistan is one among those countries that rely on agriculture, though preserves adequate potential to distract the economic dependence on her mineral capitals that have been asking for the consideration. Little attention to the coal sector can not only increase the severe energy crisis the country is dealing, but it can also influence economy.

Figure 1. Hardgrove grindability index machine [19]

Energy deficiency in Pakistan is a biggest problem and it can be utilized by the local coal as a solid fuel for power generation and if its use is given top priority by the industrialists [16].

As matter of coal-fired is concerned, it is usual practice to make convenient blend of local coals apart from separate coals within Pakistan. Generally, coals and blends are ground before use for burning.

The coal grindability is usually influenced by the blending factor, as stated in the literature [17- 18]. A few studies have revealed some confident result on grindability because of its blending. The current research has been assumed to investigate the effect of coal blending on the HGI grindability of local and foreign coal.

2. Factors affecting the Hardgrove grindability values

The HGI is mostly affected by the petrographic structure of coal. Usually, grindability grows as the content of volatile matter rises of about 30%, on the far side that the grindability declines. Likewise, with the increment in carbon content, the HGI value will increases as well and the grindability then decrease quickly with the carbon value greater than about 92%. The coal with the classification of lithotype having comparable percentages of volatile matter comprise variance in the HGI results. Durite is also labeled as dull coal is a lithotype attribute by low HGI and is usually the hardest. Classification fusite is considered by means of lithotype with the principal value of HGI is uncertain as a result of its highest fragility is affected by initiation of substantial quantity of pulverized portions rather through screening and grinding in the investigating tool [20]. Glittering vitrinite is another type of lithotypes in black coal that have considerably greater HGI values as compared to the durites in the identical coal classification. The variance in grindability of distinct lithotypes permits for particular grinding. It is usually effective with the existence of vitrinite in coal raises the value of HGI, however, the liptinite and micronite macerals decline the grindability.

3. Materials and methodology

Approximately 10 kg of coal sample from Indonesia was provided by Engineer Faisal Raza traders from their coal stores located in Karachi and 10 kg of Lakhra coal was directly taken from the mining region of Lakhra. Each sample of 10 kg was thoroughly mixed in order to ensure homogeneity as far as possible. The two coals selected for the present studies were such that one coal had the low HGI (Indonesian coal) while the other coal had high HGI (Lakhra coal).

The experiments were carried out on two dissimilar coal samples with their unary and binary blends. The standard ASTM D409-D409M was followed for the determination of HGIs. For a realistic study, two normal reference coals were conjointly used. The results of these experiments are given in Tables 1 to 4.

The proximate and ultimate analysis was also achieved on each blended coal sample in agreement with ASTM standards. All experiments were carried out on air-dried origin. Total carbon and sulfur were measured with Carbon-Sulfur analyzer ASTM-D-5016-08 standard.

The process, for the determination of HGI, was as follow;

The 50 mg sample of prescribed size -75+3350 mesh was taken in the ball mill of HGI machine along with 8 iron balls with diameter 25.4±0.003 mm. The mouth of the ball mill was closed and was set to rotate for exactly 70±0.25 revolutions. After the requisite rotation was achieved, the machine stopped automatically. The sample left within the ball mill was later collected along with any pulverized material holding on to the surface of the HGI machine with the assistance of a brush.

This sample was after placed in a 75μ size of sieve and was shivered approximately for 10 minutes. The sample which passed through 75μ size and retained on 3350μ size was weighed on the balance. The HGI value is determined by the given experimental formula [21]:

$$HGI = 13 + 6.93W \tag{1}$$

where: W is weight of the test sample passing through 75μ sieve after grinding in the HGI machine.

4. Calculation for the determination of the percentage of coal blends

The blends of two dissimilar coal samples on thermal based on NCV were prepared by using the following calculation [22]; Suppose the total heat to be obtained from the blend is 100,000 kJ. If the 90 % heat is required from Indonesian coal than heat required from it is 90,000 kcal. Then, heat required from Lakhra coal is 10 % which total to 10,000 kcal.

kg coal of Indonesian coal required for 90,000 kcal = $\frac{90{,}000\ kcal}{NCV\ of\ Indonesian\ coal\ kcal/kg} = \frac{90{,}000}{6483}$

Hence, kg coal of Indonesian for 90,000 kcal =13.88 kg coal.

Similarly, kg coal of Lakhra coal required for10, 000 kcal = $\frac{10{,}000\ kcal}{NCV\ of\ Lakhra\ coal\ kcal/kg} = \frac{10{,}000}{4877}$

Hence, kg coal of Lakhra for 10,000 kcal = 2.05 kg coal

Percentage (%) of Indonesian coal by weight = $\frac{13.88}{(13.88+2.05)} \times 100 = 87.131\ \%$

Percentage (%) of Lakhra coal by weight = $\frac{\text{kg coal of Lakhra}}{(\text{kg coal of Indonesian} + \text{kg coal of Lakhra})} \times 100$

$= \frac{2.05}{(13.88+2.05)} \times 100 = 12.868\ \%$

The thermal percentages of other blends were calculated in similar way and their results are presented in Table 2.

The Net calorific value (NCV) and hydrogen (%) was determined by the following formula;

$$NCV = GCV - \left[(0{,}089.H) + \frac{TM}{100}.587\right] \tag{2}$$

$$H = 0{,}069.\frac{GCV}{100+VM} - 2.86 \tag{3}$$

where: GCV is the Gross calorific value in kcal/kg; H is Hydrogen content present in the coal in %; TM is the Total Moisture in %; VM is the volatile matter.

Table 1. Analysis of coal samples and their HGI values as received basis

Sample	TM (%)	Ash (%)	VM (%)	FC (%)	GCV (kcal/kg)	NCV (kcal/kg)	TC (%)	S (%)	H (%)	HGI value
Indonesian	11	13	37.9	34.5	6 420	6 483	65.90	0.80	10.58	44
Lakhra	8.6	15	41.5	38.9	4 828	4 877	55.78	5.68	6.99	66

TM- total moisture; VM- volatile matter; FC-fixed carbon; GCV-gross caloric value; NCV-net caloric value; TC-total carbon; S-sulfur; H-hydrogen, HGI- Hardgrove grindability index

Table 2. Calculated percentage of each assumed sample

Blend ratios (%)	Thermal blending ratio (%)		Weight blending ratio (%)	
	Indonesian	Lakhra	Indonesian	Lakhra
1	100	0	100	0
2	90	10	87.131	12.858
3	80	20	74.938	25.061
4	70	30	63.695	36.304
5	60	40	53.008	46.991
6	50	50	42.928	57.071
7	40	60	33.401	66.598
8	30	70	24.378	75.621
9	20	80	15.811	84.188
10	10	90	7.703	92.296
11	0	100	0	100

Table 3. Measured analysis of the binary blends of two dissimilar coal samples

Blend ratios	TM (%)	Ash (%)	VM (%)	FC (%)	GCV (kcal/kg)	NCV (kcal/kg)	TC (%)	S (%)	H (%)	HGI value
1	11	13	37.9	34.5	6420	6 483	65.90	0.80	10.58	44
2	10.80	13.2	38.3	35	6 360.64	6 423	64.04	1.03	10.42	46
3	10.58	13.5	38.9	35.44	6 279.24	6 340	62.22	1.17	10.19	49
4	10.32	13.7	39.2	35.82	6 097.48	6 156	60.38	1.37	9.79	52
5	10.1	14	40.10	36.28	5 916.44	5 956	58.54	1.58	9.33	54
6	9.87	14.3	40.3	36.73	5 735.04	5 792	58.08	2.46	8.94	57
7	9.6	14.4	40.6	37.14	5 553.64	5 608	57.62	3.20	8.55	59
8	9.73	14.6	41	37.59	5 372.24	5 426	57.16	3.82	8.14	62
9	9.13	14.7	41.1	38.01	5 190.84	5 243	56.70	4.44	7.76	63
10	8.88	14.9	41.3	38.48	5 009.44	5 060	56.24	5.18	7.38	64
11	8.6	15	41.5	38.9	4 828	4 877	55.78	5.68	6.99	66

Table 4. Calculated analysis of the binary blends of two dissimilar coal samples

Blend ratios	TM (%)	Ash (%)	VM (%)	FC (%)	GCV (kcal/kg)	NCV (kcal/kg)	TC (%)	S (%)	H (%)	HGI value
1	11	13	37.9	34.5	6 420	6 483	65.9	0.80	10.58	44
2	10.91	13.4	38.6	35.02	6 261	6 163.1	64.44	0.996	10.19	47
3	10.46	13.7	38.8	35.5	6 012	6 016.2	63.98	1.064	9.65	50
4	10	13.8	39.1	35.97	5 943	5 868.3	63.52	1.105	9.48	51
5	9.76	14.1	39.6	36.42	5 784	5 704.4	64.06	1.477	9.10	53
6	9.52	14.3	40	36.86	5 635	5 576.5	60.38	2.228	8.76	55
7	9.48	14.5	40.2	37.29	5 466	5 428.6	58.54	2.992	8.40	57
8	9.25	14.6	40.5	37.72	5 307	5 283.7	57.15	3.29	8.05	60
9	8.90	14.7	41	38.14	5 148	5 135.8	56.23	4.267	7.68	61
10	8.78	14.8	41.2	38.54	4 951	4 988.9	56.01	4.89	7.26	62
11	8.6	15	41.5	38.9	4 828	4 877	55.78	5.68	6.99	66

TM- total moisture; VM- volatile matter; FC-fixed carbon; GCV-gross caloric value; NCV-net caloric value; TC-total carbon; S-sulfur; H-hydrogen, HGI- Hardgrove grindability index.

5. Results and discussion

The overall results those have been extracted from the study are discussed here in the aspect of relative grindability of ease of pulverization of the local as well as international coals.

In case of comparison with the grindability of low-rank coals, it was observed that some cases regarding low-rank coals within other countries have similarities with the coal found in Pakistan.

Results of this research work are presented together in tabular and as well as in graphical order. Table 1 to 4 represents the proper investigation of two dissimilar coal samples with different grade and their unary and the binary blends comprising the determined data of their HGI contents.

5.1. Effect of coal blending on Hardgrove grindability index

The current research determines the HGI of coal blends of different heating ratios arranged from two different coals. One from Indonesia hard coal having HGI 44 and second local coal from Lakhra having HGI 66. The experimentally measured HGI values of different blends ranged between 46 and 64 whereas the weighted average calculated values ranged between 47 and 62 as given in Table 3 and 4.

On the other hand, the weighted average calculated values of HGI are lesser by 1 to 2 compared to the experimentally determined HGI values for blending ratios having 60 % to 10 % of Indonesian coal as indicated in table 4.

The consequences of current work are supported by related work conducted in past research on coal as following;

The results of this study specify that experimentally measured HGI values of coal blends varied by about 1 to 2 with the weighted average calculated values [23]. Moreover, he added that the influence of moisture and coal blending on HGI of Western Australian coal where it has been perceived that measured HGI values of binary and tertiary blends resembled sound with the weighted average values of HGI within ±2.

Contrary to the above-cited conclusions of researchers, results of [24] state that even though coals with the same HGI mixed together, the measured HGI values of blends determines smaller than the calculated values, in certain conditions poorer than either blended constituents. Consequently, it was determined that there is no other technique except experimentally measured method for the determining of the HGI of the different coal blends.

5.2. Effect of chemical properties of coal blending on Hardgrove Grindability Index of coal samples

5.2.1. Proximate analysis

5.2.1.1. Moisture

The calculated moisture contents found to be marginally higher related to the experimentally determined contents for all blending ratios of Indonesian coal in Lakhra coal. The contrast between the measured and calculated values ranges 0.25 % to 1%.

Thus, the consequences have exposed advancement of moisture contents in blends within the range 0.25 % to 1 %. These results are supported by the reflection [25] who specified that to any form of moisture content comprising only internal and surface moisture constituent, advancement should apply.

5.2.1.2. Volatile matter

The change between experimentally measured and calculated values was found and ranges 0% and 2.6 %. The experimentally measured values conclude higher than the calculated values for total blending ratios. The results of the present study are supported by the results of [25] and [26].

5.2.1.3. Ash

The experimentally measured ash content values of different blends ranged between 18 % and 40 % whereas the weighted average calculated values ranged between 15.9% and 39.1% as mentioned in Table no 3 and 4. The experimentally measured values always conclude higher than the calculated values for total blending ratios [26-27].

5.2.1.4 Fixed carbon

There is no any method to determine the fixed experimentally, hence it is determined by using the following formula;
FC = 100 - Moisture + ash + volatile matter; where FC is the fixed carbon.

The progression of fixed carbon content can be determined with the addition of the other three components i.e. moisture content, volatile matter content and ash content. It is affected by mistakes in their determination. It has been perceived that the calculated values are always higher than the measured values of fixed carbon.

5.2.2 Partial ultimate analysis

5.2.2.1 Total carbon

The results clearly indicate that the blends of total carbon seem to be an additive property. These evaluations of the present work are equivalent to the results of [27-28].

5.2.2.2 Sulfur

The experimentally measured total sulfur values of different blends ranged between 1.08 % and 5.18 % whereas the weighted average calculated values ranged between 0.996 % and 4.89 % as shown in Table 3 and 4 representing a variance from 0.034% to 0.29%. The results of the current study are supported by the opinion of [28].

5.2.2.3 Hydrogen content

The reason for a difference between the measured and calculated values of hydrogen content may be because of the volatile matter value and the gross calorific value rises or reduces steadily. The Syler's equation has been used for the determination of hydrogen value when GCV was in kJ/kg.

6. Conclusion

The industrial sector in Pakistan, particularly the cement sector is consuming blends of high sulfur local coal and low sulfur imported coals. The two coals are blended together to carry the sulfur content of the blend to a limit of about 2% acceptable in the cement industry. The pulverization characteristics of imported coal and local coal are completely dissimilar.

This study was conducted to experimentally measure the pulverization characteristics which are measured by HGI and it was concluded that the blends of two dissimilar coals indicate the prime consequences and are acceptable for power plants and cement industries.

In addition, it was concluded that;

- Out of the 9 potential blends, the blend 2 & 3 show the prime results which are in good agreement for the cement industries about 46 & 49 HGI value with sulfur content 1.01 & 1.17.
- Although blend 4 & 5 are meet for power plants about 52 & 54 HGI value with sulfur content 1.37 & 1.58.

The blends value for HGI and moisture content indicates the opposite relation, as the moisture content rises HGI value decreases instantly. Past studies revealed that coal with high moisture content noted as a hard coal though it may include the small HGI values on grinding but talking about the Lakhra coal which shows uniqueness with low moisture content is 8.6 and HGI value is high 66 nearly. It is because of the maceral present in the Lakhra coal that is vitrinite. It is commonly valid that the existence of vitrinite in coal increases the HGI value, though the micronite and liptinite macerals diminish the grindability.

Moreover, it is also confirmed that the blends value of moisture content and volatile matter (VM) demonstrates the opposite relation with HGI. As the HGI value increases the value of moisture content and volatile matter decreases. Similarly, the total carbon also show the opposite relation with HGI. However, the value of ash and fixed carbon shows the direct relation with the blends value for HGI. Likewise sulfur also show the direct relation with the HGI.

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To whom correspondence should be addressed: Niaz Muhammad Shahani, School of Mines, China University of Mining & Technology, Xuzhou, 221116, China, Email: shahani.niaz@cumt.edu.cn