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Investigating the optimum fineness of the coal grain in the Brown Coal Mine Kakanj in order to fully exploit its calorific value

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Abstract: In an array of mechanical operations undertaken during the processing of raw coal at the reloading system of the "Vrtlište" open-cut mining in the brown coal mine Kakanj, the tendency is to separate the combustible from the non-combustible parts of coal all with the aim of obtaining a product with higher calorific value and fewer ash components. Depending on the physical and chemical composition of the raw material and the purpose of the obtained product, our objective was to determine the optimal size of the coal grain in the "Brown Coal Mine Kakanj" whereby the most agreeable aspect in terms of the energy value was to separate the valuable fractions from the tailings. It was established that the top-quality granulation in the raw material being delivered to the client in terms of its energy characteristics is -40+35 mm with a calorific value of 16918 kJ/kg followed by -35+20 and -20 +10 with a calorific value of 13035 kJ/kg and 13819 kJ/kg respectively. They generate the smallest amounts of ash after combustion while the free, hygro and total moisture have the lowest values in these samples.

INTRODUCTION

Safe delivery of adequate selection and quality of coal from the "Vrlište" open-cut mine of the Brown Coal Mine "Kakanj" for the requirements of the "Kakanj" thermal power plant imposed the need to build a coal reception, preparation and wagon loading system at the "Vrlište" open-cut mine whereby the client requested, among other features, that the coal is to be < 40 mm in size.

The granulometric composition of raw coal from the "Vrlište" open-cut mine ranges from 0 mm to a maximum of 400 mm in size. Coal exploitation from the "Vrlište" open-cut mine is conducted on the surface while the exploitation system consists of the removal and depositing of the coal overburden layers and coal exploitation. Due to the geological composition of the coal seams, it is not possible to obtain pure coal and manual separation of tailing is thus conducted within this coal preparation system.

EXPERIMENTAL

Sampling

For the purpose of implementing the experimental part of this paper, sampling of coal was performed on March 23, 2013 at three locations within the coal reception, preparation and wagon loading system. It was established that the coal samples taken from three different locations differed in their granulometric composition and contained tailings. The method used for sampling and processing of the basic coal sample is included in the BAS ISO 5069-1:2002 standard. The calculation of variances for the sampling method was performed in line with the ASTM D 2234-00 method.

An outline drawing of the reloading system including the sampling location is presented in Figure 1. Location (1) is the rubber belt conveyor in the tailing selection room immediately before the manual selection of tailing. Location (2) is also a rubber belt conveyor in the tailing selection room but after the manual selection of tailing and before the entry into a grinder. The coal at the locations (1) and (2) was taken from the +40 mm sieve and the granulation ranges from 40 mm to 400 mm with somewhat smaller fractions created by the movement and inter-crushing of the material.

Location (3) is a rubber belt conveyor that takes on the sieved and the crushed coal from the grinder and transports it to a closed depot. The granulation of the coal sampled at Location (3) ranges from 0 mm to 40 mm.

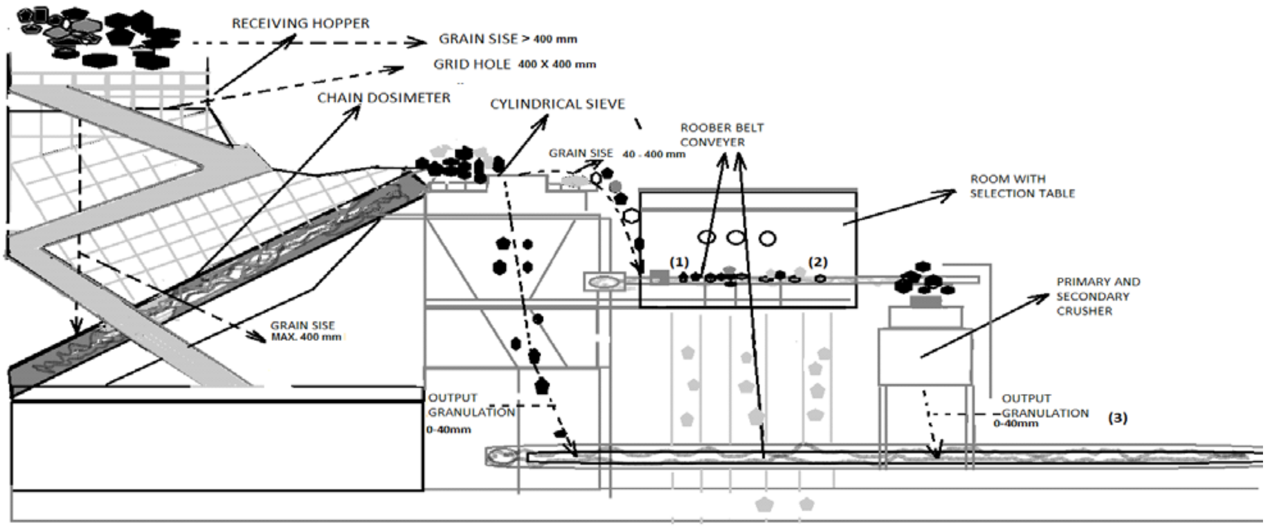

Figure 1: An outline drawing of the reloading system for coal reception, preparation and wagon loading including sampling locations (1), (2) and (3).

Grain-size analysis of samples

The grain-size analysis of coal was conducted on sieves with 400 mm, 250 mm, 100 mm, 50 mm openings and granulation of coal varying between 40 mm to 400 mm.

For 0 mm to 40 mm coal granulation, the following openings of sieves were used: 40 mm, 35 mm, 30 mm, 20 mm, 10 mm, 5 mm, 3 mm and 1 mm.

Physical and chemical analysis of sieves

The methods used for physical and chemical analysis of coal samples were in line with internationally recognized standards: BAS ISO 5069 2:2002; ISO 5068 2:2009; ISO 1171:1999; ISO 1928:2010 and are described in the operational instructions of the "Brown Coal Mine Kakanj."

Tables 1, 2, 3 and 4 present the physical and chemical composition of 40 mm to 400 mm grain-size coal immediately before manual separation of tailing, the same granulation after manual separation of tailing and 0-40 mm granulation after grinding.

The method applied in analysing coal for carbon, hydrogen and nitrogen components by means of a LECO CHN-100 Element Analyser produced by „LECO Corporation" Michigan, USA is part of an internationally recognized standard ASTM D 5373:2008. Identifying the higher calorific value of coal was conducted by a C 5000 Calorimeter manufactured by „IKA-Werke GmbH & Co. KG, Germany while the lower calorific value was established through calculations.

RESULTS AND DISCUSSION

Physical and chemical composition of 40 mm to 400 mm coal fractions prior to manual separation of tailing

Table 1 indicates that the coal sample of 40 mm to 400 mm granulation taken from the sampling location (1), in our case coal containing tailing immediately before its manual separation, is most abundantly present in grains smaller than 250 mm and larger than 100 mm.

Tiny grains of coal smaller than 1 mm and 50 mm that were created by crushing of coal during its transportation as a result of mechanical effects are the least represented.

Table 1 indicates that grains smaller than 250 mm and larger than 100 mm contain the least amount of ash and the highest amount of combustible materials carrying the highest lower calorific value. Coal grains smaller than 100 mm and larger than 50 mm create the largest amount of ash during combustion and have the least amount of combustible material that consequently results in the smallest lower calorific value.

In coal grain samples ranging from 40 mm to 400 mm in size that contain the same amount of tailing after the grinding process until analytical sampling, we can perceive almost the same moderate amount of total moisture in all obtained granulation samples, from which we can conclude that that the differences in calorific values of samples do not originate from the variable content of moisture but rather from the differences in the amount of tailing.

Grains smaller than 50 mm in size have uniform amounts of ash generated by combustion with a tendency for further size degradation which reflects in almost the same lower calorific value as smaller granulations as indicated in Table 1.

Sudden reduction of the lower calorific value for coal grains larger than 50 mm and smaller than 100 mm can be explained by the increased content of tailing in the sample which consequently also means higher amounts of ash after combustion. Grains smaller than 100 mm and larger than 50 mm contain higher amounts of tailing embedded in the pieces of coal which represents a mixture of coal and tailing for these types of granulations.

Volatile materials are most widely present in grains smaller than 250 mm and larger than 100 mm which was expected due to the high amount of combustible materials in these grain samples.

Table 1. *Results of a physical and chemical analysis of 40 mm to 400 mm grain size of coal before manual separation of tailing*

Sieve opening size (mm)	Fraction involvement (%)	Free moisture (%)	Hygroscopic moisture (%)	Total moisture (%)	Ash (%)	Combustible material (%)	Composition of volatile material (%)	Lower calorific value of coal (kJ/kg)
- 400 + 250 mm	6,35	4,80	4,36	9,16	45,42	45,42	25,39	12384
-250 + 100 mm	77,86	4,50	4,24	8,74	39,77	51,49	26,90	14057
- 100 + 50 mm	14,62	5,70	3,00	8,70	57,06	34,24	19,05	8479
- 50 mm	0,50	5,80	3,10	8,90	50,56	40,54	23,32	11659
- 1 mm	0,67	5,86	3,48	9,34	49,89	40,77	23,66	11711
Mean value	63,67	4,71	4,06	8,77	42,78	48,45	25,62	13108

Physical and chemical composition of 40 mm to 400 mm coal fractions after manual separation of tailing

Coal grain samples of 40 to 400 mm in size from the sampling location (2) i.e. coal from which the tailing was separated manually, is most widely present in granulations smaller than 250 mm and larger than 100 mm in size, as indicated by Table 2. The least present granulations are the ones smaller than 1 mm and smaller than 50 mm that were created by mechanical fragmentation of larger pieces of coal as a result of inter-collision of pieces at the sieves and during transportation.

The chemical analysis of various coal grain samples that were partially separated from tailing by means of manual separation indicated that grains smaller than 250 mm and larger than 100 mm have significantly reduced amount of ash (39.77%) in comparison to 51.47% as was established in sample 1, an increased amount of volatile material and the highest lower calorific value. After the separation of tailing coal grains smaller than 100 mm and larger than 50 mm generate significantly smaller amounts of ash during combustion and have larger amounts of volatile material which consequently results in an increased lower calorific value in comparison to the sample with tailing inclusive (Table 1, Table 2).

The total moisture in coal grain samples of 40 to 4000 mm in size indicates to a slight increase in the amount of moisture in smaller-sized grain samples. Its larger presence may be the result of moisture absorption on a now larger area created by fragmentation but also the increased presence of tailing which carries moisture in itself, as evident from an increased amount of ash in grains smaller than 50 mm and 1 mm.

Coal grain samples smaller than 50 mm contain a larger amount of ash generated by coal combustion which is the result of a higher percentage of this fraction in the sample that was created by mechanical shocks on the sieves during longer transportation than with sample 1. It is also the result of a release of small tailing fractions from larger pieces of coal and their sinking through the sieves which brings about a decrease in the calorific value of the sample thus attesting to the lower quality of coal in this fraction in view of its lower calorific value (Table 2). The small amount of ash that was created by combustion is almost uniformly present in granulations smaller than 400 mm and larger 250 mm as well as in grains smaller than 100 mm and larger than 50 mm in size. The smallest amount of ash after combustion was identified in the coal grains smaller than 250 mm and larger than 100 mm.

Table 2. *Results of granulometric and physical and chemical analysis of coal grains of 40 mm to 400 mm in size after manual separation of tailing*

Sieve opening size (mm)	Fraction involvement (%)	Free moisture (%)	Hygroscopic moisture (%)	Total moisture (%)	Ash (%)	Combustible material (%)	Composition of volatile material (%)	Lower calorific value of coal (kJ/kg)
- 400 + 250 mm	31,45	3,20	4,55	7,75	39,32	52,93	28,79	15292
-250 + 100 mm	36,54	2,90	5,28	8,18	22,55	69,27	35,23	21709
- 100 + 50 mm	28,41	3,80	4,86	8,66	38,73	52,61	27,95	15693
- 50 mm	2,12	6,00	2,50	8,50	53,45	38,05	23,03	10601
-1 mm	1,47	6,50	3,13	9,63	49,62	40,75	22,55	11697
Mean value		3,37	4,84	8,21	33,48	58,32	30,69	17599

Considering that this sample contains the optimum amount of moisture and a large amount of combustible material, we can foresee that this coal sample releases the most thermal energy during combustion. The reduction of the lower calorific value in the smaller coal grains can hereby be justified by the increase of tailing reported through the amount of ash in the sample.

The amount of volatile material in coal grains of 40 mm to 400 mm in size following annual separation of tailing is reduced with the reduction in the size of the coal grain. Taking into consideration the results of the physical and chemical analysis of various coal grain samples (Table 2), we can perceive that there is a reduction of the lower calorific value with smaller coal grain samples. We can conclude that the isolated, smaller fractions carry in this phase a larger amount of tailing which as a result of its geological composition binds smaller amounts of organic material and water. In addition to the organic material that encompasses this volatile phase, the carbon mass also includes a significant amount of water that files the carbon mass pores which would not be feasible in the argilic tailing without such a developed porous system.

Physical and chemical composition of coal fractions of 0 to 40 mm in size

The largest number of coal samples that were taken at location (3) i.e. from the conveyor belt after the crushing of coal to a smaller granulation, is comprised of grains smaller than 40 mm and larger than 35 mm. Smaller grains are individually present in small numbers while the least present granulations are those smaller than 3 mm and larger than 1 mm (Table 3).

The physical and chemical analysis of coal grain samples undergoing a reloading system at the open-cut mine “Vrtlište” (Table 3) indicates that the grains smaller than 40 mm and larger than 35 mm contain significantly less ash and respectively more combustible material and have the highest lower calorific value. Coal grains smaller than 3 mm and larger than 1 mm in size generate more ash during combustion thus contain less combustible material and have smaller lower calorific value.

The amount of total moisture is slightly increased in the smaller grain samples. The total moisture together with the ash contributes to the non-combustible part of the coal and heat consumption. Therefore, the smaller coal grain samples in this case have a smaller calorific value.

It is evident that larger amounts of ash generated by coal combustion are present in smaller grain samples, which indicates to a smaller amount of combustible material and thus smaller lower calorific value. (Table 3)

Table 3. *Results of granulometric and physical and chemical analysis of coal grains of 0 mm to 40 mm in size*

Sieve opening size (mm)	Fraction involvement (%)	Free moisture (%)	Hygroscopic moisture (%)	Total moisture (%)	Ash (%)	Combustible material (%)	Composition of volatile material (%)	Lower calorific value of coal (kJ/kg)
- 40 + 35 mm	57,41	4,70	4,53	9,23	32,93	57,84	29,68	16918
-35 + 30 mm	6,95	6,20	4,43	10,63	42,16	47,21	25,36	13035
- 30 + 20 mm	14,84	7,80	3,84	11,64	38,58	49,78	26,19	13819
- 20 + 10 mm	14,01	9,60	3,00	12,60	45,08	42,32	22,53	11243
- 10 + 5 mm	3,15	9,85	1,64	11,49	43,78	44,73	23,25	11909
- 5 + 3 mm	1,60	10,24	1,66	11,90	43,89	44,21	22,57	11876
- 3 + 1 mm	0,33	10,61	1,78	12,39	48,10	39,51	20,67	10149
- 1 mm	1,71	10,33	1,23	11,56	48,65	39,79	20,58	10304
Mean value		6,32	4,00	10,32	36,23	52,73	27,36	15019

Physical and chemical analysis of coal grains for carbon, hydrogen and nitrogen substances

The percentage of carbon is smaller in samples that contain less combustible materials and have a smaller lower calorific value.

The amount of hydrogen as well as nitrogen is also smaller in samples with less combustible material in comparison to the samples with higher presence of combustible material (Table 4).

Table 4. *Results of a chemical analysis of specific coal grains for the percentage of carbon, hydrogen and nitrogen obtained through a CHN-Element Analyser prior to and following the separation of tailing*

Sieve opening size (mm)	Free moisture (%)	Hygroscopic moisture (%)	Total moisture (%)	Ash (%)	Combustible material (%)	Lower calorific value of coal (kJ/kg)	C (%)	H (%)	N (%)
Coal grain sample (-250 + 100) extracted from the basic coal granulation of 40 mm to 400 mm prior to separation of tailing	4,5	4,24	8,74	39,77	51,49	14057	35,6	2,82	0,59
Coal grain sample (-250 + 100) extracted from the basic coal granulation of 40 mm to 400 mm following separation of tailing	2,90	5,28	8,18	22,55	69,27	21709	54,2	3,88	0,84
Coal grain sample (-100+50) extracted from the basic coal granulation of 40 mm to 400 mm prior to separation of tailing	5,70	3,00	8,70	57,06	34,24	8479	21,9	2,00	0,43
Coal grain sample (-100+50) extracted from the basic coal granulation of 40 mm to 400 mm following separation of tailing	3,80	4,86	8,66	38,73	52,61	15693	38,7	3,13	0,65
Coal grain sample (-50+20) extracted from the basic coal granulation of 40 mm to 400 mm prior to separation of tailing	5,80	3,10	8,90	50,60	40,54	11659	29,7	2,37	0,51
Coal grain sample (-50+20) extracted from the basic coal granulation of 40 mm to 400 mm following separation of tailing	6,00	2,50	8,50	53,45	38,05	10601	26,5	2,26	0,47
Coal grain sample (-50+20) extracted from the basic coal granulation of 0 mm to 40 mm	9,60	3,00	12,60	45,80	42,34	11243	29,3	2,26	0,52

For grains smaller than 250 mm and larger than 100 mm in size and for grains smaller than 100 mm and larger than 50 mm in size, the amount of carbon is smaller in samples where the tailing has been separated. There is also a slight increase in the amount of carbon for grains smaller than 50 mm in size that have been freed of tailing in comparison to the samples containing tailing.

The amount of hydrogen for grain samples less than 250 mm and more than 10 mm and for granulations smaller than 100 mm and larger than 50 mm is insignificantly smaller for samples that have not been subjected to tailing extraction.

Almost the same amount of hydrogen is evident in granulations smaller than 50 mm for samples that have been separated from tailing and samples of the same grain size that still contain tailing.

For grains smaller than 250 mm and larger than 100 mm in size and for grains smaller than 100 mm and larger than 50 mm in size, the amount of nitrogen is smaller in samples where tailing has not been extracted. Moreover, smaller amount of nitrogen is present in grains smaller than 50 mm in size for the sample that has been separated of tailing in comparison to the samples of the same grain size that still contain tailing.

CONCLUSION

The optimum granulation regarding energy characteristics is -40+35 mm with a calorific value of 16918 kJ/kg followed by -35+20 and -20+10 with a calorific value of 13035 kJ/kg and 13819 kJ/kg respectively. They generate the least amount of ash after combustion while the free, hygro and total moisture is also the lowest in these samples.

The moisture present in other samples is approximately the same and its amount is subjected to change in the granulations depending on air humidity and porosity or grain composition. From this we can conclude that its effect on the calorific value of coal will be constant for the listed granulations and that the changes in the coal grain energy value are caused by variable amount of tailing.

Grains smaller than 250 mm and larger than 100 mm in size have the largest amount of volatile and combustible material which results in the largest separation of organic material i.e. hydrogen and organic nitrogen.

Considering the fact that as Table 2 indicated, the largest amount of ash after manual separation of tailing is to be found in the grains smaller than 50 mm which are mixed with other coal after grinding to get the same grain size, it is recommended that this grain size is subjected to separation of tailing through a sink-float separation method.

Grains smaller than 250 mm and larger than 100 mm in size are most widely present in the raw coal sample and carry the most combustible material. Therefore, these should be put aside during the separation process and then proceed with fragmentation.

In order to identify the most favourable coal granulations regarding their energy values and environmental effects during combustion, it is important to carry out an analysis of the content and form of sulphur in individual granulations and investigate the possibility of extracting these fractions during the process of separation.

It is undoubtedly necessary to analyse the economic validity of specific granulation treatments before they are brought down to grains smaller than 40 mm in size or before the whole grain smaller than 40 mm in size is subjected to some form of the applicable separation methods in order to maximise the release of tailing. In addition to an increase of energy value of the raw material, this would reduce transport costs to the supplier as well as the costs of ash treatment after combustion and boost the conditions for better environmental protection.

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Summary/Sažetak

U nizu mehaničkih operacija kroz koje prolazi oplemenjivanje sirovog uglja, na pretovarnom sistemu površinskog kopa „Vrtlište“ rudnika Kakanj teži se razdvojiti gorivi od negorivog dijela uglja, a sve u cilju dobivanja proizvoda koji će imati veću toplotnu vrijednost, a manji sadržaj komponenata pepela. U zavisnosti od fizičko-hemijskog sastava sirovine i namjene dobivenog proizvoda, cilj nam je bio odrediti optimalnu veličinu zrna uglja " Rudnika Kakanj" pri kojoj je razdvajanje korisnih od jalovinskih komponenata najpovoljnije u pogledu energetske vrijednosti.

Utvrđeno je da je u sirovini koja se isporučuje kupcu najkvalitetnija granulacija u pogledu energetskih karakteristika jeste -40+35 mm sa toplotnom vrijednoću od 16918 kJ/kg a slijede je -35+20 i -20+10 sa toplotnim vrijednostima 13035 kJ/kg i 13819 kJ/kg, respektivno. Iz njih nastaje i najmanja količina pepela nakon izgaranja, dok su gruba, higro i ukupna vlaga takođe najniže u ovim uzorcima.