

Article

Selective Crushing of Run-of-Mine as an Important Part of the Hard Coal Beneficiation Process

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Abstract: To obtain commercial product of required quantitative and qualitative parameters, hard coal must be subjected to a number of processing operations. Preliminary stone removal from run-of-mine is one of them. Methods of such removal, including the method of selective crushing are described. Design solutions for a KOMAG-type device for dry stone removal of run-of-mine are presented. The results of laboratory tests for selective crushing susceptibility of steam coal and coke are presented, and a comparative analysis of the tested types of coal is made. Possibilities of increasing the production of commercial products by using a Bradford drum crusher is analyzed from the economical point of view.

Keywords: run-of-mine; destoning; selective crushing; economy



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1. Introduction

The extracted hard coal is a mixture of grains of various sizes and shapes and with a different mineral composition. The run-of-mine in this form is not suitable for direct use, therefore it is subjected to a series of processes to obtain its required industrial quality [1].

In the mechanical processing of coal, three main processes separating the useful grains and the waste grains can be distinguished:

- Classification—the material is divided into grains with specific dimensions;
- Grinding—to obtain grains of the required size or to separate coal from waste rock;
- Beneficiation—to separate groups of grains of the same mineral characteristics [2,3].

Minerals beneficiation is the most important process, in terms of improving the quality parameters of the processed material. The beneficiation process, depending on the grain size of the material (feed), is carried out in specialized machines and devices, including dense liquid separators (e.g., DISA), pulsating water jigs, and flotation machines. Technological and design solutions of these devices are constantly improved to increase their efficiency [4–15].

The concept of using the fine-grained silicon as a weight instead of magnetite is an interesting issue regarding the process of coal separation in cyclones with a heavy liquid. The suggested modification of the technology results from the quality requirements of the coal concentrate product which should not be contaminated with magnetite grains [4].

Impact of the pulsation cycle on the parameters of the water flow and bed layers—as one of the most important parameters in the jig beneficiation process—is constantly tested [8]. The control systems of the jig beneficiation node are being developed to find more perfect and reliable algorithms that enable effective control of both the feed flow

rate and the efficiency of bucket conveyors [11]. Attempts are made to use an isotope densimeter to control the separation zone in pulsating jigs [12].

Development of a procedure for assessing the flotation properties of coal fines, called the release analysis, considered to be an equivalent of the washability analysis for density separation, is an important contribution to increasing the efficiency of the flotation process [13]. Development of the control of the column flotation with the use of fuzzy control is also underway [14]. On the other hand, the authors of [15] reviewed, in a comprehensive way, the models of coal flotation kinetics, with particular emphasis on the impact of particle size on coal kinetic rate, recovery, and product quality.

The efficiency of the coal feed beneficiation process depends on a number of factors [16,17]. Density composition of the feed and the share of waste fractions in it are the most important of them.

Stone removal from the run-of-mine is the operation that allows for the initial separation of some of the waste grains and, as a result, to reduce load to the technological line of coal processing. Due to the large share of waste rock grains in coarse grain classes (>80 (100) mm), which reaches up to 70%, the above activities allow not only to increase the efficiency of further processes, but also to extend the service life of machines and processing devices [18].

Economic analysis to justify the advantage of installation of the device for stone removal—selected drum crushers in new sites for the specified types of hard coal is the article's objective.

1.1. Methods of Stone Removal from Run-of-Mine

Stone removal is carried on the surface at the site of mining, the so-called feed preparation station, which is the first step in the hard coal beneficiation process.

Proposals for application of the stone removal process in mine underground, to reduce the costs of transportation and storage of wastes on the surface, are known in the literature [19].

Stone removal can be carried out by the “dry” method, which uses the selective crushing method, or the “wet” method using the differences in the density of coal and waste rock [20].

1.1.1. Dry Stone Removal Method

The idea of the most commonly used “dry” method has been known in the world of mechanical processing since the mid-twentieth century. It consists in dropping grains of coal and waste rock from the required height on a hard floor. Coal and waste rock grains, being more fragile, are crushed when dropping. The dense grains of the waste rock remain intact or broken to a small extent [21,22].

Bradford drum crusher, in which the following three main processes are simultaneous, grinding, classification, and beneficiation [22], is the device designed for the selective crushing of the run-of-mine.

The use of drum crushers allows to obtain a relatively coarse-grained product of a given grain size, producing a relatively small amount of fine grains.

Due to the fact that there is no need to build a water-sludge system that is expensive in terms of investment and operation costs, the Bradford type crushers are basically the cheapest and most suitable devices for stone removal from the run-of-mine.

It is commonly used for stone removal from the run-of-mine containing coking coal. This technology is especially advantageous, where there is a significant difference in the crushing ability of stone (waste rock) and coal.

Therefore, the decision on its use, in the case of using the “dry” method of stone removal, should be preceded by tests of the susceptibility to crushing of the potential feed and justified by an economic analysis.

The tests that can be carried out by two methods, drop and drum, in addition to the decision on the possibility of using the selective crushing process, should allow for positive

results of analyses and technological and economic analyses to select the basic parameters of the device, i.e., diameter and rotational speed of the crusher drum [20,21].

There are a number of manufacturers in the world market offering drum crusher for stone removal from run-of-mine, including TerraSource Global, McNally Sayaji Engineering Limited, Elgin Separation Solutions, McLanahan [23–26].

KB Bradford drum crusher designed at the KOMAG Institute of Mining Technology, presented in Figure 1, is the Polish equivalent of this type of equipment.

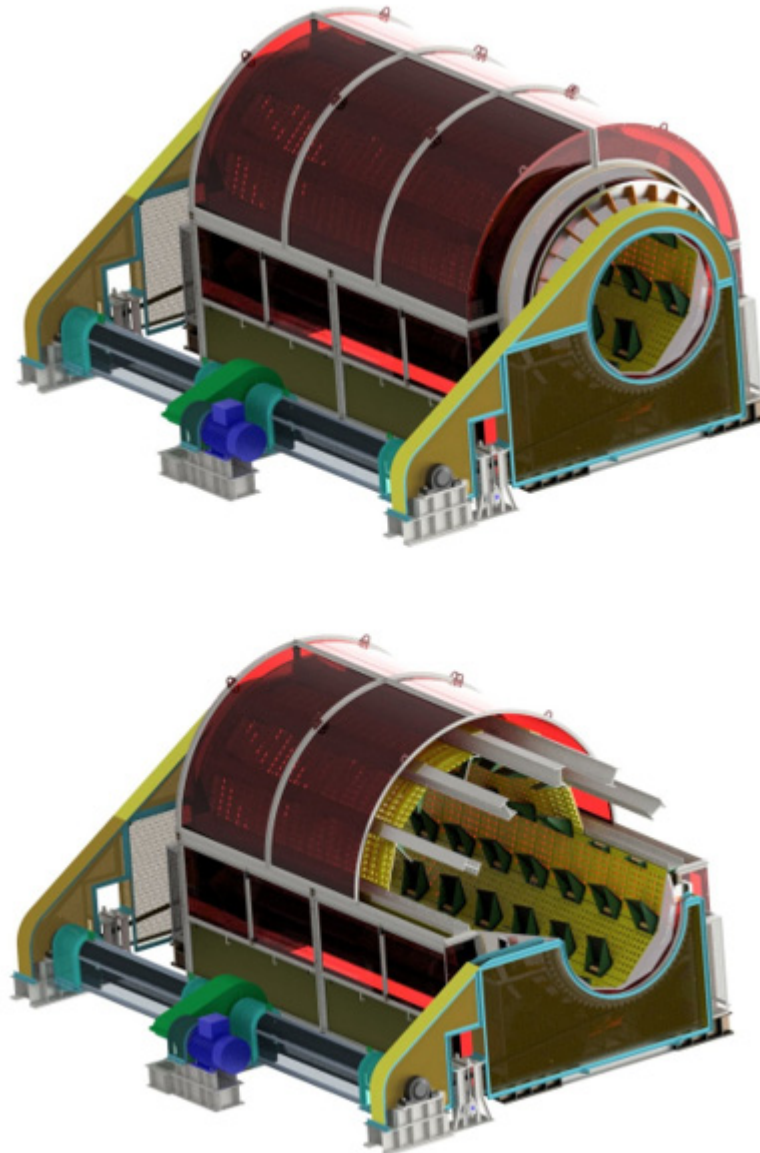


Figure 1. Drum crusher KB 3200 × 6000 (view and section) [20].

Drum crusher's main component is a drum with a horizontal axis of rotation. Rotation of the drum is forced by two chain gears installed at the inlet and outlet sections. The rotational movement from the motor is transmitted through a cylindrical gear and via two driving shafts, to the sprockets. The center of the drum is lined with screen decks with holes (50–200 mm) depending on the technological requirements.

The output grains sent to the crusher move along the drum's axis and are simultaneously lifted upwards by lifters installed inside the drum shell.

Crushed grains of lower compactness, most often coal, are discharged through holes in the side, while grains of higher compactness, most often stone, move along the drum's axis and discharged from the crusher through an outlet opening at its end [20,22].

Drum crushers implementing the “dry” stone removal process directly in the underground mines were also developed at KOMAG. Such design solutions were used to facilitate underground transport and assembly [23].

Other devices used for stone removal applying the “dry” method include, air jigs and air concentrating tables [27]. Separation in an air pulsating jig is based on similar principles as in the case of conventional water jigs, where different falling speeds of the beneficiated grains are applied. Allair jig is the most popular industrial solution [28–31]. In the case of air tables, FGX table is the most commonly used device [32–37]. It should be noted, however, that there is a significant reduction in the maximum grain size in the above equipment compared to the grain range used in Bradford type crushers. It should be noted, however, that there is a significant reduction in the maximum grain size in the above equipment in relation to the grain range used in Bradford type crushers. The maximum grain size for the Allair jig is 50 mm, and for the FGX device—80 mm.

1.1.2. Wet Stone Removal Method

The wet method for separation of stone from run-of-mine can be based on the jig beneficiation technology or the dense liquid beneficiation technology.

In the 1980s, the ROM Jig was developed by KHD Humboldt Wedag in Germany, for underground stone removal from the mined rock. Movable screen to induce a pulsating motion of the beneficiated material, adapted to separate the grain size of 350–30 mm, is a characteristic feature of the device [38,39].

Polish jig intended to remove stone from the run-of-mine of a grain size of 150 (200)–50 mm was designed in the 1990s at the KOMAG Institute of Mining Technology. The KOD jig implemented on surface at the Preparation Station of the Budryk coal mine was equipped with a wheel lifting the separation products [40].

The concept of technology for a suspension separator with a dense liquid based on a magnetite sinker, suitable for removal of stone from run-of-mine in coal mines was developed by KOMAG [41].

The device consists of a trapezoidal trough and scraper devices for discharging the separation products. This method enables separation of the run-of-mine of a grain size of 250–80 (50) mm, with the stone content in the feed reaching 100%.

Another solution used for “wet” stone removal is the so-called Barrel washer. The device, which separates the material in an autogenous dense liquid, is adapted to separate the material of a grain size <200 mm [42]. The device, which separates the material in an autogenous dense liquid, is adapted to the separation of material of a grain size <200 mm [42].

2. Materials and Methods

Laboratory tests on the susceptibility of the selected hard coal types to selective crushing using the so-called “drop” method were conducted at the KOMAG Institute of Mining Technology.

The following coal samples from the selected Mining Plants were tested:

- Gas coal type 33 (2 Mining Plants);
- Gas-coking coal type 34 (3 Mining Plants);
- Ortho-coke coal type 35 (1 Mining Plant).

A test stand equipped with a steel plate, a shield, and an elevation enabling grain crushing by dropping was used as showed in Figure 2.

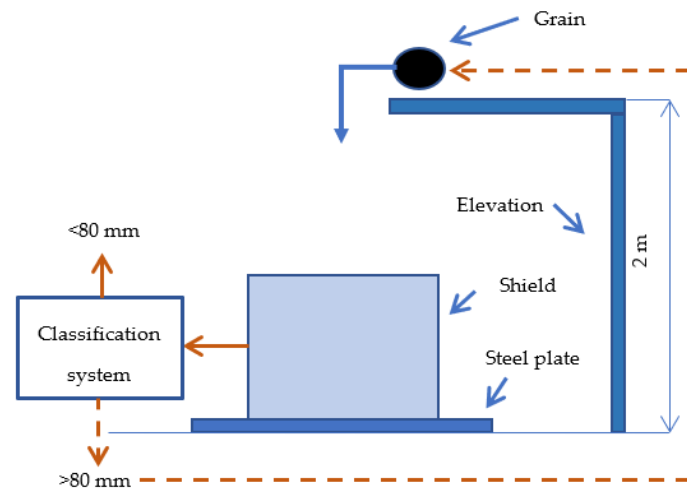


Figure 2. Diagram of the test stand [43].

Drop tests were performed from a height of 2 m for randomly selected coal and stone grains.

During the material crushing tests, also a single block was dropped. The series was defined as multiple drops of a single grain until it was completely crushed to a size <80 mm. A maximum number of 30 drops was assumed.

Grains <80 mm were screened out after each drop. Grains larger than this size were successively dropped until they were crushed below 80 mm or until the maximum accepted number of drops. After every 5 drops, the weight of grains below 80 mm was determined. Average output of coal and stone grains as the percentage share of the 80–0 mm class were adopted for the analysis, separately for each type of coal.

The susceptibility to crushing of coal grains and waste rock of the analyzed run-of-mine was determined, and the tested coal types were compared [43].

3. Results

3.1. Gas Coal (Steam Coal) Type 33

Comparison of the results of susceptibility to crushing of type 33 coal from two mining plants (Mine 33A and Mine 33B) showed differences in the obtained results, especially in the case of waste rock content. Table 1 shows the average output of crushed grains below 80 mm for the tested coal—type 33.

Table 1. Output of 80–0 mm class depending on number of drops—comparative results for coal type 33 [43].

Number of Drops	Mine 33A		Mine 33B	
	Coal, %	Stone, %	Coal, %	Stone, %
0	0	0	0	0
5	57.8	27.0	64.0	34.2
10	83.8	37.7	85.0	56.2
15	93.3	46.2	92.3	61.3
20	97.7	52.4	94.4	70.3
25	99.0	60.1	97.0	75.3
30	99.1	62.6	99.4	79.4

Tests of coal type 33, obtained from the mine 33A showed that coal grains were almost totally crushed, to the size <80 mm after 25 drops (99.0%).

After 5 drops, slightly more than half of the grains crushed to the size <80 mm—57.8%, and after 10 drops 83.8% of the required particle size was obtained.

In the case of waste grains, for the same number of drops, the output was 27.0% and 37.7%, respectively. After the maximum accepted number of drops (30), the waste output in the <80 mm class was 62.6%.

Coal grains from the mine 33B had a very similar susceptibility to crushing. After 5 drops, the output of 80-0 mm class was 64.0%, and after 10 it was equal to 85.0%. The maximum number of drops allowed to obtain an output of class <80 mm at the level of 99.4%. At the same time, the waste rock grains were crushed much faster. After 10 drops output of 80-0 mm class was 56.2%, after 20 drops—70.3%, and after 30 drops the total output was 79.4%.

The results of the test for type 33 coals are graphically presented in Figure 3.

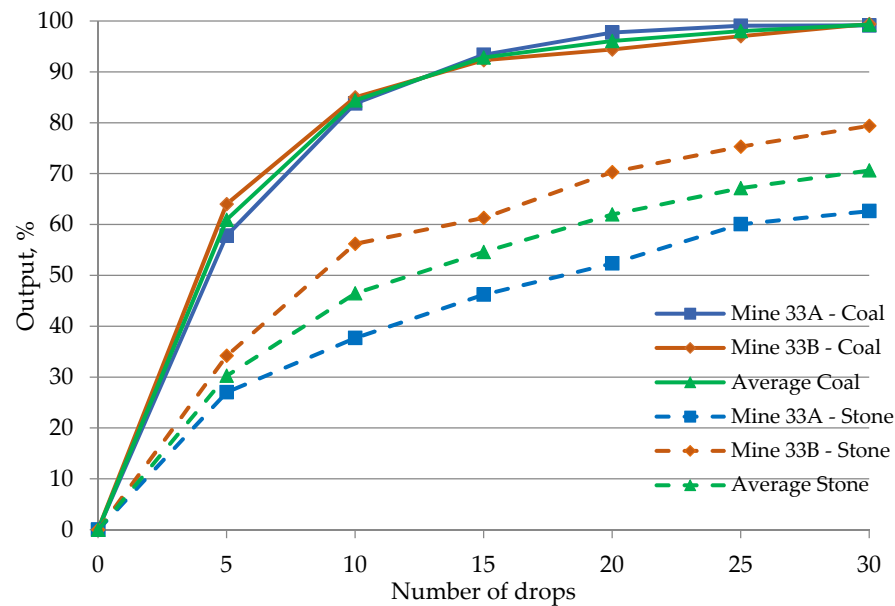


Figure 3. Comparative results of 80-0 mm class output depending on number of drops (type 33) [43].

3.2. Gas-Coke Coal Type 34

Comparison of the results of susceptibility to crushing the coal type 34 from three mining plants (mines) showed differences in the obtained results—crushing ability of the material. While in the case of coal grains the above differences were not very large, in the case of waste rock grains (stone) they were very significant. The difference between the extreme results obtained after 30 discharges was about 65%.

Table 2 presents the average output of crushed grains below 80 mm for the analyzed coal type 34.

Table 2. Output of 80-0 mm class depending on number of drops—comparative results for coal type 34 [43].

Number of Drops	Mine 33A		Mine 33B		Mine 34C	
	Coal, %	Stone, %	Coal, %	Stone, %	Coal, %	Stone, %
0	0.0	0.0	0.0	0.0	0.0	0.0
5	69.7	40.7	59.5	8.6	76.8	39.4
10	89.1	58.2	85.0	15.5	95.4	62.8
15	97.6	67.6	96.4	20.1	99.7	81.1
20	100.0	75.2	99.1	24.7	100.0	89.9
25	-	80.5	99.6	26.2	-	91.6
30	-	84.4	99.7	29.9	-	95.3

The tests of type 34 coal output obtained from the 34A mine showed that the coal grains were crushed to size <80 mm after a maximum of 20 drops.

Most of the grains <80 mm were obtained after five discharges (69.7%), and after ten discharges 89.1% of the required grain size was obtained.

In the case of waste rock grains, for the same number of drops, the output was 40.7% and 58.2%, respectively. After the maximum accepted number of drops (30), the waste rock output in the <80 mm class was 84.4%.

Coal grains from the 34C mine showed similar crushing susceptibility. Crushing all coal grains to the size <80 mm required 20 drops, while compared to the grains from mine 34A, they were crushed faster. After 5 drops, the output of the 80-0 mm class was 76.8%, and after 10 drops it was 95.4%.

At the same time, the waste rock grains were crushed much faster. After 10 drops their output was 62.8%, after 20–89.9%, and after 30 drops the total output was 95.3%.

Coal from the mine 34B behaved differently, especially in the case of waste rock. The total output of the 80-0 mm grain class after 30 drops was 29.9%. The coal grains were also crushed more slowly. The differences to other Type 33 coal samples are primarily seen in the first 10 drops. The output of the 80-0mm grade after 5 drops was 59.5% and after 10 it was 85.0%. After maximum number of drops, output of the grain class 80-0 mm was below 100%.

The results of the tests of type 34 coals are graphically illustrated in Figure 4.

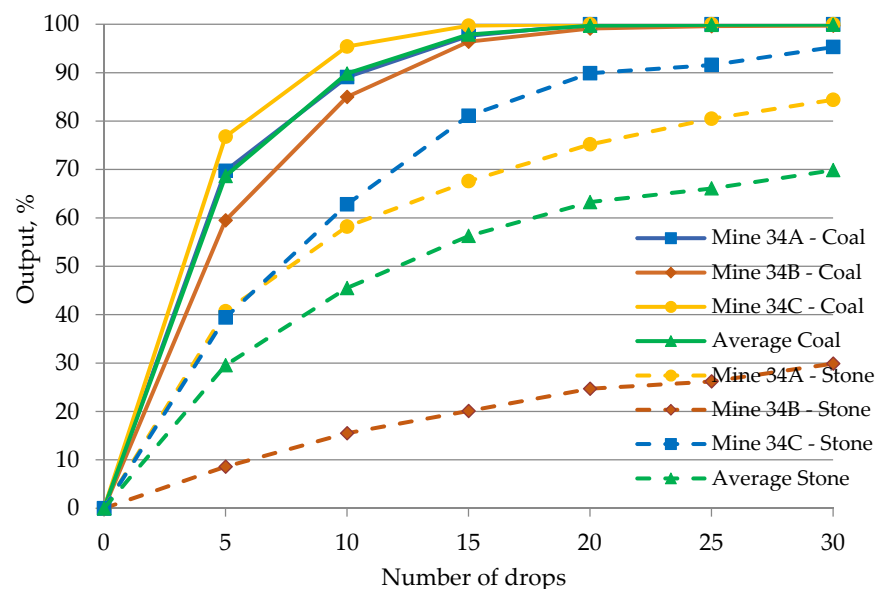


Figure 4. Comparative results of the 80-0 mm class output depending on the number of drops—coal grains (type 34) [43].

3.3. Orthocoking Coal Type 35

The crushing susceptibility of orthocoking coal type 35 was also tested. Table 3 shows the average output of crushed grains below 80 mm for the tested coal—type 35.

Table 3. Output of 80-0 mm size class depending on number of drops of the coal type 35 [43].

Number of Drops	Mine 35A	
	Coal, %	Stone, %
0	0.0	0.0
5	86.4	30.8
10	96.9	39.8
15	99.5	47.2
20	99.5	50.3
25	99.6	54.0
30	100.0	56.2

The test results of susceptibility to crushing of coking coal type 35 showed its high susceptibility to crushing. In most of the tested grains, their complete crushing to a size >80 mm took place already after 10 drops.

Stone grains (waste rock) had a very low susceptibility to crushing.

The significant difference between the crushing ability of the tested grains enables high efficiency of the selective crushing of run-of-mine, with very small losses in coal grains and the separation of a significant part of the stone grains from run-of-mine before subsequent beneficiation processes.

Test results of coal type 35 is graphically illustrated in Figure 5.

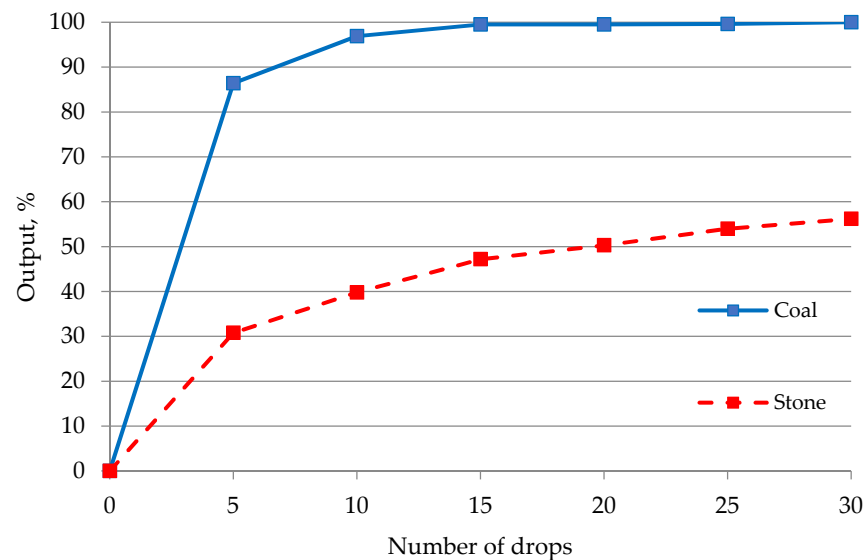


Figure 5. Comparative results of the 80-0 mm class output depending on the number of drops (coal type 35) [43].

3.4. Comparative Analysis of Susceptibility to Crushing of the Tested Coals

Test results on the susceptibility to crushing of coal depending on its type are compared. Table 4 gives the average output of crushed grains below 80 mm for the tested types of coal.

Table 4. Output of 80-0 mm size class depending on the drops number—comparative results for different coal types [43].

Number of Drops	Coal Type 33		Coal Type 34		Coal Type 35	
	Coal, %	Stone, %	Coal, %	Stone, %	Coal, %	Stone, %
0	0	0	0	0	0	0
5	60.9	30.3	68.7	29.6	86.4	30.8
10	84.4	46.5	89.8	45.5	96.9	39.8
15	92.8	54.6	97.9	56.3	99.5	47.2
20	96.1	62.0	99.7	63.3	99.5	50.3
25	98.0	67.2	99.9	66.1	99.6	54.0
30	99.3	70.6	99.9	69.9	100.0	56.2

Analysis of the test results confirmed that susceptibility of coal grains to crushing increases with degree of carbonization. Coal grains of type 35 had the highest susceptibility, and coal grains of type 33 the lowest.

Average results, given for multiples of 5 drops, almost in every case confirm the relation described below. For example, after 10 drops 84.4% of coal grains of type 33, 89.8% of coal grains of type 34 and as much as 96.9% of coal grains of type 35 were crushed to the required size <80 mm.

The maximum number of drops, equal to 30, resulted in virtually complete crushing of type 33 and 34 coal grains and complete (100%) crushing of type 35 coal grains.

Very similar susceptibility results were obtained for coal types 33 and 34 in the case of grains of stone (waste rock). For example, after 10 drops, 46.5% of grains from run-of-mine type 33 and 45.5% of grains from run-of-mine type 34 were crushed. The total amount of crushed grains after 30 drops was approximately 70% for both types of coal. Grains of waste rock from run-of-mine type 35 had lower susceptibility to crushing, where the output of crushed grains after 30 drops reached 56%.

Figure 6 shows the average results of the class <80 mm outputs depending on the number of drops, for each analyzed coal type.

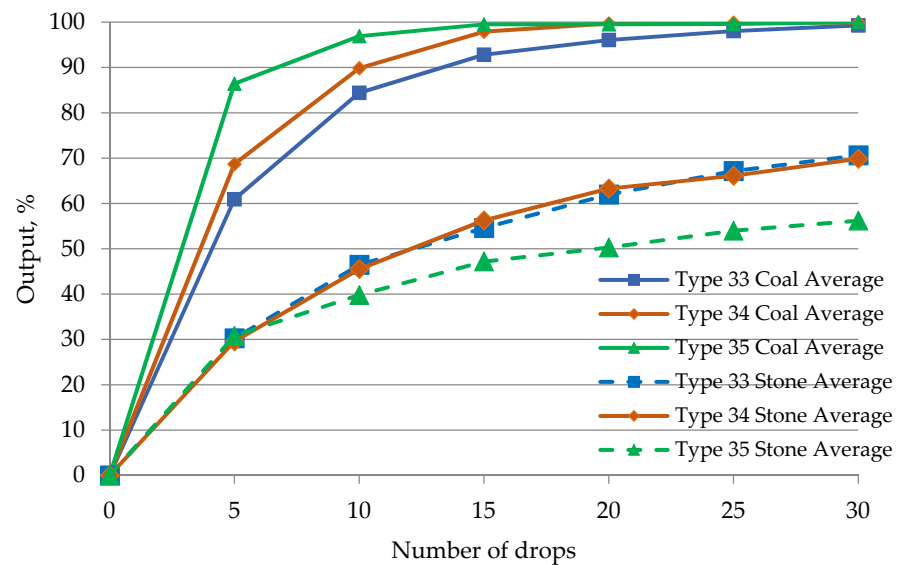


Figure 6. Comparative results of the 80-0 mm class output depending on the number of drops (average output) [43].

However, a more detailed analysis of the results showed that averaging the results for each coal type may cause significant errors in the assessment of their susceptibility to crushing and the possibility of using the selective crushing process for hard coal.

Differences can be observed in the susceptibility to crushing the run-of-mine grains among coal types. Particularly significant differences are found in the case of the stone grains, due to their mechanical properties depending on the lithological type of the waste rock.

Figures 7 and 8 show the average susceptibility to crushing of all analyzed coal types, with the division into coal grains and waste rock grains.

For some types of tested coals, the effectiveness of selective separation of stone from output by the “dry” method may be limited due to the high crushing ability of the coal rocks and the excessively long process of stone removal in the drum crusher.

In the case of coal grains of good crushing ability, the efficiency of their separation from waste rock grains can be increased by using shorter crushers compared to those of a standard size. Reducing the time of crushing the material to minimum time allowing the total drop of coal grains through the screens, potentially positively affects the efficiency of the selective stone separation due to lower degradation of the waste rock grains.

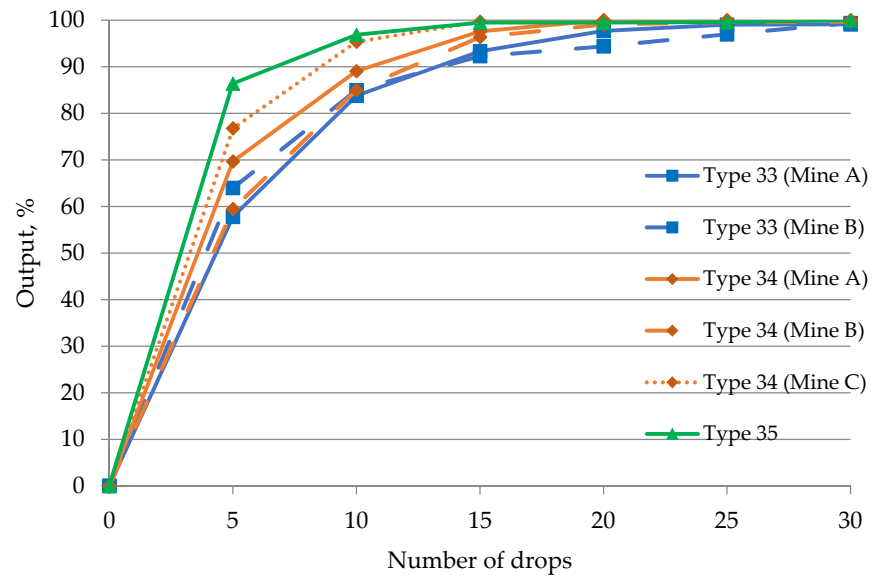


Figure 7. Comparative results of testing the susceptibility to crushing for the 33, 34, and 35 coal types—coal grains [43].

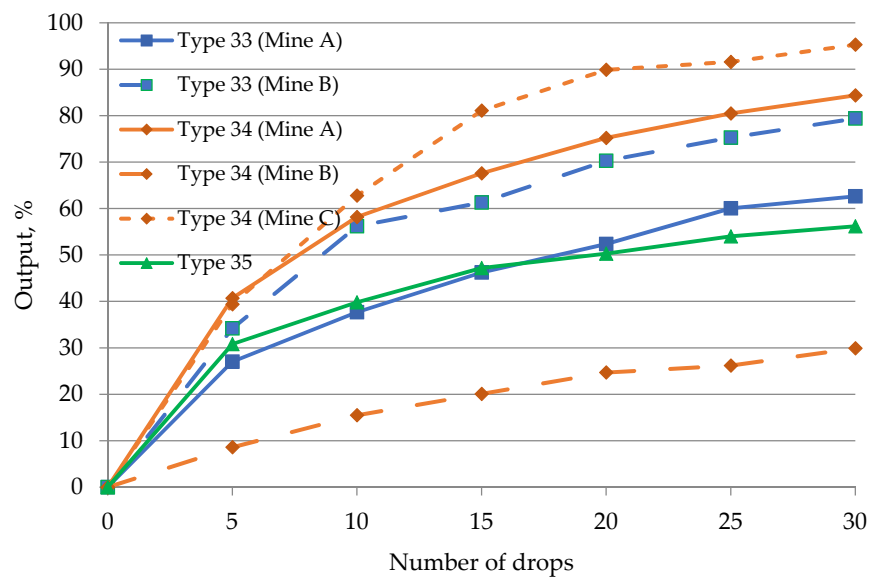


Figure 8. Comparative results of testing the susceptibility to crushing for the 33, 34, and 35 coal types—stone grains (waste rock) [43].

3.5. Economic Analysis of the Application of Selective Crushing Process for Tested Coal Types

Profitability of the selective crushing process for the given types of hard coal was economically analyzed. The following assumptions were made for the analysis:

- The feed for the selective crushing in the Bradford crusher will contain from 80% to 20% coal;
- Coal prices were as follows: type 35—PLN 600, type 34—PLN 500, type 33—PLN 400;
- 20 h of operation of the crusher per day, 30 days per month was assumed for the monthly costs of operating the system for selective crushing of run-of-mine material;
- The calculations were made for two outputs, 500 Mg/h and 1000 Mg/h.

Table 5 presents the assumed most important monthly operational costs of the selective coal crushing system.

Table 5. Monthly operating costs for the selective crushing system.

Item	Components	Amount [PLN]
1	Crusher cost (divided by 24 months)	131,250
2	Crusher screen replacement (once a year)	29,166
3	Electricity cost	38,940
4	Repairs of the system for run-of-mine crushing	6720
5	Cost of service	18,000
	Total	224,076

The results of the run-of-mine crushing tests using the drop method from the mining plants 33A, 34B, and 35 were used for the analyses.

The analyses show that use of the selective crushing enables increasing the production of commercial coal per time unit depending on the share of coal grains in the run-of-mine and the crushing efficiency of the above-mentioned grains.

The analysis did not take into account the impact of increased output of fine carbon grains formed in the crusher on the effectiveness of further beneficiation processes. This problem should be the subject of another research project.

Tables 6 and 7 present the calculation results in the form of hourly profit from the selective crushing process. Profits for the assumed outputs of the selective crushing node are given in zlotys and percentage values.

Table 6. Hourly profit from the selective crushing process—capacity 500 t/h.

Feed [%]		Type 35		Type 34B		Type 33A	
		Profit		Profit		Profit	
Share of Coal	Share of Stone	€	[%]	€	[%]	€	[%]
80	20	57,079	7.68	50,470	13.03	37,477	6.36
75	25	54,830	9.22	49,327	15.91	35,848	7.60
70	30	52,467	10.59	48,082	18.61	34,151	8.69
65	35	49,982	11.77	46,721	21.10	32,383	9.61
60	40	47,364	12.74	45,227	23.34	30,538	10.36
55	45	44,603	13.50	43,580	25.30	28,611	10.92
50	50	41,687	14.02	41,755	26.93	26,598	11.28
45	55	38,603	14.28	39,721	28.18	24,491	11.42
40	60	35,334	14.26	37,442	28.97	22,285	11.34
35	65	31,866	13.93	34,868	29.23	19,972	11.00
30	70	28,177	13.27	31,941	28.83	17,543	10.41
25	75	24,248	12.23	28,582	27.64	14,992	9.53
20	80	20,053	10.79	24,686	25.46	12,307	8.35

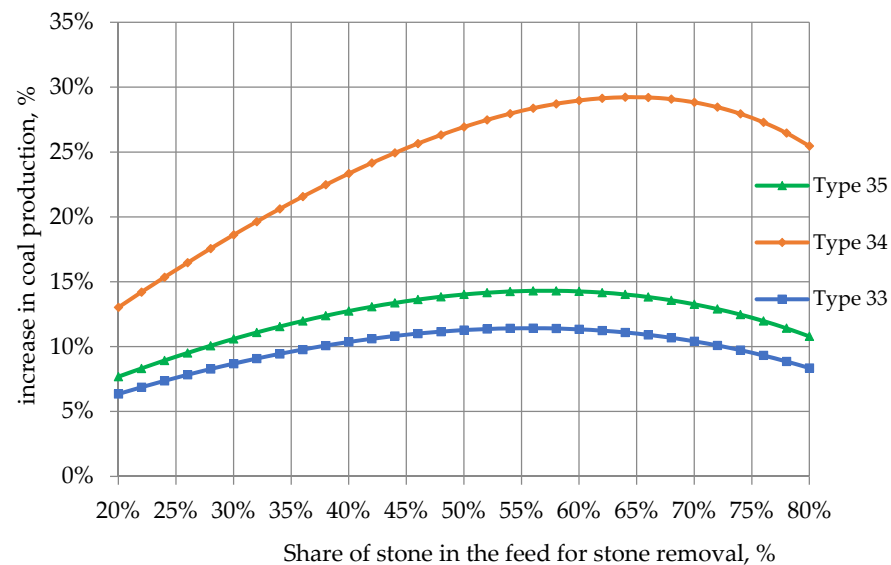
Analysis of the calculation results showed that susceptibility to crushing of coal grains and waste rock impacts the final financial effect of the process, in the form of increasing the production of commercial assortments in the processing plant. Share of waste rock in the excavated material is another factor affecting the financial effect. As its share increases, the production of coal may increase. However, for each type of run-of-mine, there is such share of the waste rock, after which the expected financial effect reduces.

For type 35 coal, the most favorable financial effect was obtained for the stone content in the excavated material in the range of 50–64% and it amounted to over 14% of the profit compared to the output without selective stone removal. On the other hand, for type 34 coal, the most favorable financial effect was obtained for the stone content in the excavated material in the range of 56–72%, which amounted to over 28% of the profit compared to the excavated material without selective stone removal. In the case of type 33 coal, the most favorable financial effect was obtained for the stone content in the run-of-mine in the range of 46–64% and it amounted to over 11% of the profit.

Table 7. Hourly profit from the selective crushing process—capacity 1000 t/h.

Feed [%]		Type 35		Type 34B		Type 33A	
Share of Coal	Share of Stone	Profit	Profit	Profit	Profit	Profit	Profit
		€	[%]	€	[%]	€	[%]
80	20	114,262	7.68	101,028	13.03	75,023	6.36
75	25	109,757	9.22	98,736	15.91	71,760	7.60
70	30	105,025	10.59	96,240	18.61	68,363	8.69
65	35	94,806	11.77	93,513	21.10	64,822	9.61
60	40	94,806	12.74	90,520	23.34	61,128	10.36
55	45	89,278	13.50	87,220	25.30	57,270	10.92
50	50	83,440	14.02	83,564	26.93	53,239	11.28
45	55	77,264	14.28	79,492	28.18	49,022	11.42
40	60	70,721	14.26	74,927	28.97	44,605	11.34
35	65	63,777	13.93	69,775	29.23	39,974	11.00
30	70	56,394	13.27	63,915	28.83	35,113	10.41
25	75	48,528	12.23	57,190	27.64	30,005	9.53
20	80	40,132	10.79	49,394	25.46	24,630	8.35

Figure 9 shows graphically the correlation between share of stone (waste rock) in the feed and the percentage increase in commercial coal production.

**Figure 9.** The economic effect of selective crushing for different compositions configurations of the run-of-mine.

4. Discussion

The literature review showed little information on testing the selective crushing of run-of-mine. The tests on the impact of the height of the coal grain drop on the products parameters, aiming at selecting the technical parameters of the Bradford crusher are one of few examples [44].

The process of selective crushing of the excavated material is very complicated and difficult to recreate in the laboratory conditions, to fully simulate real conditions. Using the literature and practical knowledge, a laboratory test stand was built to simulate the real run-of-mine destoning process.

Cyclical drops of run-of-mine grains basing on the real number of cycles in a drum crusher enabled assessing the financial benefits of using this device.

In the literature there is information on using the drum crushers in heat and power plants in India. The authors showed that such solution allowed to reduce energy and operating costs with high efficiency of material separation—coal loss was $\leq 1\%$ [45]. Drum crushers are used primarily for destoning of coking coals. Verification of applicability of the above-mentioned device for 33, 34 coals was one of the tests objectives.

Reduction in electricity consumption through more effective use of processing plant, while producing a larger amount of coal concentrate, will be an expected economic benefit. This will have a positive effect on the reduction of CO₂ emission, as electricity is largely generated from fossil fuels. Unfortunately, the detail economic benefits in this case are very difficult to be determined due to the number of variables and incomplete data. It is only possible to determine the benefits if the crusher is installed in a specific site and the results are compared. Comparison of efficiency and energy consumption of the processing plant before and after installation of the selective drum crusher is the next stage of the work. Economic analysis did not take into account the effect of increasing the output of fine coal grains generated in the crusher on the effectiveness of the further processes. This issue will be the basis of future research project.

The use of a drum crusher for destoning of coking coals results in significant financial benefits is presented in Figure 9 and Table 6. The relatively short return on investment requires the use of destoning equipment for the coking coals, and is recommended after the preliminary tests also for less carbonized coals.

5. Conclusions

The test results for the selected types of hard coal (type 33, 34, and 35) for which the technology of dry stone removal—the process of selective crushing can potentially be used, is presented.

Comparative analysis of the test results confirmed that the susceptibility of coal to crushing increases with the degree of carbonization. Coal type 35 had the highest susceptibility, and coal type 33 had the lowest susceptibility to crushing. Waste rock did not show such relationship. Among the tested coal types, both the highest and the lowest susceptibility to crushing were characteristic for stone of coals type 34.

The largest differences in “crushing” between coal and waste rock grains, which favor high efficiency of the selective crushing technology, were reported in the feed from mine 35 and mine 34B.

Significant differences in the susceptibility to crushing among of run-of-mine types, for stone and the tested coal indicate that averaging the test results for each type may cause significant errors in the assessment of the susceptibility of the material to crushing.

For this reason, it is extremely important that the decision to use the selective crushing process is preceded by testing the crushing susceptibility of the potential material (feed). Nevertheless, it is important to justify the economic profitability of using dry stone removal from feed based on the selective crushing process.

The calculations showed that in the case of a significant susceptibility to crushing of coal grains of hard coal output, it is possible to increase the production of commercial assortments, which depends on the share of coal grains in the feed and the crushing efficiency of the abovementioned coal grains, and also to a large extent from the susceptibility of waste rock to crushing.

The test results enabled obtaining important data for the stage of designing the Bradford crushers. In some cases, the coal may be completely crushed after a small number of drops. For such material, it will be advantageous to use shorter crushers than standard sizes to avoid excessive crushing of waste rock, which reduces the process efficiency.

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