Hardgrove Index Estimation of Coal, Using its Characteristics and Sink-Float Data

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ABSTRACT

The grindability of ores is a very significant parameter which is used in size reduction equipments design and selection. The Hardgrove Index (HGI) is a normal approach for measuring the coal sample grindability, which is calculated using hardgrove machine. The coals specification such as humidity, ash content, volatile matter and heating value are analytical parameters which could change the HGI amount of coal samples. In this study it has been attempted to define the coal HGI values, on the basis of sink-float experimental data. An empirical equation was defined with applying regression technique on the data of above parameters to estimate HGI values.

KEYWORDS

Hardgrove Index, Coal Characteristics, Sink-Float.

1. INTRODUCTION

Run-off-mine coals are usually washed as a final and sellable product to be achieved. This process could easily be size classification, comminution and sizing, washing (cleaning), and/or further chemical treatment. Comminution is an essential stage in any type of ore processing practices. Therefore, size reduction equipments could usually be implemented in coal cleaning plants, coal conditioning, and coke furnaces.

One of the most significant properties of coal is its grindability, which is widely applied in size reduction equipment design and selection, and estimating of size distribution of coal products, as well. Hardgrove index is a parameter which defines the coal grindability, and is experimentally calculated. The variation of raw coal grindability is very important in performance of crushers, and accordingly it is usually attempted to prepare homogenous materials, to be used in size reduction equipments (as feed) which is certainly very complicated. Therefore, it is important to estimate the hardgrove index of coals prior to their crushing and/or cleaning steps.

In previous studies the effects of individual coal physical and chemical characteristics on their hardgrove index was considered. However in this work the effects of the whole parameters on coal hardgrove index was investigated. It should be noticed that these parameters are analytically measured. The data obtained from sink-float experiments are normally used in order to estimate coal yields/recoveries. Therefore it was applied in this study which is presented in other parts.

2. MAJOR ANALYTICAL COAL CHARACTRISTICS

In order to correlate the coal Hardgrove index with its different specifications such as coal composition, heating value, many researches have been done. However any of these studies did not lead to the complete and satisfactory results, due to coal complexity and its specifications variation. Thus, it has been concluded that the relation of coal characteristics and its hardgrove value is not performed, due to the lack of smooth understanding of coal specifications variation [6]. Therefore, researchers defined a relation between (some) coal specifications such as i) humidity, ii) ash content, iii) volatile matter, and iv) the carbon percentage, and with its grindability using regression approach on the analytical data. This grindability index is calculated which is here called "statistical grindability index (SGI)" [3, 5].

More than 300 coal samples with wide range of HGI equal to 35-115 were tested which their analytical specifications were as following:

Humidity percent: 0.7 to 0.9.

Ash percent: 3 to 65.

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Volatile matter percent: 16 to 45.

Carbon percent: 15 to 66.

Equation 1 was defined to estimate SGI, using data regression method [3, 5]:

$$SGI = 93.25 + M(0.256 + 0.196M) + 3A(1.097 - 0.009A) - 3VM(1.165 - 0.029VM) - 5FC(1.103 - 0.0166) \quad (1)$$

where,

M= Humidity,

VM= Volatile matter percent,

FC= Carbon percent.

The correlation factor of this equation is about 0.93 which is very remarkable. Figure 1 presents the results obtained from equation 1 versus HGI values. The estimated standard deviation (st.d.) is about ±3 units and it is rarely more than ±5 units. As it was explained, the results of previous studies did not present a perfect relation of coal specifications with its grindability, so that to yield a good correlation factor. However, in this method all four mentioned parameters were included which the variation of results was accordingly reduced.

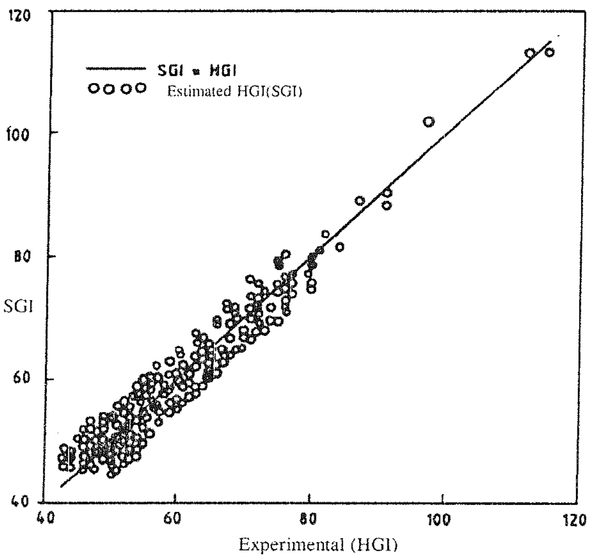

Figure 1: The relationship between estimated HGI (SGI) and experimental HGI.

A. The Importance of Correlation Equation

The equation of SGI estimation has been constructed on the statistical basis, and all four analytical parameters are included. The importance of this relation is now explained. The first parameter is humidity which has positive effects on the SGI value. For example for humidity equal to 1 and 10%, the estimated value of SGI (equation 1) is 0.5 and 22.2 respectively. This indicates that the increase of humidity causes the coals to become soft. However, in some certain conditions the humidity increase is with increases of oxygen interacting, which this produces harder coals [3].

In order to omit the above discrepancy, the relation of coal humidity and its specific gravity (SG) should be presented. If coal is considered as cellular solid, its specific gravity is increased with increase of the cells walls thickness, and therefore the volume of cavities is decreased. It is accepted that the coal humidity and volume of its cavities are directly related. Thus, when the humidity is low, the volume of cavities is low, which means its SG is increased [3].

In hardgrove tests, a 50gr of coal sample in -18+30mesh size fraction is prepared and is ground in hardgrove mill for 1 minute. The hardgrove index (HGI) is then calculated, based on the mass finer than -200mesh size fraction. Therefore coals with higher humidity and low specific gravities consume higher energy to be broken. The mass of particles finer than 200mesh which are produced in specific time is increased and the HGI is higher than those of coals with lower humidity.

On the similar assumptions, the existence of impurities in coals, the decrease of volume of coals occurs, and then HGI values will accordingly decrease [1, 4, 6]. The ash content of coals is the second parameter which always increases the SGI. The other two parameters which are volatile matter, and carbon percent, have both negative effects on the SGI. It should be noted that each of these parameters are defined with a second –order equation. These second-order equations could produce positive or negative effects, on the basis of certain values of two parameters (coals carbon and volatile matter contents) [6].

3. Estimating HGI with Sink-Float Data

The results of investigations indicate that the coal grindability is determined on the basis of specific gravity of coal compositions and their weight percentage. If the grindability is varied, it is then possible to define the type of coal (according to the coal types). The results of sink-float tests could be implemented to determine the coal grindability. There is certainly some relations between specific gravity and HGI of float mass [2].

The variation of grindability with specific gravity particularly in certain SG fractions has been investigated to specify the HGI based on the type of coals and its composition [2].

A. Experimental Studies

The results obtained from the studies in past 30 years on the decrease of coal's HGI values with increase of specific gravity reveals some interesting comments. It was shown that for the tested coals, the HGI of combined coal sample (a sample which is produced by combining some other coals) could be calculated using fractional HGI values. For these tests, the HGI and ash content of each individual sample were primarily measured. Then each sample was used in sink-float test with 6 specific gravity fractions. The heavy liquids used were zinc-chloride and tetra-chloride carbon, and the ash content and HGI values were determined [2].

B. HGI Variation with Specific Gravity

Table 1 presents HGI values and weight distribution obtained in different size fractions. The experimental HGI are in good fit with estimated HGI. It could be presented that the experimental HGI for all specific gravity fractions, using B1 coal sample are approximately equal, except for the lightest fraction which is 0.5-1% of the whole coal sample. This discrepancy using L1 coal sample is about 10% or even more (Table 1).

A certain trend is observed in the HGI variation versus specific gravity for both B1 and L1 samples. The HGI values are decreased with the consistent increase of SG, until the minimum is achieved which is related to SG 1.8. Then the HGI for heavier fractions up to SG 2.3 are increased [2]. It is obvious that the comminution process, liberate the locked particles, and therefore after size reduction, it is possible to estimate HGI values of crushing unit feed. The variation of HGI with SG for L1 sample is similar to those of B1 [2].

C. The HGI Estimation

The HGI values of various specific gravity fractions, using B1 sample are steadily decreased, but in the last fraction is increased (Table 1). As the HGI values decrease is varied for heavier fractions, therefore it is hard to define an equation to be fitted to data. The defined equation is more convenient for L1 sample, as HGI values decrease is not varied. However, the data are very scattered and HGI estimation is not valid (Figure 2) [2, 6].

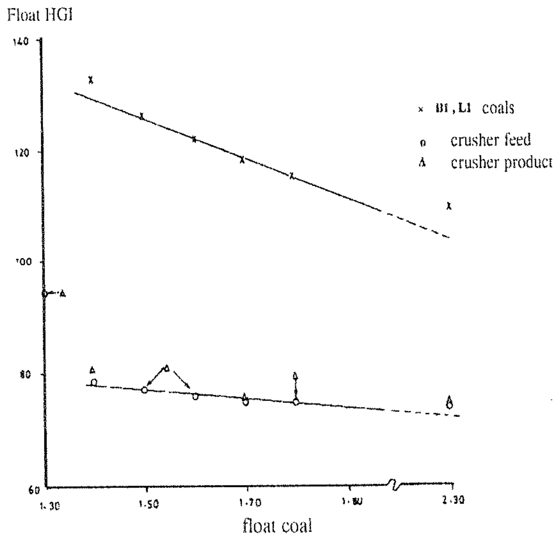

Figure 2: The HGI values versus specific gravity [5].

According to the sink-float results, which were prepared during the sampling campaigns in mineral processing plants, it is recommended that the HGI values to be determined for the ascending specific gravity fractions, as for the float part, the ash content is measured (Figure 2). These amounts are then plotted versus specific gravities which straight lines are produced. On the contrary, when based on the sink-float data, the average specific gravity and the HGI values are calculated and plotted, it is observed that a linear relationship is produced between two coal types (Figure 3). These equations are as following [2]:

$$HGI_{cum} = -65.5582SG_{cum} + 172.6564 \quad (2)$$

$$HGI_{cum} = -27.6325SG_{cum} + 116.6265 \quad (3)$$

$$HGI_{cum} = -83.1395SG_{cum} + 243.5456 \quad (4)$$

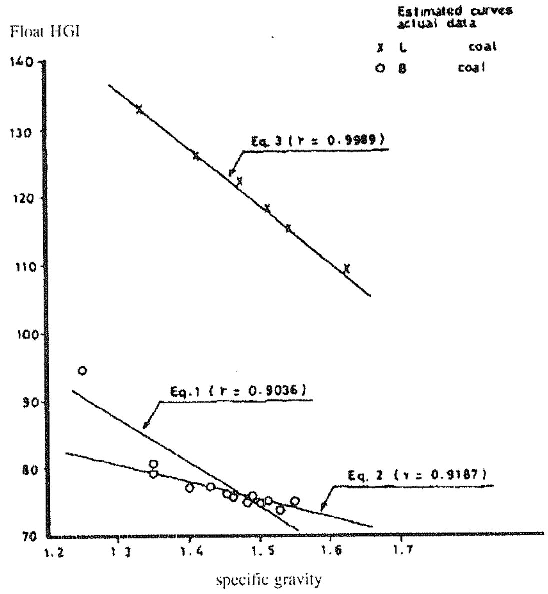

Figure 3: The relation between specific gravity and HGI values of float mass.

Equations 3 and 4 are used for the B1 sample. The first equation was prepared, concerning all specific gravities (Table 1), and in equation 4 float material lighter than 1.3 is mixed with material with SG of 1.4 and the lightest fraction is then considered to be equal to 1.4. This is based on the fact that the HGI values in SG of 1.3 is very different with other SG fractions, and its weight distribution is also negligible. In addition the object of this study is to develop an equation which is to be able to estimate the grindability index of B1 coal sample. It is observed in Figure 2 that the equation 3 is more acceptable, if the float material in SG of 1.3 is neglected.

The correlation factor, r, in equations 3, and 4 are 0.9036 and 0.9187 respectively. It is observed in Figure

3, that the best relationship for the L1 coal sample is achieved equal to 0.9988 [2].

4. Conclusions

Estimation of the HGI values for two types of coal samples were studied, using statistical method which has some advantages. Any change in the specific gravity distribution of coal might result in change of grindability and through the sink-float experiments it is possible to determine any change in HGI values.

Since the sink-float experiments are conventional in coal preparation plants, to evaluate the washability of the ore, the data obtained by these tests could be used to estimate the grindability, without performing the tests. Therefore it is possible to reduce the cost and time.

The products of coal washing of B1 and L1 samples in the steel & power plants would go for further grinding, therefore the data obtained from analysis of sink-float data of washed coal and its middling products, could be to determine grindability of samples.

TABLE 1
THE HGI VALUES OF BI AND L1 SAMPLES IN VARIOUS SPECIFIC GRAVITY FRACTIONS.

Specific Gravity	B1 Coal Type Feed Weight (%)	HGI	Product Weight (%)	HGI	L1 Coal Type Weight (%)	HGI
<1.3	1.0	95	0.5	95	-	-
1.3-1.4	22.2	78	11.0	80	11.6	133
1.4-1.5	28.1	76	42.3	76	22.4	122
1.5-1.6	20.8	73	18.3	74	24.1	117
1.6-1.7	14.3	70	11.6	72	16.9	105
1.7-1.8	6.2	69	6.9	70	9.5	90
>1.8	7.4	71	9.4	72	15.5	74
Total	100.0	-	100.0	-	100.0	-
Calculated Average	-	74	-	75	-	109
Index	-	76	-	76	-	110

TABLE 2
THE HGI VALUES OF BI AND L1 SAMPLES IN VARIOUS SPECIFIC GRAVITY FRACTIONS.

Specific Gravity (SG)		B1 Coal Type						L1 Coal Type		
SG Fractions	Average	Cumulative Amounts of Crusher feed			Cumulative Amounts of Crusher Product			Cumulative Amounts		
		Weight (%)	SG	HGI	Weight (%)	SG	HGI	Weight (%)	SG	HGI
<1.3	1.25	1.0	1.25	95	0.5	1.25	95	-	-	-
1.3-1.4	1.35	23.2	1.35	79	11.5	1.35	81	11.6	1.33	133
1.4-1.5	1.45	51.3	1.40	77	53.8	1.43	77	34.0	1.41	126
1.5-1.6	1.55	72.1	1.45	76	72.1	1.46	76	58.1	1.47	122
1.6-1.7	1.65	86.4	1.48	75	83.7	1.49	76	75.0	1/51	118
1.7-1.8	1.75	92.6	1.50	75	90.6	1.51	75	84.5	1/54	115
>1.8	1.95(B1), 2.21 (L1)	100	1.53	74	100	1.55	75	100	1.62	109

It seems that the calculated values of HGI for B1 and L1 samples is determined by the HGI values for specific gravity components and weight percent distributions. The distinct types of trends could be assigned for HGI-specific

The linear correlation observed for the both types of coal samples, which presents the relationship between the cumulative average of specific gravity and the HGI for the float part of that component. Therefore, careful estimation of HGI for both coal types should be considered using the empirical relationship.

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