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## **UPGRADE OF CONVEYOR LINE FOR COAL CHARGE PREPARATION WITH THE USE OF MODERN GRADING-AND-MIXING EQUIPMENT**

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**Introduction.** *In the current market conditions, when the demand for metallurgical products remains constant or declines, the metallurgical industry may develop due to optimizing operating costs. A significant component of the cost of final products is the cost of electricity. Its average growth rate over the past five years amounted to 125%. Therefore, there is a need for analysis of electricity consumption with its subsequent optimization.*

**Problem Statement.** *In the existing coke production process line, the most energy-intensive technological operation is crushing coal charge, which does not provide for prior screening of the finished grade. The analysis of the particle size distribution of coal concentrates has showed that only 12.5% of the input charge fractions needs to be crushed. The gross flow of coal concentrate entering the crushers, the efficiency of the crushers does not exceed 16... 18%. In addition, there is re-crushing of coal concentrates, which increases the content of the 0–0.5 mm fraction and, consequently, adversely affects the quality of resulting coke.*

**Purpose.** *The purpose of this research is to develop practical recommendations for improving the process of coal charge preparation for coking and equipment in it in order to reduce electricity consumption and to increase the quality of resulting coke.*

**Materials and Methods.** *Empirical research methods with the use of the mathematical apparatus of statistical data processing.*

**Results.** *As a result of the research, an improved process flowchart for coal charge preparation has been proposed. It allows improving the quality of blast furnace coke and reducing electricity costs per unit of product, at least, 48 times.*

**Conclusions.** *Improving the quality of coal charge preparation for sintering and reducing the electricity consumption of equipment may be implemented through upgrading the existing conveyor lines by organizing screening sections of the finished grade before crushing.*

*Key words:* coke, crushing, screening, mixing, and electricity consumption.

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**Introduction**

Currently, world industry is in the era of the so-called “New Normality” when no major events that can provoke a steady increase in consumption of metallurgical products are expected. In these conditions, the development of industry is possible through the introduction of new technologies to optimize operating costs [1].

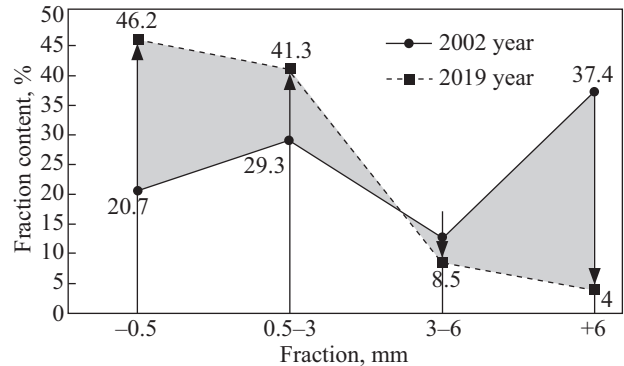
Given that over the past five years, the average growth rate of electricity prices for non-household consumers in Ukraine reached 123.9% [2], there is a need to analyze electricity consumption for its further optimization, especially at the stages of preparation of the coal charge for coking, which requires energy-intensive technological operations, such as coal charge crushing.

Technological schemes of coke production at corporations of the European Union and India [3–5] provide preliminary enrichment of coking coal, as a result of which technological operations on coal charge crushing are necessarily preceded by material size grading on vibrating screens and there is no need for mixing operation since a single-component charge is used.

While preparing a coal charge for coking, Ukrainian corporations mainly use the processes of charge crushing (CC) and group crushing of components (CGC). The main difference between the processes used is that the charge crushing requires fewer crushers, because in the GCC case, the performance rate of crushing department is chosen on the condition that it shall be not lower than the coal intake capacity that is much higher than

*Table 1. Specific Parameters of Crushing Processes*

Parameter	Crushing process			
	CC		CGG	
	Design	Fact	Design	Fact
Specific productivity, t/(g · m <sup>2</sup> )	18.4	2.3	23.2	3
Electricity consumption, (kW · g)/t	1.8	14.3	1.7	13
Metal consumption of equipment, t/(g · t)	15.6	2	19.4	2.4



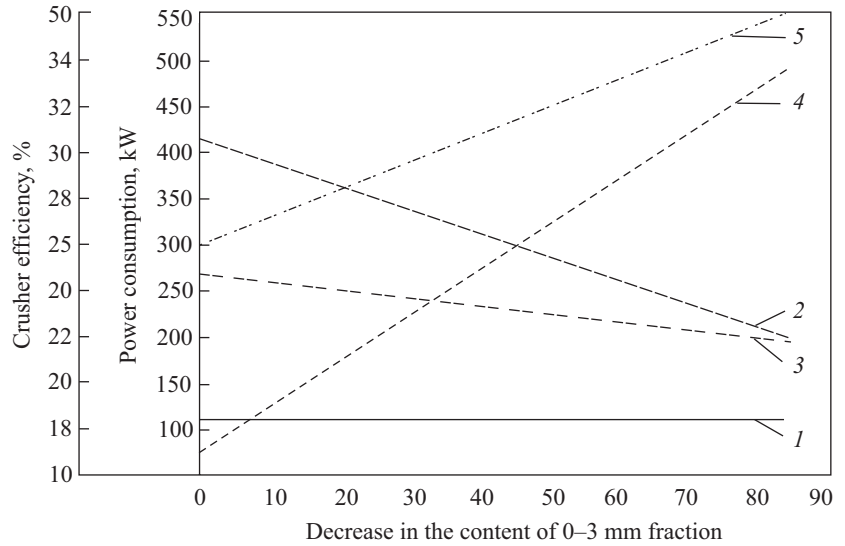
**Fig. 1.** Variability of averaged particle size composition of coal concentrates

the capacity of the conveyor line that supplies coal to the coke-oven battery where the department for charge crushing process is located. In addition, in the case of GCC process, the installation of mixing equipment is required, while in the case CC process, the mix is stirred during its crushing in hammer crushers. Table 1 shows the main design parameters of the used processes of charge crushing [6].

Given the variability and deterioration of the raw material, the particle size distribution of coal concentrates that are processed for the last seventeen years (Fig.1) has been analyzed. The obtained graphs show that the content of fractions +6 and 6–3 mm decreases by 33 and 4%, respectively. So the input charge contains only 12.5% of fractions that need to be crushed (+6; 6–3 mm). Since the process trains do not provide for screening, the gross flow of coal concentrate goes to the crushers that actually play a role of mixers, which is not effective both in terms of quality of the mix (the degree of mixing in terms of quality averages 75%, which does not correspond to the optimal value [7] and in terms of the parameters (see Table 1), as a result of which the crusher efficiency does not exceed 16... 18%. In order to reduce electricity consumption, several processes use of hammer crushers without grate [8, 9], which allows raising the efficiency up to 25... 27%.

In addition, the crushing of the charge with specified particle size distribution leads to its re-crushing and increasing the share of 0–0.5 mm

**Fig. 2.** Dependence of electricity consumption and efficiency of the hammer crusher on the reduction of the content of the 0–3 mm fraction in the coal charge with moisture content  $W = 11.2\%$ : 1 – idle power of the crusher; 2 – experimental electricity consumption of the crusher with grate; 3 – experimental electricity consumption of the crusher without grate; 4 – efficiency of a hammer crusher with a grate; 5 – hammer crusher efficiency without grate



grade, which impairs the physical and mechanical properties of the resulting coke [10]. Hence, it is necessary to apply the pre-screening technology and to prevent re-crushing of the finished product, which increases the bulk density of the charge, improves its homogeneity and, consequently, the quality of the resulting coke.

Given the above, the purpose of this research is to develop reasonable recommendations for improving conveyor line for the preparation of coal charge for coking and the necessary equipment in order to reduce electricity consumption and to improve the quality of blast furnace coke.

**Main Part of the Research**

At the first stage of research, we study the influence of 0–3 mm fraction content on electricity consumption and hammer crusher efficiency and the influence of 0–0.5 mm fraction on the coke quality. The research is carried out in the coal preparation shop at the coke production facilities of

PJSC *ArcelorMittal Kryvyi Rih*. The grade and particle size distribution of coal charge and its mechanical properties are given in Table 2.

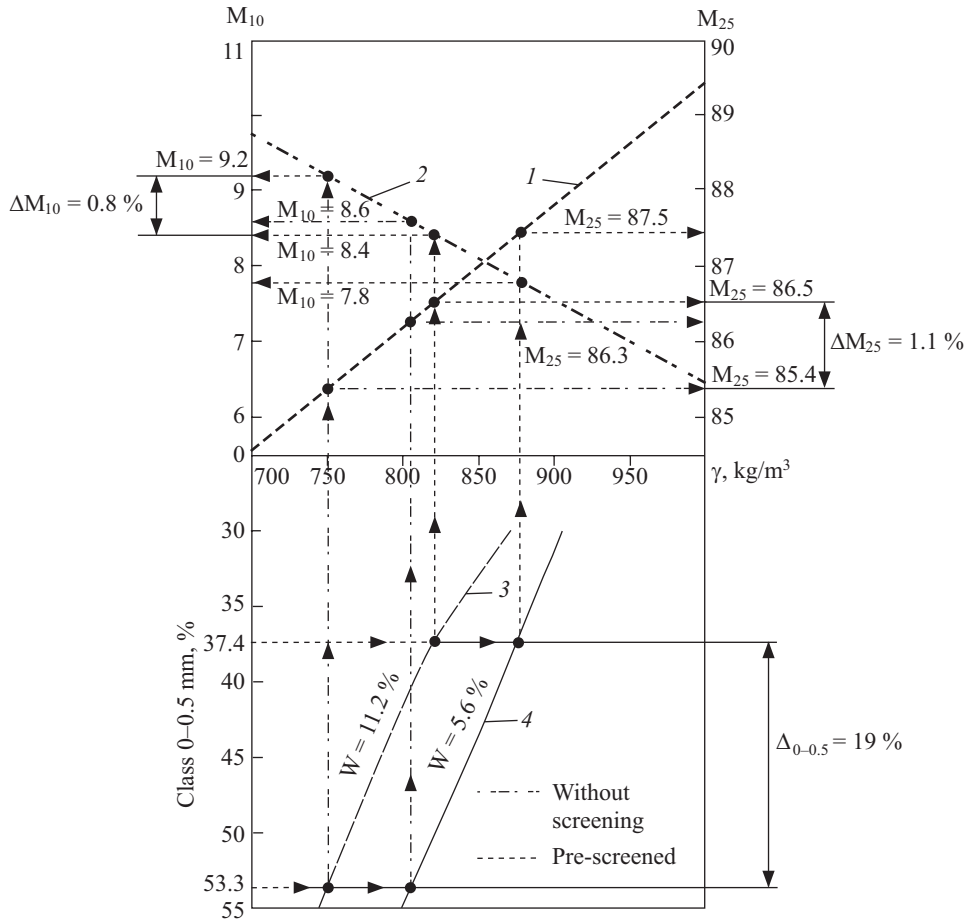
The given dependences (Fig. 2) show that the crusher efficiency for the grade and size distribution content of coal charge does not exceed 17%. The reduction in the content of 0–3 mm fraction in the charge that is fed for crushing leads to a decrease in electricity consumption by the hammer crusher and increases its efficiency.

As a result of reducing the content of the 0–3 mm fraction before crushing by 51%, electricity consumption of the hammer crusher with a grate decreases by 37% (from 412 to 260 kW) and by 19% (from 267 to 216 kW) for the crusher without a grate. The efficiency of the crusher increases by 10%, with the use of grate, and by 6% without it.

Thus, the screening of 0–3 mm fraction from the coal charge before crushing significantly reduces the electricity consumption of the hammer

**Table 2. Grade and Size Distribution Content of Coal Charge in the Coal Preparation Shop at the Coke Production Facilities of PJSC *ArcelorMittal Kryvyi Rih***

Charge, %	Particle size composition (%) by grades, mm				Coal elasticity modulus, MPa	Coal breaking stress, MPa	Average imaginary density of coal, kg/m <sup>3</sup>
	+6	6–3	3–0.5	–0.5			
Ж/27; К/35; К+КО+ОС/12; К+КО+КЖ/26	106	22	132	47	47	47	47



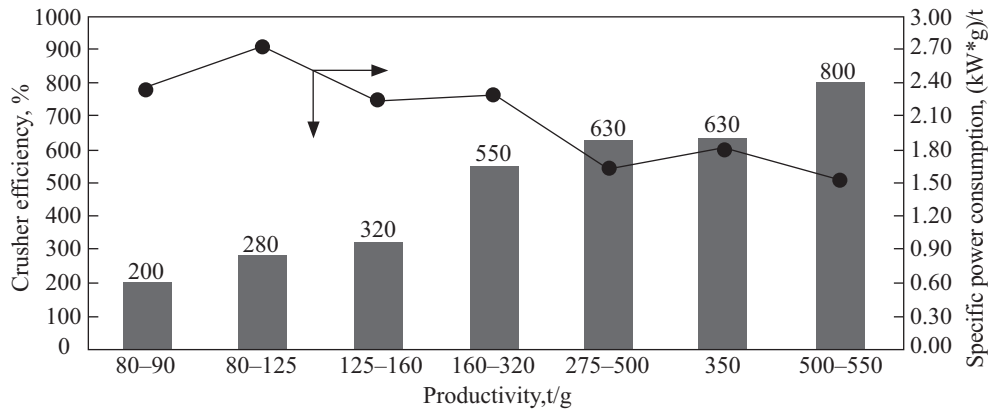
**Fig. 3.** Nomogram for determining the coke quality indicators of M25 and M10 depending on the content of the 0–0.5 mm dust fraction and the bulk density of coal charge at different moisture content: 1 – strength in terms of crushability (indicator M25); 2 – strength in terms of abrasion (M10); 3 – the content of the 0–0.5 mm grade at an average moisture content in the charge  $W = 11.2\%$ ; 4 – the content of 0–0.5 mm at an average moisture content in the charge  $W = 5.6\%$

crusher, both with a grate and without it. However, when using standard screens, the screening efficiency of which is 50% for 0–3 mm fraction, it is impossible to increase the efficiency of the crusher by more than 32%, which is quite low for the equipment used.

Based on the results of studying the effect of 0–0.5 mm fraction on the bulk density of the coal charge, as well as experimental coking, a nomogram has been obtained (Fig. 3). The nomogram allows assessing the quality of coke for “cold” strength in terms of crushability ( $M_{25}$ ) and abrasion ( $M_{10}$ ), given the preliminary screening

of 0–3 mm fraction at different humidity of the coal charge.

The obtained nomogram shows that as the content of dust fraction 0–0.5 mm in the coal charge increases, its bulk density and quality of coke decreases. For example, as a result of reducing the content of 0–3 mm fraction in the coal charge with a moisture content of  $W = 11.2\%$  and  $W = 5.6\%$  (curves 3, 4), the strength of coke increases in terms of crushability by 1.1% and 1.2% (from 85.4 to 86.5% and from 86.3 to 87.5%), respectively, and in terms of abrasion by 0.8% (from 9.2 to 8.4% and from 8.6 to 7.8%), respectively.



**Fig. 4.** Power of the reversible hammer crusher and average specific consumption of electricity depending on its productivity

The hot strength also improves: reactivity (CRI) decreases by 2.6% (from 40.1% to 37.5%), and post-reaction strength (CSR) increases by 3.3% (from 43.1% to 46.4%).

The studies show that reducing the content of the defined grade in coal charge before crushing in the hammer crusher may improve the quality of the resulting coke, but the efficiency of this process remains low, indicating the need to use a reversible hammer crusher of other size or other type of crusher.

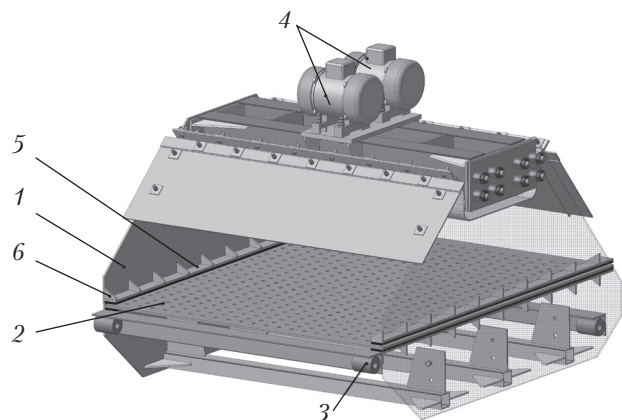
Having studied the market offer of hammer reversible crushers used for crushing coal of different grades before coking (Fig. 4) [11–13], we conclude that economically justified reduction in electricity consumption may not be achieved unless the productivity in terms of oversized product is, at most, 250 t/g, which, given the productivity of the process line of 700 t/h and the existing particle size distribution of the coal charge, requires the use of screens with an efficiency of, at least, 80%.

Ensuring the above efficiency of screening on existing structures of domestic and foreign screening facilities in a limited production area, as well as preventing the clogging of the sieving surface with initial coal concentrate that has average moisture content of 10... 12%, as a result of its sticking, are complicated tasks.

In connection with the above, a group of engineers of the Kryvyi Rih Metallurgical Institute

of the National Metallurgical Academy of Ukraine has proposed a configuration of steep vibration-impact screen (Fig. 5), the main elements of which are box 1 with sieving surface 2 supported by rubber shock absorbers 3. The box vibrations are transmitted by two kinematically unbound inertial vibration generators 4 operating in self-synchronization mode. Given research [14], the sieving surface is formed by a freely supported plate with round holes, which performs periodic shock-pulse oscillations in the vertical plane limited by support 5. To prevent the longitudinal movement of the sieving surface it is fixed by stoppers 6 [15].

To assess the efficiency of the separation of the defined grade before crushing, in the existing pro-



**Fig. 5.** General view of steeply inclined vibrating-impact screen with freely supported screening surface

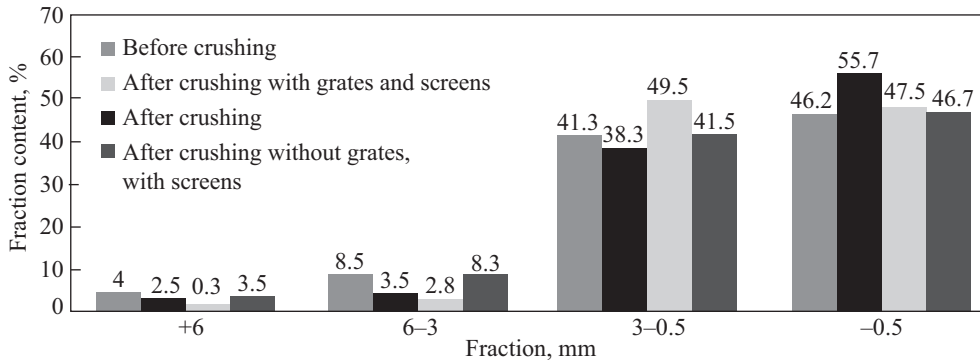


Fig. 6. Histogram of changes in the particle size composition

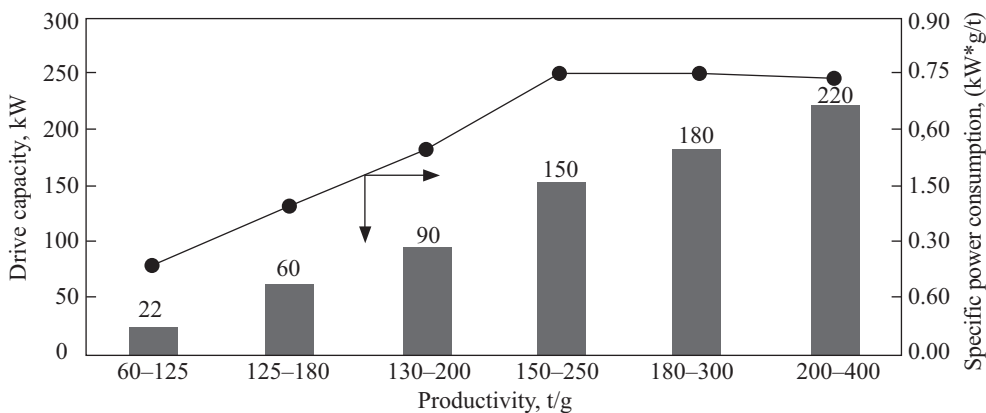


Fig. 7. Power of two-roll-gear crusher drive and average specific electricity consumption depending on its productivity

duction conditions, the changes in the particle size distribution of the coal charge with a moisture content of  $W = 11.2\%$ , during the motion along the conveyor line, have been analyzed (Fig. 6).

The obtained histogram shows that the screening of 0–3 mm fraction from the coal charge with its subsequent crushing on hammer crushers both with a grate and without it, leads to a decrease in the content of –0.5 mm grade by 8 and by 9% respectively, however, the effect of coal crushing with the formation of this grade, is not removed. In addition, the use of hammer crushers with a capacity of less than 320 t/h, because of a 1.5 times increase in the electricity consumption per a ton of finished product (see Fig. 4) is not effective.

An alternative type of crushers used for crushing coal charge, with a productivity of up to 400 t/h is two-roller-toothed crushers. The study

of the market range of sizes (Fig. 7) [16] has showed that this type of equipment is more efficient, because it has a lower electricity consumption (specific electricity consumption does not exceed 0.75 (kWh)/t) and prevents re-crushing of the material.

In some processes, hammer crushers act as mixers for incoming coal concentrates in addition to crushing. However, if screening of more than 75% of the defined grade is ensured, practically there is no mixing, so it is necessary to use equipment for forced mixing.

Table 3 presents the main types of mixers that may be or are used in coal processing facilities [6, 17, 18].

Table shows that the revolving-arm and disc stack mixers are less energy-intensive, but they require significant additional space, which in the



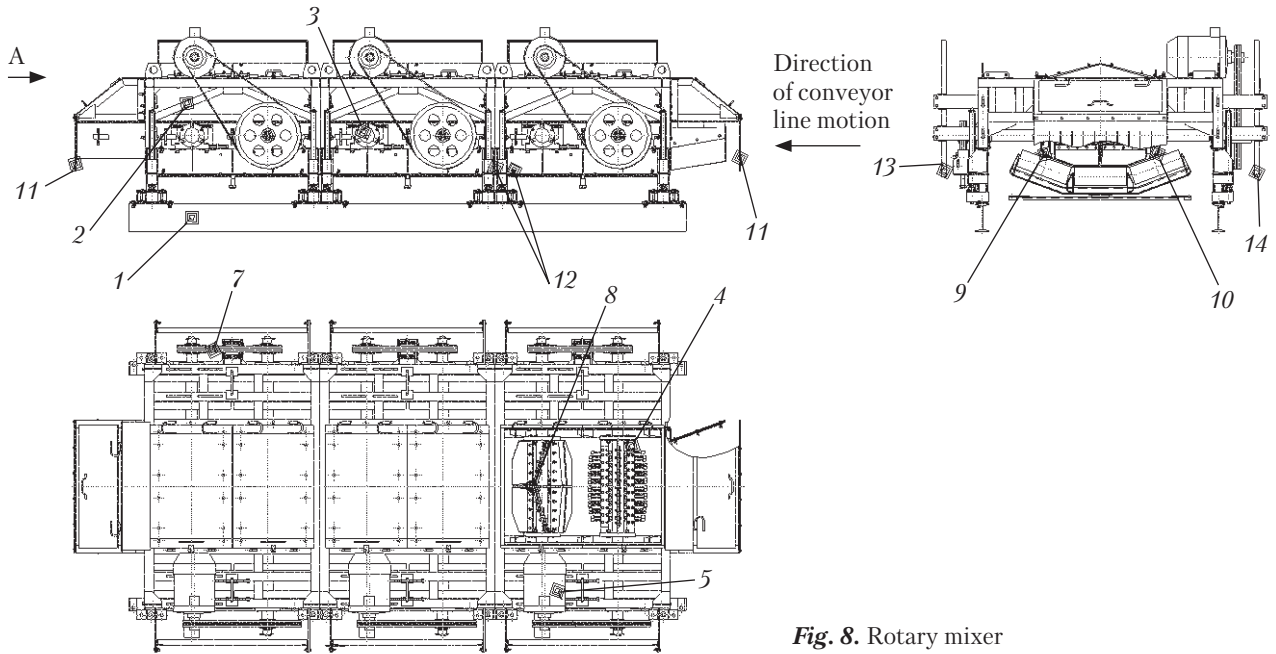


Fig. 8. Rotary mixer

conditions of existing coal preparation facilities not always may be realized. Alternative options are beater-type and rotary mixers. The beater-type mixer, like the revolving-arm or disc stack mixer, requires additional space for mounting and operation, while the rotary mixer is mounted directly above the conveyor and does not require re-design of the existing lines in coal preparation facilities.

Disadvantages of the existing rotary mixer configuration is poor quality of the mix and the

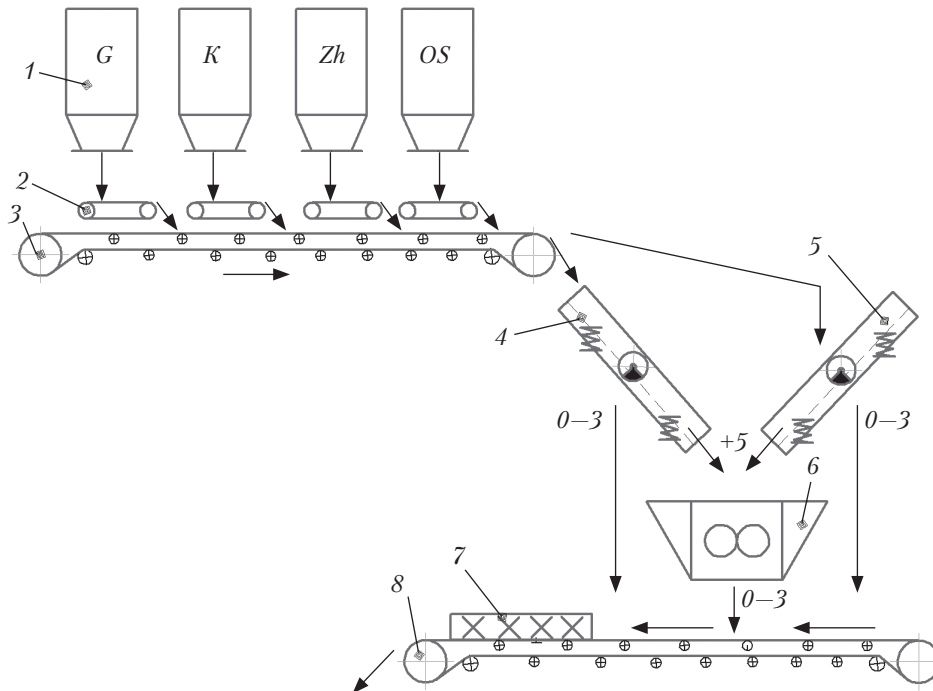
possibility of significant damage to the conveyor belt in the case where metal objects or non-shredding materials fall between the belt and the finger rotor formed by metal pins welded to its shaft.

To remove these disadvantages, an engineer team of the Kryvyi Rih Metallurgical Institute of the National Metallurgical Academy of Ukraine has proposed a rotary mixer configuration (Fig. 8). The mixer is mounted directly above the belt conveyor and consists of welded frame 1 and sections 2. Two rotor are installed on bearing sup-

Table 3. Equipment for Coal Charge Mixing

Parameters	Type of mixer					
	Revolving-arm mixer	Disc stack mixer	Beater-type mixer	Disintegration-type mixer	Organized charge mixing plant	Rotary mixer
Power, kW	6	6	15	75	110	23
Productivity, t/g	700	500	400	750	1100	600
Mixer weight, t	1.4	0.3	0.4	11.4	4.09	5.65
Area with electromotor included, m <sup>2</sup>	2.4	3.24	1.96	12.5	6.6	17.1*
Specific electricity consumption, (kW · g)/t	0.009	0.012	0.038	0.1	0.1	0.038
Specific quantity of metal, t/(g · t)	500	1667	1250	66	269	106
Specific productivity, t/(g · m <sup>2</sup> )	175	154	255	60	167	0

Note: \* does not require additional space, mounted above conveyor



**Fig. 9.** The offered CC process chart for coal charge preparation: 1 – bunker; 2 – belt dispenser; 3 – charge conveyor; 4, 5 – screens; 6 – roller crusher; 7 – rotary mixer; 8 – main conveyor

ports 3 of each section. The rotors with flexible cable elements 4 are moved by electric motors 5 connected via V-belt transmission 6. On the opposite side, blade rotors 8 are moved by means of V-belt transmission 7. For ensuring tight coupling of the sections, laminated rubber elements 9 and 10 are used. At the mixer input and outlet, on the end walls, there are installed sealing rubber curtains 11. Adjusting screws 12 are used to maintain and to adjust the gap between the belt and the rotors. The side walls of the sections are protected with shields 13 and 14 to prevent injuries from rotating actuators. Depending on the needs and process requirements, additional sections may be added or detached [19].

Thus, the research allows us to conclude that the process flowcharts used to prepare the coal charge for coking are energy-consuming, and, moreover, do not enable improving the quality of the resulting coke. In our opinion, it is possible to reduce electricity consumption and to make bet-

ter the quality of coal charge preparation before sintering by improving the existing conveyor line through preliminary screening of the finished grade 0–3 mm with its subsequent blending with coal concentrate that has been crushed on roller crushers.

For example, proceeding from the primary particle size distribution of the coal charge (Fig. 1) and its flows along the conveyor line at the coal preparation facilities of *ArcelorMittal Kryvyi Rih*, the following generalized improved process chart for CC may be offered (Fig. 9).

In the proposed flowchart, screening is realized by two steeply inclined inertial screens with a freely supported screening surface having a capacity of 350 t/g with a cell of 5 mm, which allows achieving efficiency of 80–90% for 3 mm grade (due to a high absorption capacity for class 0–3 mm). A standard range of such screens has been developed by *KVMSH PLUS* together with the Industrial Machine-Building Engineering Depart-



Table 4. Parameters of the Proposed CC Flowchart

Parameters	Equipment of the proposed CC process flowchart			Proposed process line
	Steeply inclined vibrating-impact screen with a freely supported screening surface	Roll crusher	Rotary mixer of improved configuration	
Power, kW	$25 \times 2 = 50$	150	23	223
Actual performance, t/h	$350 \times 2 = 700$	250	700	700
Specific electricity consumption (kWh)/t	$0.08 \times 2 = 0.16$	0.6	0.038	0.3

ment of the Kryvyi Rih Metallurgical Institute of the National Metallurgical Academy of Ukraine specifically for materials with a high moisture content, tending towards clogging and sticking to screen surfaces. In addition, the scheme provides for the use of a roll crusher with a capacity of 250 t/h that is sufficient for processing the oversized product after screening. After the crushing stage, a multi-section rotary mixer is mounted above the main conveyor. The capacity of the proposed grading & crushing & mixing equipment, as estimated based on the specifications, is 223 kW (Table 4).

Having compared the obtained capacity of all equipment in the proposed process flowchart for the option with the crushing equipment currently used for the CC scheme (see Table 1), i.e. the two crushers each having a capacity of 630 kW, with their actual productivity of 88 t/h caused by a low content of the fractions to be crushed in charge, it may be concluded that the specific electricity consumption of coal concentrate processing at the crushing and mixing site may be reduced at least 48 times, from 14.3 kWh/t to 0.3 kWh g/t.

The use of additional screening sites in the proposed process flowchart leads not only to reducing

electricity consumption, but also to improving the quality of coke due to the prevention of re-crushing of the finished product and, as a consequence, reduction in the content of 0–0.5 mm fraction, which increases coal load density. This causes decreasing CRI (coke reactivity index) and growing CSR (coke strength after reaction) of the resulting coke by 3%, on average. The forced mixing of all charge components, as foreseen in the proposed process flowchart, increases the homogeneity of the chemical composition and the physical and mechanical properties of the resulting coke.

## Conclusions

The research has shown that with the existing raw material base and those coal concentrates that are supplied for processing to the coal preparation facilities of coke plants, the existing conveyor lines are low-efficient and energy-intensive. Improving the quality of coal charge preparation for sintering and reducing electricity consumption of the equipment may be realized through improving the existing conveyor lines by organizing sites for pre-screening of the finished grade 0–3 mm before crushing followed by crushing of screened sorted material to 0–3 mm and subsequent mixing of the entire product on the main conveyor.

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#### УДОСКОНАЛЕННЯ ТРАКТІВ ПІДГОТОВКИ ВУГІЛЬНОЇ ШИХТИ ДО КОКСУВАННЯ ШЛЯХОМ ВИКОРИСТАННЯ СУЧАСНОГО СОРТУВАЛЬНО-ЗМІШУВАЛЬНОГО ОБЛАДНАННЯ

**Вступ.** В умовах існуючої кон'юнктури ринку, коли попит на металургійну продукцію залишається сталим або знижується, розвиток металургійної галузі можливий за рахунок оптимізації операційних витрат. Оскільки значною складовою собівартості готової продукції є витрати на електроенергію, середній темп зростання цін на яку за останні п'ять років склав 125 %, виникає необхідність у виконанні аналізу енергоспоживання з подальшою його оптимізацією.

**Проблематика.** В діючій технологічній лінії виробництва коксу найбільш енергоємною технологічною операцією є подрібнення вугільної шихти, в якій не передбачено попереднє відсівання готового класу. Аналіз гранулометрично-

го складу вугільних концентратів показав, що вхідна шихта містить лише 12,5 % фракцій, які потребують дроблення. Зважаючи що, валовий потік вугільного концентрату надходить до дробарок, це призводить до того, що коефіцієнт корисної дії використовуваних дробарок не перевищує 16–18 % та відбувається переподрібнення вугільних концентратів, що збільшує вміст фракції 0–0,5 мм, яка негативно впливає на якість коксу.

**Мета.** Розробка науково-обґрунтованих рекомендацій щодо вдосконалення тракту підготовки вугільної шихти до коксування та використання в них необхідного обладнання задля зниження споживання електроенергії та підвищення якості доменного коксу.

**Матеріали й методи.** Використано емпіричні методи досліджень із застосуванням математичного апарату обробки статистичних даних.

**Результати.** Розроблено технологічну схему підготовки вугільної шихти, яка дозволяє підвищити якість доменного коксу та зменшити питомі витрати електроенергії орієнтовно в 48 раз.

**Висновки.** Підвищення якості підготовки вугільної шихти до спікання з одночасним зниженням енерговитрат обладнання, що виконує її переробку, може бути реалізовано удосконаленням існуючих технологічних трактів шляхом організації ділянок попереднього відсіву готового класу перед дробленням.

*Ключові слова:* кокс, дроблення, грохочення, змішування, енергоємність.