PRACTICAL ASSESSMENT OF GRINDING CAPACITY AND POWER CONSUMPTION BASED ON HARDGROVE GRINDABILITY INDEX AND COAL CHARACTERISTICS

by

Marko O. OBRADOVIĆ**, *Dejan B. RADIĆ*, *Dušan M. TODOROVIĆ*, *Aleksandar M. JOVOVIĆ*, *Nikola V. KARLIČIĆ*, *and Miroslav M. STANOJEVIĆ

Faculty of Mechanical Engineering, University of Belgrade, Belgrade, Serbia

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This paper analyzes the effects of coal grindability and its characteristics on the grinding capacity and power consumption for beater wheel mill during exploitation in thermal power plant TENT B in Obrenovac, Serbia. For this purpose, experiments were made on the mill, before and after its reconstruction. Experiments included the determination of grinding capacity, mill power consumption, and laboratory analysis of coal characteristics and Hardgrove grindability index (HGI). The analysis of experimental results found that the grinding capacity has a negative correlation with the ash content in coal. Moisture content in analysis sample of coal has a positive correlation with the consumption of electricity and grinding capacity. Between the grinding capacity and the value of HGI exists a negative correlation. Analysis of the influence of grindability of coal and coal characteristics on grinding capacity and energy consumption was carried out. Based on coal characteristics and values of HGI, mathematical expressions were derived for the calculation of grinding capacity and electric energy consumption. In addition, ability to predict specific power consumption of the mill on the basis of HGI values, were carried out. Specific power consumption obtained from HGI values showed good agreement with the experimentally determined specific power consumption of the mill.

Key words: *Hardgrove grindability index, beater wheel mill, grinding capacity, mill power consumption, regression and correlation analysis*

Introduction

There are significant efforts and investments in thermal power plants to maintain electric power generation at maximum design parameters, or even to increase capacities of previously designed existing units. A whole range of different activities is to be conducted in thermal power plants to provide achieving higher efficiencies and increase of unit's power. One of the most important limitations to achieve maximum possible capacity at coal-fired thermal power plants is grinding capacity of mills for pulverized coal preparation. Coal grindability directly affects grinding capacities, therefore it is key parameter for design, construction and exploitation of pulverized coal mills. Thermal power plants in Serbia are based on beater wheel mills which pulverize low rank coals (lignite) to required particle size distribution in order to be burned in boilers.

Limitations are primarily related to grinding capacity with guaranteed coal. In order to eliminate or reduce these limitations, it is possible to increase grinding capacity without signifi-

*Corresponding author, e-mail: mobradovic@mas.bg.ac.rs

cant investments. Examples of design modifications are given in [1, 2]. Repeated tests were conducted on the beater wheel mill as a part of the activities preceding the mill reconstruction in order to increase grinding capacity [3], and several tests following the beater wheel mill reconstruction with different operating regimes and different design solutions [4].

Combustion tests that were conducted in a pulverized coal-fired power plant in Healy Alaska, burning low rank high volatile content coal are reported in [5]. The intent of the tests was to determine impact on combustion when coal was ground to a coarser particle size distribution than nominal. Tests showed that combustion of coarser grind coal did not change steam production and power of thermal power plant.

Efforts to determine impact of HGI values and granulometric composition of pulverized coal on mill power consumption are given in [6]. Correlations derived from experimental data show increase in grinding energy consumption with finer grind than designed, with increased grinding capacity and decrease in HGI.

The impact of particle size distribution of pulverized, low rank high volatile content of coal on combustion related power plant performance was studied in [7]. Performance was gauged through efficiency, emissions of SO_2, NO_x, CO and carbon content of ash. The tested coal could be burned at a grind as coarse as 50% passing 76 [μm], with no significant impact on power generation and emissions. The particle size distribution was in the range of 41-81% passing 76 [μm]. Correlation between particle size distribution and the followings factors: efficiency, SO_2, NO_x and CO was negligible. Results show that these plants can reduce in-plant load by grinding the coal less, without impacting plant performance on emissions and efficiency.

In order to optimize coal fineness in coal mill, series of tests were conducted on 650 [th^{-1}] pulverized fuel boiler [8]. Authors derived relationships between the fineness of the produced pulverized coal and operating parameters, efficiency of the boiler and energy consumption of the mill and its fan.

Results of experimental investigation conducted for the purpose of determining HGI values of Serbian coal (lignite) from Kolubara basin are given in [9]. Research results obtained indicate that coal rich in mineral matter and thus, of lower heating value is characterized by higher HGI values. Therefore, analyses presented in the paper suggest that characteristics of solid fuels analyzed in the research investigation conducted are such that the use of coals less rich in mineral matter *i.e.* coals characterized by lower HGI values will cause coal mills to operate at reduced capacity. The results obtained indicates that variation of HGI values in the range of 37.1-48.2 may cause an increase in the grinding capacity of even up to 13.1%.

The impact of HGI values and characteristics of lignite from Kolubara coal basin on grinding capacity and grinding power consumption was considered in experimental research [10] giving correlations to be used for calculations of grinding capacity and grinding energy consumption in beater wheel mills.

The impact of different coal lithotypes (matrix coal, yellow, brown and black types of xylite-rich coal) from Kolubara lignite basin on grindability properties was studied in [11]. The yellow type of xylite-rich coal demonstrated the most negative impact on HGI. All xylite types, as well as total xylite-rich coal have a negative impact on the grindability properties. Matrix coal does not show a consistent effect on HGI. Mineral matter has a positive impact on HGI ($r = 0.72$). The HGI is controlled by amount and type of mineral matter. The mineral matter from the Kolubara lignite basin mainly consists of quartz, while clays and feldspar are less abundant. These results are in concordance with the results of previous investigations [12, 13] which also showed that quartz has a positive impact on grindability. Also author in [10] analyze impact of coal characteristics (proximate analysis, petrological and organic geochemical properties) of lignite from the Kolubara and Kostolac basin on HGI and derive expressions between values of HGI and coal characteristics, which can be used to predict the behavior of coal in comminution process.

Experimental investigations

The experimental research was carried out on beater wheel mill (mill No. M-12, type N400.42) at 1200 MWe thermal power plant TENT B in Obrenovac, to investigate impact of coal characteristics on pulverized coal mill performance. Coal samples used in this study originate from Kolubara basin. The HGI values were determined according to ISO 5074, while granulometric distribution was determined by the use of sieve analysis according to ASTM D4749.

Proximate analysis of coal included determination of:

- ash content according to ISO 1171 - Solid mineral fuels - Determination of ash content,
- total moisture content according to ISO 5068-1 - Brown coals and lignites - Determination of moisture content - Part 1: Indirect gravimetric method for total moisture, and
- moisture content in analysis sample according to ISO 5068-2 - Brown coals and lignites Determination of moisture content - Part 2: Indirect gravimetric method for moisture in the analysis sample.

Grinding capacity was determined based on coal mass on the belt conveyor and by the feeder geometry. Mill power consumption (mill load given as electric energy consumption) was measured using plant system instruments.

Energy consumption used for grinding and other processes per unit of mass (specific power consumption) is [14, 15]:

$$W_1 = \frac{N}{B} \tag{1}$$

The total power of mill electric motor (power at mill load) is obtained from the expression [14, 15]:

$$N_{\max} = \left(1 + \frac{1}{2 \cdot D_1^{0.66}}\right) N \tag{2}$$

where D_1 [m] is outer diameter of beater. Beater wheel mill M-12 diameter is $D_1 = 4.2$ [m].

As well, the total power of mill electro motor based on energy consumption was calculated using the expression:

$$N_{\max} = \sqrt{3}\, U I \cos\varphi \tag{3}$$

Dependence between HGI values and specific power consumption is given by expression [16]:

$$W_i = \frac{435}{HGI} \tag{4}$$

Software packages IBM SPSS Statistics and Microsoft Office Excel were used to establish correlation between expressions for grinding capacity and grinding power consumption.

Results and discussion

Beater wheel mill experimental investigations are given in tab. 1, while tab. 2 presents specific power consumption calculated using expressions (1) and (2) based on measured values of voltage, electric energy consumption and grinding capacity, respectively using expression (4) based on HGI values.

Table 1. Beater wheel mill experimental investigations results

	No.	B [th^{-1}]	R_{90} [%]	D_{90} [%]	I [A]	I_{sp} [Aht^{-1}]	HGI [–]	W [%]	$W_{h,a}$ [%]	A [%]	$W_{h,a,up}$ [%]
Before reconstruction	1	128.5	72.1	27.9	–	–	–	49.8	–	14.5	13.4
	2	132.0	70.7	29.3	–	–	44.2	51.1	–	13.9	16.2
	3	138.7	64.8	35.2	162	1.1680	38.7	49.6	19.2	12.3	15.7
	4	140.2	62.3	37.7	165	1.1769	42.9	50.1	18.9	12.1	15.1
	5	137.9	68.0	32.0	162	1.1748	39.6	49.7	19.7	13.7	12.5
	6	125.5	63.8	36.2	170	1.3546	40.6	52.7	19.6	9.4	16.4
Minimum		125.5	62.3	27.9	162	1.1680	38.7	49.6	18.9	9.4	12.5
Maximum		140.2	72.1	37.7	170	1.3546	44.2	52.7	19.7	14.5	16.4
Average		133.8	67.0	33.1	164.8	1.2186	41.2	50.5	19.4	12.7	14.9
After reconstruction	7	137.4	50.6	49.4	198	1.4410	40.9	49.0	18.4	17.9	4.1
	8	137.4	55.4	44.6	195	1.4192	37.5	49.5	19.3	16.3	3.4
	9	159.1	56.3	43.7	187	1.1754	30.7	52.6	23.7	10.4	9.0
	10	159.2	51.9	48.1	194	1.2186	30.7	52.1	23.5	9.8	6.8
	11	154.2	59.0	41.0	200	1.2970	40.8	49.8	18.3	17.2	11.9
	12	154.3	55.1	44.9	193	1.2508	46.8	49.7	19.5	16.2	10.8
	13	129.9	61.7	38.3	188	1.4473	38.1	50.3	20.0	14.2	14.1
	14	132.4	63.5	36.5	190	1.4350	41.0	49.1	18.3	18.3	10.5
	15	152.3	58.2	41.8	190	1.2475	43.7	50.6	20.3	15.6	14.0
	16	141.9	61.2	38.8	190	1.3390	42.8	51.6	21.4	13.6	15.0
	17	156.5	59.4	40.6	199	1.2716	36.1	52.4	23.4	11.2	17.7
	18	145.2	64.7	35.3	182	1.2534	48.5	48.7	17.2	20.6	11.3
	19	148.2	70.8	29.2	174	1.1741	35.6	49.0	17.8	16.8	13.5
	20	144.0	55.2	44.8	175	1.2153	35.8	46.9	13.4	17.3	14.2
	21	147.8	63.0	37.0	175	1.1840	36.6	51.1	20.6	11.2	17.7
	22	138.4	62.9	37.1	168	1.2139	51.6	48.1	17.1	16.4	15.5
	23	137.4	72.0	28.0	175	1.2737	41.4	50.3	20.4	13.9	19.2
	24	148.6	68.8	31.2	180	1.2113	47.2	49.9	18.8	16.7	18.8
	25	146.9	64.3	35.7	180	1.2253	40.6	50.6	22.2	15.8	18.0
	26	147.2	66.7	33.3	182	1.2364	47.0	51.7	19.6	13.6	17.4
Minimum		129.9	50.6	28.0	168	1.1741	30.7	46.9	13.4	9.8	3.4
Maximum		159.2	72.0	49.4	200	1.4473	51.6	52.6	23.7	20.6	19.2
Average		145.9	61.0	39.0	185.8	1.2765	40.7	50.2	19.7	15.2	13.1
Coefficient of correlation, *r*											
B			–0.242	0.242	**0.231**	**–0.689**	–0.286	0.503	**0.442**	**–0.449**	**0.030**
HGI		**–0.286**	0.355	–0.355	–0.249	0.035		–0.367	–0.402	**0.571**	0.306
I		0.231	**–0.633**	**0.633**		0.545	–0.249	0.360	**0.377**	–0.099	–0.563

Table 2. Specific grinding energy consumption

	No.	I [A]	U [V]	$cos\varphi$	N_{max} [kW]	N [kW]	B [th^{-1}]	HGI [–]	$W_i^{a)}$ [kWht^{-1}]	$W_i^{b)}$ [kWht^{-1}
Before reconstruction	1	–	6600	0.9	–	–	128.5	–	–	–
	2	–	6600	0.9	–	–	132.0	44.2	–	9.842
	3	162	6600	0.9	1666.7	1392.4	138.7	38.7	10.039	11.240
	4	165	6600	0.9	1697.6	1418.2	140.2	42.9	10.115	10.140
	5	162	6600	0.9	1666.7	1392.4	137.9	39.6	10.097	10.985
	6	170	6600	0.9	1749.0	1461.1	125.5	40.6	11.643	10.714
Average		165	6600	0.9	1695.0	1416.0	134.9	41.2	10.473	10.584
After reconstruction	7	198	6600	0.9	2037.1	1706.2	137.4	40.9	12.418	10.636
	8	195	6600	0.9	2006.2	1680.4	137.4	37.5	12.230	11.600
	9	187	6600	0.9	1923.9	1611.4	159.1	30.7	10.128	14.169
	10	194	6600	0.9	1995.9	1671.8	159.2	30.7	10.501	14.169
	11	200	6600	0.9	2057.7	1723.5	154.2	40.8	11.177	10.662
	12	193	6600	0.9	1985.7	1663.1	154.3	46.8	10.779	9.295
	13	188	6600	0.9	1934.2	1620.1	129.9	38.1	12.472	11.417
	14	190	6600	0.9	1954.8	1637.3	132.4	41.0	12.366	10.610
	15	190	6600	0.9	1954.8	1637.3	152.3	43.7	10.750	9.954
	16	190	6600	0.9	1954.8	1637.3	141.9	42.8	11.538	10.164
	17	199	6600	0.9	2047.4	1714.8	156.5	36.1	10.957	12.050
	18	182	6600	0.9	1872.5	1568.3	145.2	48.5	10.801	8.969
	19	174	6600	0.9	1790.2	1499.4	148.2	35.6	10.117	12.219
	20	175	6600	0.9	1800.5	1508.0	144.0	35.8	10.472	12.151
	21	175	6600	0.9	1800.5	1508.0	147.8	36.6	10.203	11.885
	22	168	6600	0.9	1728.4	1447.7	138.4	51.6	10.460	8.430
	23	175	6600	0.9	1800.5	1508.0	137.4	41.4	10.975	10.507
	24	180	6600	0.9	1851.9	1551.1	148.6	47.2	10.438	9.216
	25	180	6600	0.9	1851.9	1551.1	146.9	40.6	10.559	10.714
	26	182	6600	0.9	1872.5	1568.3	147.2	47.0	10.655	9.255
Average		186	6600	0.9	1911.1	1600.1	145.9	40.7	11.000	10.904

Beater wheel mill is driven by electric motor. Motor voltage is U = 6000 [V] and cosφ = 0.9 [14]
a) specific power consumption based on grinding capacity (expressions 1 and 2)
b) specific power consumption based on HGI (expression 4)

Experimental investigations were conducted on mill M-12 with different operating regimes tab. 1. Grinding capacity was 129.9-159.2 [th^{-1}], mill load 168-200 [A], specific grinding energy consumption 1.1741-1.4473 [Aht^{-1}], HGI 30.7-51.6 [–], total moisture content in coal 46.9-52.6 [%], and ash content in coal 9.8-20.6 [%].

Experimental results given in tab. 1 show moderately strong negative linear correlation between grinding capacity and specific grinding energy consumption ($r = -0.689$), and positive correlation between electric energy consumption and grinding capacity ($r = 0.231$).

Also, there is moderately strong positive correlation between cumulative passing through 90 [μm] sieve and electric energy consumption ($r = 0.633$), which would mean higher mill load and higher electric energy consumption with higher cumulative passing through 90 [μm] sieve (higher share of finer fraction in pulverized coal). The opposite conclusion is valid for cumulative retained on 90 [μm] sieve ($r = -0.633$).

There is negative correlation between grinding capacity and ash content in coal ($r = -0.449$), while there is no correlation with moisture content in analysis sample of pulverized coal ($r = 0.030$). However, there is positive correlation between moisture content in analysis coal sample at the mill input and electric energy consumption ($r = 0.377$), as well as with grinding capacity ($r = 0.442$). That results in higher electric energy consumption (as expected), but also in achieving higher capacities at the same time with increase of moisture in coal.

Higher energy consumption is resulted by increased grinding capacity, but presumably and partially caused by moisture impact on grinding [10, 16], where coals with higher moisture content may have better grindability and tendency to form cracks in structure.

However, there is negative correlation between grinding capacity and HGI values ($r = -0.286$), what is not apparently obvious. Increase in HGI value should be followed by grinding capacity increase, as HGI value has direct impact on grinding capacity. Experimental results show that increase of ash content in lignite is followed by HGI value increase ($r = 0.571$), but lignite with higher ash content has lower heating value what results in higher coal (lignite) consumption for the same boiler load. On the other hand, burning the same amount of lignite with higher ash content, higher HGI and lower heating value will result in lower boiler output power, accordingly lower flue gas temperature. Lower re-circulation flue gas temperature, used for drying lignite in mill, causes lower level of drying and lower mill ventilation, therefore lower grinding capacity. This research evidently shows negative effect of poor drying and ventilation in mill as dominant, comparing to HGI, therefore results in negative correlation of HGI and grinding capacity.

Correlation analysis was performed on data from tab. 1 to obtain expressions for forecasting of grinding capacity, fig. 1, and grinding energy consumption fig. 2 based on coal technical analysis and HGI. The analysis considered only beater wheel mill experimental investigations results after reconstruction.

Expression for grinding capacity calculation:

$$B = 3.041\, HGI^{-0.094} \left(\ln \frac{100}{R_{90}} \right)^{0.139} W^{1.025} A^{0.063}\, W_{h,a,up}^{0.054}, R^2 = 0.388 \tag{5}$$

Expression for grinding energy consumption calculation:

$$I = 64.847\, HGI^{-0.049} \left(\ln \frac{100}{R_{90}} \right)^{0.164} W_{h,a}{}^{0.301} A^{0.169}, R^2 = 0.667 \tag{6}$$

Design parameters of beater wheel mill M-12 from [14] are: required grinding power 2000 [kW], maximum capacity 40 [kgs^{-1}] (144 [th^{-1}]) with coal HGI value 56, cumulative retained on 90 [μm] sieve 65% and moisture content in pulverized coal 10%, while specific

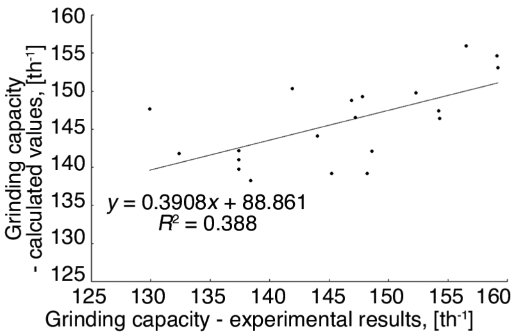

Figure 1. Graphical representation of results obtained using expression (5)

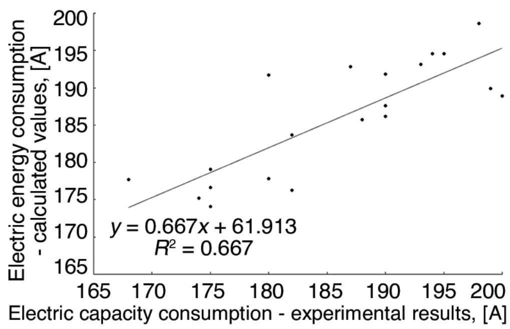

Figure 2. Graphical representation of results obtained using expression (6)

grinding energy consumption is 11.7 [kWht^{-1}]. Experimental investigation of mill in [12] showed maximum capacity of mill 45.79 [kgs^{-1}] (168.4 [th^{-1}]) for pulverized coal with moisture content 7.65%, while required grinding power was 1763.4 [kW], total power of driving electric motor 2110.8 [kW], and specific power consumption 10.7 [kWht^{-1}].

Experimental research on beater wheel mill prior to reconstructions showed required grinding power of 1416.0 [kW] at average grinding capacity 134.9 [th^{-1}], tab. 2. Accordingly, pre-reconstruction research showed specific power consumption of 10.473 [kWht^{-1}], what is in good agreement with data in [15].

Post-reconstruction experimental research on beater wheel mill showed required grinding power of 1600.1 [kW], at average grinding capacity 145.9 [th^{-1}], tab. 2, and specific power consumption of 11.0 [kWht^{-1}].

As given in tab. 2, the total required power for driving electric motor of mill before reconstruction was 1695.0 [kW], and 1911.1 [kW] after reconstruction.

Concerning specific power consumption particular values, tab. 2, some cases show significant bias between experimental research values and values calculated by expression (4). This could be explained in terms of grinding capacity determination problem and regarding errors, as well as negative correlation between grinding capacity and HGI.

Combining expression (3) and correlation for mill electric energy consumption (6), total required power for driving electric motor of mill could be calculated by using data on HGI, coal proximate analysis and cumulative retained on 90 [μm] sieve. Calculated data is given in tab. 3, and graphical representation of results in fig. 3.

As given in tab. 3, average value of mill electric motor total power, based on measured values of electric energy consumption, was 1911.1 [kW] and based on calculation using expressions (6) and (3) 1911.7 [kW].

Concerning electric energy consumption, measured values average was 186 [A] and calculated value using expression (6) was 185.6 [A].

Analysis of the particular values of mill electric motor total power, tab. 3, showed that difference between measured and calculated values was 1.56-120.7 [kW] (average 39.6 [kW]). Relative difference, according to tab. 3, was 0.1-6.5 % with average relative difference 2.1%.

Concerning electric energy consumption, analysis of particular values, tab. 3, showed that difference between measured and calculated values using expression (6) was 0.15-11.7 [A] (average 3.9 [A]) and relative difference 0.1-6.5 % with average relative difference 2.1%.

There is evident agreement between calculated and measured data, tab. 3, therefore obtained correlations can be used for calculation of mill electric energy consumption and required coal grinding power in considered beater wheel mill plant.

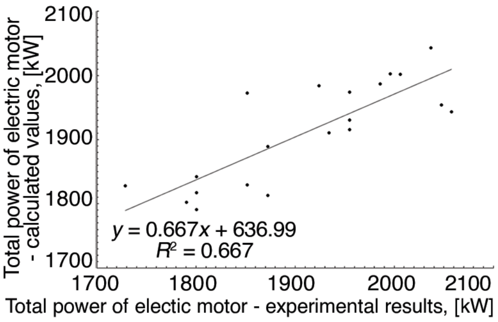

Figure 3. Graphical representation required driving electric motor power of mill obtained using expressions (3) and (6)

Table 3. Driving electric motor power calculated from measured values and calculated using expression (6)

	No.	$I^{a)}$ [A]	$N_{max}^{b)}$ [kW]	$I^{c)}$ [A]	$N_{max}^{d)}$ [kW]
After reconstruction	7	198	2037.1	198.6	2043.4
	8	195	2006.2	194.6	2001.8
	9	187	1923.9	192.8	1984.1
	10	194	1995.9	194.6	2002.3
	11	200	2057.7	188.9	1943.5
	12	193	1985.7	193.2	1987.2
	13	188	1934.2	185.7	1911.0
	14	190	1954.8	186.2	1915.8
	15	190	1954.8	191.9	1973.9
	16	190	1954.8	187.6	1930.5
	17	199	2047.4	189.9	1954.0
	18	182	1872.5	183.7	1889.5
	19	174	1790.2	175.2	1802.8
	20	175	1800.5	176.7	1817.7
	21	175	1800.5	179.1	1842.6
	22	168	1728.4	177.7	1828.1
	23	175	1800.5	174.1	1791.0
	24	180	1851.9	177.8	1829.4
	25	180	1851.9	191.7	1972.6
	26	182	1872.5	176.2	1813.3
Average		186	1911.1	185.8	1911.7

a) measured value
b) calculated value based on measured values using expression (3)
c) calculated value using expression (6)
d) calculated value using expression (6) and (3)

Conclusions

Experimental research results on beater wheel mill led to establishing a positive correlation with moderately strong coefficient of determination ($R^2 = 0.667$) for calculating grinding energy consumption. Further, experimental research provided establishing correlation to calculate grinding capacity based on HGI values, proximate and sieve analysis. Moderately strong coefficient of determination of expression for electric energy consumption calculation and moderate coefficient of determination of expression for grinding capacity calculation, therefore obtained correlations can be used for calculation of these process parameters on beater wheel mills.

The literature review presents many expressions relating HGI and Bond work index, or specific power consumption. Based on expression (4) and experimental HGI data, specific power consumption for grinding lignites from Kolubara basin was calculated. Average calculated specific power consumption was 10.904 [$kWht^{-1}$], and this values is in good agreement with mill design parameters, 11.7 [$kWht^{-1}$], as well as with previous mill examinations, 10.7 [$kWht^{-1}$].

Specific power consumption values were calculated in two different methods. The first method correlates HGI and specific power consumption, and the second method implies calculating power of mill driving electric motor, and then obtaining specific power consumption by dividing with grinding capacity. These two methods have very close average values, 10.904 [$kWht^{-1}$] respectively, 11.000 [$kWht^{-1}$], but single values in some cases show significant bias. This could be explained in terms of grinding capacity determination problem and regarding errors.

Required power of mill driving electric motor was calculated based on experimental research results and obtained correlations for grinding power consumption ($R^2 = 0.667$), with average value of 1911.7 [kW], while calculated value based on measured electric energy consumption was 1911.1 [kW].

General conclusion of the research is that obtained correlations could be used to define mill load and power requirements for coal grinding in considered mill plant. Derived methodology of correlation forming is applicable to beater wheel mill plants preparing pulverized lignite coal for combustion.

Nomenclature

A – ash content in coal (mass fraction), [%]
B – grinding capacity, [th^{-1}]
$\cos\varphi$ – power factor, [–]
D_1 – outer diameter of beater, [m]
D_{90} – cumulative passing through 90 [μm] sieve, [%]
HGI – Hardgrove grindability index, [–]
I – mill load (electric energy consumption), [A]
I_{sp} – specific grinding energy consumption (specific mill load) (= I/B), [At^{-1}h]
N – grinding power, [kW]
N_{max} – total power of mill driving electric motor, [kW]
r – coefficient of correlation, [–]
R^2 – coefficient of determination, [–]
R_{90} – cumulative retained on 90 [μm] sieve, [%]
U – mill electric motor voltage, [V]
W – total moisture content in coal (mass fraction), [%]
W_i – specific power consumption, [kWht^{-1}]
$W_{h,a}$ – moisture content in analysis sample of coal at mill input (mass fraction), [%]
$W_{h,a,up}$ – moisture content in analysis sample of pulverized coal (mass fraction), [%]

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