Effects of Moisture and Coal Blending on Hardgrove Grindability Index of Pakistani Coals

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Abstract

The Hardgrove Grindibility Index (HGI) of coal is a measure for understanding its grindibility characteristics leading to know the energy input required for its pulverization. The present study is aimed at investigating the effects of moisture and the blending behaviour on HGIs of indigenous coals.

Experiments were carried out on the standard Hardgrove Grindibility Machine to determine HGIs of three indigenous coals belonging to Lakhra, Degari and Chamalang coal deposits. In addition, the blending effect of six binary and six ternary blends of parent coals with different blending ratios, were also tested for their HGIs. Results have been presented in Tables: 1 to 5 and Figures: 1 to 3.

Regarding the effect of moisture among the three parent coal samples, the Lakhra coal showed the highest HGI value of 66 against 23% of residual moisture, whereas the Degari and Chamalang coals respectively indicated HGI values of 53 and 32 against 10% and 6.95% of moisture contents. This indicated that as the residual moisture in coal increased the HGI values also increased. Lakhra coal, having highest HGI value, was found to be easy to grind as compared to Degari and Chamalang coals which were comparatively harder to grind as they had lower HGI values. This indicated that the moisture levels have played a significant role in grindibility characteristics of coals.

The binary and ternary blends of parent coals, in various proportions, had also affect on the grindibility behavior, but the HGI values of blends were more or less the average values derived from the parent coals.

Key Words: Subbituminous Coal, Hardgrove Grindibility Index, Pulverization, Moisture Content, Coal Blending

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1- Introduction

The size reduction of ores, minerals and coal is a cost effective operation, especially when very fine grinding is required for their utilization [1]. The energy required for their grinding depends upon their physical and chemical characteristics which determine whether it will be easy or hard to grind them. [2]

The grindibility of coal is related to its hardness, tenacity and fracture and is further influenced by its rank and grade. As the coal is used in pulverized form in coal fired utilities so, its grindibility is an important economic and practical factor. The grindibility of coal is evaluated by Hardgrove Grindibility Index (HGI) which is predictive measure to assess the performance of industrial pulverizes in terms of energy required for grinding. [3]

The HGI values, obtained on testing of coals, largely depend on the level of moisture, volatile matter and the nature of mineral matter present in coals. Among these components of coals, the moisture is one of the important constituents to affect the HGI values of coals. A number of studies in this regard have been reported in literature. [4, 5, 6]

Coal is porous and hydrophilic in nature and absorbs moisture in greater amount in winter and to a lesser extent in summer. Hence the moisture variations are affected by temperature and humidity [7]. The moisture accumulated on surface also penetrates deep into the coal matrix and contributes to the inherent moisture of coal. The change of moisture is often substantial to alter the grindibility characteristics of coals[8].

The local coals are used for combustion in thermal power plants and cement production units. They are mostly lignite to high volatile subbituminous in nature and are characterized relatively by high moisture levels and low heating values [9].The present study has been undertaken to investigate the effect of moisture on grindibility of a few important indigenous coals and the coal blends made out of them.

The blending parameter, affecting the grindibility of coal, has also been reported in literature. A few investigations have shown some beneficial effect or ease of grinding due to blending [10,11]. but some studies have negated this beneficial effect .

For coal fired utilities in Pakistan, it is a quite common practice to make convenient blends of local coals. However, the blending of local and imported coals is also largely carried out. Coals as well as blends are pulverized before use for combustion. The blending effect on HGI has also been indicated in this study.

2- Experimental

The HGI tests on parent coals and their binary and ternary blends were carried out at the Centre for Coal Technology, University of the Punjab, Lahore, Pakistan, using standard

Hardgrove method. This method (ASTM D 409-02), issued under the fixed designation D-409 and approved and published in 2002, has been accepted as the standard method for grindibility study of coal by Hardgrove Machine. [12, 13] The experimental work done was based on this standard method and all the test instructions, assigned for the test, were fully followed. Four standard reference coals were also used for comparative study of the actual coal samples for accuracy of the results. The results of the tests have been given in Tables 1 to 5 and reproduced in Figures 1 to 3.

2.1-Gross Samples

Representative gross samples of coal, weighing about 5 kg from each mine of Lakhra (Sind Province), Degari (Balochistan Province) and Chamalong (Balochistan Province), were collected for the grindibility tests.

2.2- Preparation of Test Samples

Each gross sample was crushed to 4 mesh size (4.75mm) and splitted into the desired lots by using riffle splitter. For each test, a sample weighing 250 g was taken and air dried at 40^0C for 3 hours till a constant weight loss was observed. Then the air dried sample was shaked using 16 mesh sieve (1190µm) for two minutes. The -16 mesh fraction was saved and +16 mesh fraction was stage crushed by a laboratory crusher. The crushed material was again put on 16 mesh sieve and shaked well till all the material passed through 16 mesh sieve. The -16 mesh fraction, which was saved earlier, and this -16 mesh fraction were collectively put on 30 mesh sieve and shaked for 5 minutes. The -30 mesh fraction was discarded and the +30 mesh fraction was saved for the determination of Hardgrove Grindibility Indexes.

2.3-Hardgrove Grindibility-Index Machine and its Operation

The Hardgrove Grindibility machine consists of a stationary grinding bowl of cast iron which contains eight polished steel balls of 25.4 mm in diameter. The balls are driven by a grinding ring which is rotated by means of a spindle. The machine is equipped with a counter which is adjusted for automatic stopping of the machine after 60 revolutions.

For grindibility test, a 50 g of +30 mesh sample as described above was evenly distributed over the balls in grinding bowl, which was fastened in a position. The machine was put in operation at the speed of 20 rpm. After the machine was automatically stopped after 60 revolutions, the bowl was removed and the ground contents were collected from the bowl and put on 200 mesh sieve (74µm). The 200 mesh sieve was shaken by mechanical sieve shaking machine for ten minutes. Both the fractions i.e. +200 mesh and -200 mesh were separated from the sieve. Both fractions were weighed and only the weight of -200 mesh fraction was used for the determination of HGI.

2.4- Hardgrove Grindibility Index

The Hardgrove Grindibility Index (HGI) of coal is a number which indicates the relative ease with which a coal may be pulverized in comparison with coals chosen as standards.[14] The HGI also gives an idea about the nature of coal whether it is soft or hard to grind. It also gives an approximate indication of the amount of energy required for pulverization.

In the USA, a soft coal belonging to the state of Pennsylvania, having HGI of 100 is taken as a standard. Coals with greater HGI values than 100 are taken as easy to grind coals and those with less than 100 HGI values are considered to be hard to grind coals. [15, 16] In some other countries, the coal is assumed to be a standard which has HGI value of 50. Coals with exceeding values of 50 are soft coals and those having less than 50 HGI values are hard to grind coals[17]. The HGI numbers, therefore, are arbitrarily assumed and are used for comparison of the grindibility of coals. The following empirical formula has been reported in the literature [18] by which HGI may be determined.

$$\mathbf{HGI = 13+6.93W}$$

Where W is weight of -200 mesh fraction of test sample obtained through Hardgrove Grindibility Machine.

The HGI value may also be approximately converted to Bond Grindibility Index (or work index) by means of the following formula:

$$\mathbf{W_i = 437/HGI^{0.91}}$$

Where W_i is the Bond Index expressed in kilo Watt hour per short ton (kWh/t) [19]

2.5-Determination of Hardgrove Grindibility Indexes

As the Hardgrove Method (ASTM D-409) has been accepted as standard method of grindibility of coal by Hardgrove Machine, so for this study, the Hardgrove machine was calibrated with 6 months old 4 standard coal samples of known grindibility indexes of 39, 57, 87 and 100. Tests were carried out to obtain -200mesh fractions of each standard coal. A calibration chart was drawn taking the weights of -200 mesh fractions on y-axis and the HGI values on x-axis. [20, 21]

For the determination of HGI of each test sample, the weight of -200 mesh fraction experimentally determined by Hardgrove Grindibility Machine, was put on y-axis of the calibration chart and the corresponding HGI value was read off on x-axis of the chart. By this way the HGI data of the parent coals and the blends were determined and recorded.

3.0- Results and Discussions

The results of this study have been discussed in view of the relative grindibility or ease of pulverization of the locals in comparison with the grindibility of low rank coals reported in the literature. [22] It has been observed that some low rank foreign coals have similarity with the Pakistani coals and the literature survey has helped to understand the grindibility behavior of indigenous coals and their blends.

Results of this study have been given both in tabular and graphical forms. The Tables (1 to 5) show complete analysis of the parent coals and their binary and the ternary blends including the measured data of their Hardgrove Grindibility Indexes (HGIs). The graphs (Figs. 1 to 3) are confined only to indicate the effects of residual moisture and the blending behaviour of coals on the HGI values. It may be pointed out that although this study required only the analytical data regarding the inherent moisture contents of parent coals and their blends, yet the complete analysis of each parent coal and its blends have been included in the study to give complete information about their nature and composition.

3.1- Effect of Residual Moisture on HGI of Coal Samples

The coal has two types of moisture i.e. the surface moisture which is released by air drying and the inherent moisture which is often called bound or residual moisture and that still remains as a part of coal. This inherent or residual moisture plays a significant role in grindibility of coal. It has been reported in literature that the following aspects must be kept into consideration while analyzing the effect of moisture on grindibility of coals.

(1) The low rank coals can undergo physical changes as the inherent moisture often comes out during mining, handling, transportation and preparation. The change in inherent moisture is often significant to alter the grindibility characteristics of coals.
(2) The inherent moisture of coal varies from seam to seam and within the same seam due to nature, origin and occurrence of coal.
(3) The inherent moisture is physically held up in coal matrix due to some physical factors, and as a result it dilates or loosens the internal structure and thus the coal becomes easy to grind.
(4) The porosity of coal allows the surface moisture to deeply penetrate and contribute to the inherent moisture. The humidity and seasonal effects are important factors to alter the inherent moisture content and consequently the grindibilty of coals.
(5) The lignite and subbituminous coals have several levels of inherent moisture and, due to high inherent moisture, are easy to crumble.

The experimental investigations, carried out under this study, reflect the above salient features of inherent moisture affecting the grindibility characteristics of indigenous coal samples selected for this study. The inherent moisture content was found to be an important factor regarding the energy requirement in pulverizing of coal. This energy requirement was assessed by determining the Hardgrove Grindibility Indexes of the coal samples.

The Table-1 shows complete analysis, including measured values of HGI of Lakhra, Degari and Chamalang coal samples. The results indicate a consistent increase in HGI values with the increase of the residual moisture contents. However, Lakhra coal sample shows the highest value of 66 HGI against 23% of moisture; whereas the Degari and Chamalang coal samples respectively show 53 and 32 HGIs against 10% and 6.95% of residual moisture. This indicates that with the increase in residual moisture the HGI also increases. This increase of inherent moisture facilitates the easy grinding of coal. The Lakhra coal is comparatively the soft coal as compared to Degari coal which is relatively less soft but Chamalang coal is a bit harder to grind.

The graph in Fig.2, showing the relationship between the moisture and the measured and predicted values of HGIs for Lakhra, Degari and Chamalang samples that illustrates the linear trend of relationship between the moisture and HGIs and further supports the conclusion that as the residual moisture of coal increases, the HGI also increases and also shows the easy grindibility of coal. It was observed that the results of this study are in close agreement with the results reported in the literature. [23]

3.2- Effect of Coal Blending on HGI of Coal Samples

The Table-2 indicates the results of 6 binary blends of Lakhra and Chamalang coals with different ratios and having moisture range of 9.96% to 17.49% with the measured and predicted HGI values of 38 to 55. Results show that with the increase of moisture content, the measured and predicted values of HGI also increase progressively. Fig-2 indicating the measured and predicted values of HGI of binary blends, also supports the increasing trend of HGI values with the increase of residual moisture contents.

Table-3 shows the results of 6 ternary blends with varying ratios of Lakhra, Degari and Chamalang coals having moisture level ranging from 10.57% to 13.88 % and the corresponding measured HGI values in the range of 42 to 51. Results indicate that as the moisture content increases the HGI values also increase. The Fig-3 representing the measured and predicted values of HGI of ternary blends, also supports the relationship that as the moisture of the blends increases the HGI values also increase.

The calculated HGI values of binary and ternary blends corresponding to their respective ratios of parent coals and the moisture levels as shown in Table2 and 3 indicate that the measured HGI values are more or less the average values derived from the parent coals. The coal blending, therefore, does affect the values of HGI whether the blending is binary or ternary. The

results of the present study regarding the effect of blending of coals on HGI are in close agreement with the results of the studies indicated in the literature.

In Tables 4 and 5 the 3rd column shows the experimentally measured HGI values of binary and ternary blends and the 4th column indicates their perdicted values, which have been worked out by using self-designed software. It is observed that the measured values of HGI, pertaining to the binary and the ternary blends, are slightly lesser than the calculated values. However, the comparison shows that experimentally measured HGI values of binary and ternary blends have been correctly determined with a slight experimental error as compared to the calculated HGI values.

4-Conclusion

The principal conclusions, drawn from the experimental investigations on grindibility of coal samples and their blends, are given below:

- The variations of inherent moisture contents in coal have a significant effect on the grindibility of coal and consequently affect the energy input required for its pulverizing. The progressive increase in moisture content in coal facilitates the ease of grinding and show higher HGI values whereas the lower HGI values indicate that coal is harder to grind.
- The blending of coals in various proportions does affect the grindibility characteristics and their HGI values appear to be the average HGI values of parent coals from which the blends were made.
- The results of this study may prove to be valuable for coal users in understanding the role of moisture and the effect of blending on grindibility of coals.

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TABLE – 1: Analysis of Coal Samples of Lakhra (A), Degari (B) and Chamalang (C) and their HGI Values

Parent Coals	Moisture (%)	Ash (%)	V.M (%)	Fixed Carbon (%)	GCV (kcal/kg)	Sulphur (%)	HGI Value
A-Lakhra	23.00	28.00	30.00	22.00	5100	6.40	66
B-Degari	10.00	3.98	37.20	48.81	6050	5.60	53
C- Chamalang	6.95	25.74	31.06	36.25	4980	7.20	32

TABLE – 2: Analysis of Binary Blends of Lakhra (A) and Chamlang (C) Coals and their HGI Values

Blends with Ratios of coal A and C	Moisture (%)	Ash (%)	V.M (%)	Fixed Carbon (%)	GCV (kcal/kg)	Sulphur (%)	HGI Value
Blend- 01 A% :C% 20:80	9.96	26.39	30.65	33.00	5011	6.87	38
Blend- 02 A% :C% 30:70	11.46	26.72	30.44	31.37	5035	6.79	42
Blend- 03 A% :C% 40:60	12.97	27.04	30.24	29.75	5058	6.70	45
Blend- 04 A% :C% 50:50	14.47	27.37	30.03	28.13	5082	6.62	47
Blend- 05 A% :C% 60:40	15.98	27.70	29.83	26.50	5105	6.54	53
Blend- 06 A% :C% 70:30	17.49	28.02	29.62	24.88	5129	6.45	55

TABLE – 3: Analysis of Ternary Blends of Lakhra (A), Degari (B) and Chamlang (C) Coals and their HGI Values

Blends with ratios of Parent Coals A, B and C	Moisture (%)	Ash (%)	V.M (%)	Fixed Carbon (%)	GCV (kcal/kg)	Sulfur (%)	HGI Value
Blend-01 A%: B% :C% 20 :20 :60	10.54	22.04	31.87	35.51	5238	5.57	42
Blend-02 A%:B%:C% 20:40:40	11.18	17.69	33.10	38.02	5465	4.28	46
Blend-03 A%:B%:C% 25:25:50	11.47	21.12	32.08	35.32	5307	5.21	45
Blend-04 A%:B%:C% 30 :35:35	12.53	19.10	32.59	35.77	5432	4.51	49
Blend-05 A%:B%:C% 35:35:33	13.13	20.35	32.18	34.33	5387	4.80	50
Blend-06 A%:B%:C% 40:30:30	13.88	20.52	32.08	33.52	5399	4.76	51

TABLE – 4: Values of Moisture and Measured and Predicted Values of HGI of Binary Blends of Lakhra (A) and Chamalang (C) Coals

Blends with Ratios of coal A and C	Moisture %	Measured value of HGI	Predicted Values of HGI
Blend-01 A% : C% 20 : 80	9.96	38	39
Blend-02 A% : C% 30 : 70	11.46	42	42
Blend-03 A% : C% 40 : 60	12.97	45	46
Blend-04 A% : C% 50 : 50	14.47	47	49
Blend-05 A% : C% 60 : 40	15.98	53	52
Blend-06 A% : C% 70 : 30	17.49	55	53

TABLE – 5: Values of Moisture and Measured and Predicted Values of HGI of Ternary Blends of Lakhra (A), Degari (B) and Chamalang (C) Coals

Blends with Ratios of Coal-A, Coal-B and Coal-C	Moisture %	Measured Values of HGI	Predicted values of HGI
Blend-01 A% : B% : C% 20 : 20 : 60	10.57	42	43
Blend-02 A% : B% : C% 20 : 40 : 40	11.18	46	47
Blend-03 A% : B% : C% 25 : 25 : 50	11.48	45	46
Blend-04 A% : B% : C% 30 : 35 : 35	12.53	49	50
Blend-05 A% : B% : C% 35 : 35 : 30	13.13	50	51
Blend-06 A% : B% : C%	13.88	51	52

40 : 30 : 30			

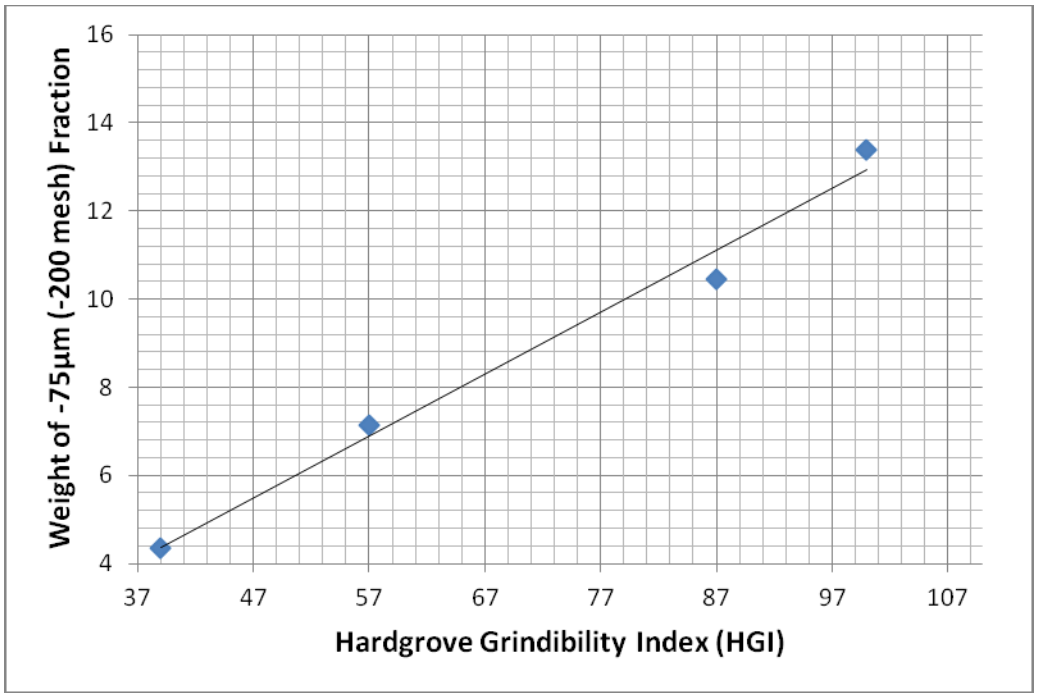

Fig-1 Calibration Curve between Hardgrove Grindibility Indexes (HGIs) of Reference Samples and the Experimental Weights of -75µm Fractions of Standard Samples

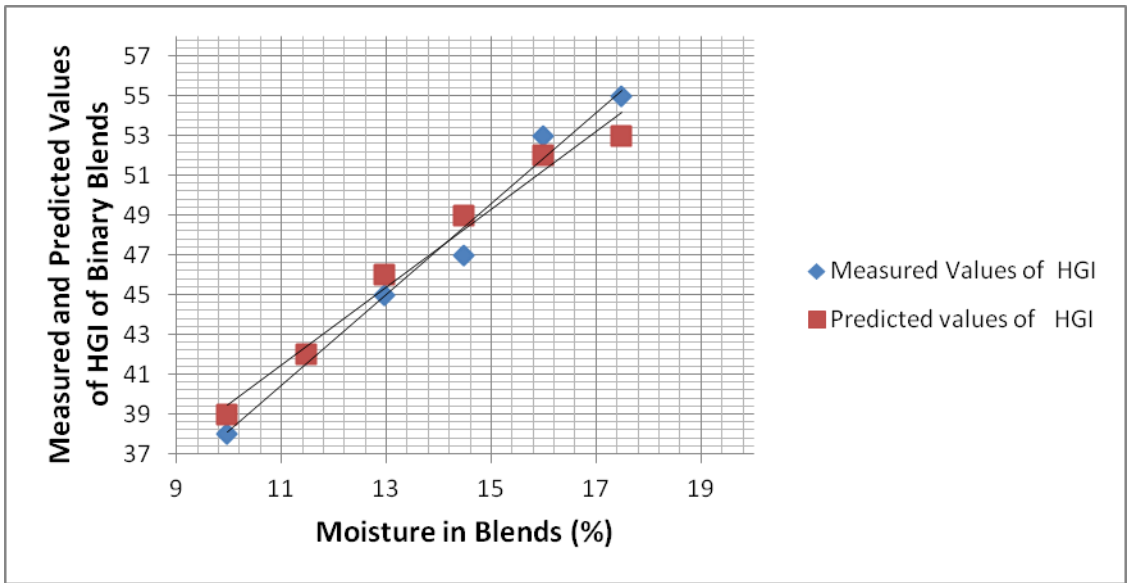

Fig-2: Graph showing Effect of Moisture on Measured and Predicted Values of HGI of Binary Blends of Lakhra and Chamalang Coals (Data taken from Table-4)

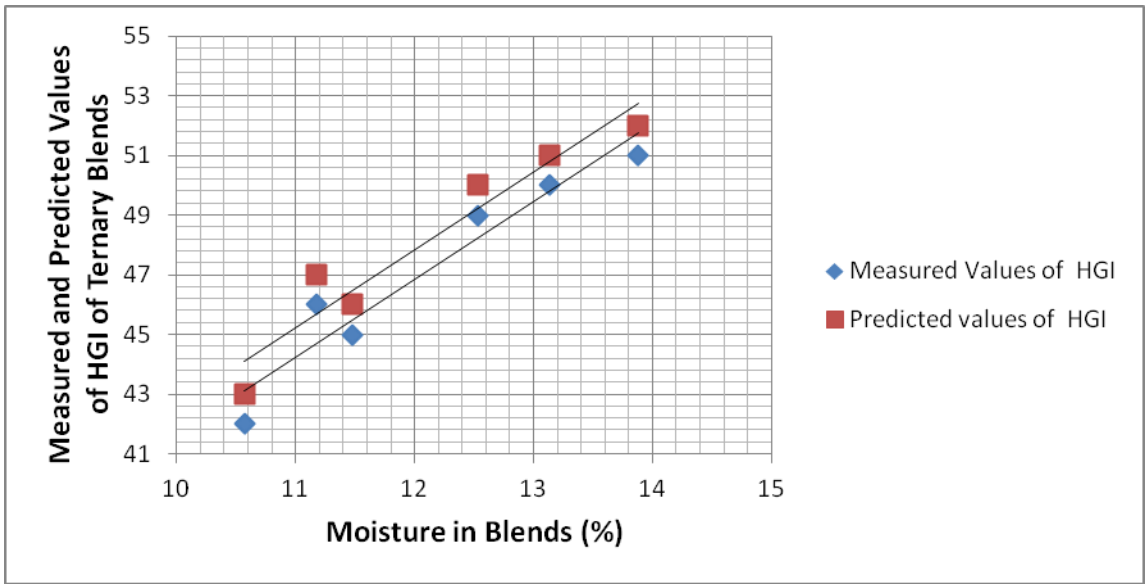

Fig-3: Graph showing Effect of Moisture on Measured and Predicted Values of HGI of Ternary Blends of Lakhra,Degari and Chamalang Coal Samples (Data taken from Table-5)