**Article** **Open Access**

# IMPROVING THE TECHNOLOGY OF PREPARING COAL FOR THE PRODUCTION OF BLAST-FURNACE COKE UNDER THE CONDITIONS OF MULTI-BASIN RAW MATERIAL BASE. MESSAGE 1. OPTIMIZING THE COMPOSITION OF COAL BATCH BY MEANS OF PETROGRAPHIC CHARACTERISTICS

*V. P. Lyalyuk, D. A. Kassim, E. O. Shmeltser*, I. A. Lyakhova*

*Kryvyi Rig Metallurgical Institute, Ukraine National Metallurgical Academy, 50006, Kryvyi Rig, Ukraine*

Received September 27, 2018; Accepted December 21, 2018

**Abstract**

The optimality of coking batch may be assessed on the basis of the coefficient $K_{opt}(v_t)$. A method is proposed for determining $K_{opt}(v_t)$ by means of petrographic analysis. This approach permits an ongoing assessment of the optimal composition of the coking batch and prediction of the coke's mechanical strength.

***Keywords****:* coke; coal batch; optimal rank composition; petrographic analysis.

## 1. Introduction

The coal raw material base of the coke production of PJSC ArcelorMittal Kryvyi Rih, like the majority of the coke enterprises of Ukraine, has a multi-basin character, and the share of domestic raw materials is about 20%. The increase in the share of imported coal (coal concentrates in Russia, Kazakhstan, and the United States, Canada) is associated both with a shortage of Ukrainian coal of suitable quality (low sulfur content, $I_0 \leq 2.5$ basicity index), and with an increase in the quality requirements for coke to reduce its consumption in blast smelting, as well as in connection with the introduction of pulverized coal injection technology in blast furnace production.

Analysis of the qualitative characteristics of coal concentrates that make up the raw material base for coking an enterprise allows us to formulate its features and basic principles of formation: both now and in the future, the coal raw material base of the coke production will be multi-basin in nature; in the batch, along with coal concentrates from Ukraine, Russia and abroad, the own assets of the Karaganda basin in the amount of 25-30% will be used, which increases the ash content of the batch by 1% on average, the coke ash content by 12% or more. At the same time, the introduction of pulverized coal injection technology into blast furnaces necessitates the attraction or production of blast-furnace coke with high mechanical strength ($M_{25}$> 88%, $M_{10}$ <7.5%), low reactivity CRI <30-35% and high hot strength (CSR> 55-60%) [1].

Under the conditions of the formed multi-basin raw material base of coking, which predetermines the differences in the technological properties and material composition of imported and domestic coal concentrates, it is necessary to clarify and improve the basic technological methods of preparation for their use in coal mixtures. Achieving these characteristics of coke for blast furnace smelting conditions is possible with a comprehensive, scientifically based approach to improving the technology of preparing coal for coking, which consists in developing methods and technological measures aimed at optimizing the composition, properties, and degree of grinding of the batch, taking into account its petrographic characteristics.

## 2. Results and discussions

The aim of our research was an attempt to determine the criteria for optimizing the parameters of the batch to obtain coke of a given quality for modern blast furnace smelting.

Because the quality of the incoming coal is unstable and its supply is erratic, the rank composition of the batch will vary and will not always ensure the required coke quality. The correct choice of the rank composition is very important. For this purpose, it is expedient to use not only the yield of volatiles and clinkering properties of the coal but also petrographic analysis [2].

Petrographic analysis is an effective method of determining the actual composition of coal mixtures. On that basis, the rank composition of coal blends and the uniformity of the vitrinite component may be determined. The vitrinite reflectograms of concentrates from enrichment facilities give a clear idea of the actual content of the declared rank in the given concentrate and are essential in assessing the concentrate's quality. The actual rank composition of a batch containing concentrates from different enrichment facilities must be determined on the basis of the petrographic characteristics—in particular, the reflectograms—of the batch [3].

The vitrinite reflectance is the most reliable basis for quantitative metamorphic assessment of the coal. By petrographic analysis, we may establish the actual content of vitrinite components corresponding to a particular rank in commercial coal from mines, in concentrates from enrichment facilities, and in coking batch. Coal from Ukraine, Russia, Kazakhstan, and the United States differs sharply in technological properties and petrographic characteristics. Most Ukrainian enrichment facilities do not have a steady coal supply and consequently must enrich coal of two or more ranks. That results in mutual interference of the components and reduces the technological value of the concentrate produced [4].

Accordingly, the earlier practice of batch formulation on the basis of the assigned rank of the concentrates, together with technical analysis and plastometric characteristics, does not permit correct assessment of the coal's technological value or prediction of the expected coke quality, as shown in [4]. Reliable monitoring of the concentrates sent to the plant and the well-founded formulation of coking batch must take account of petrographic characteristics: the maceral composition, mean reflectance, and reflectogram of the vitrinite.

Of the extensive research in this area, we base our analysis on [5]. An optimal batch composition with 43% clinkering components and 57% lean components was proposed in [5]. In this composition, the coke group constitutes 37% of the lean components, while Zh coal (bituminous coal) constitutes 23% of the clinkering components. (These figures are assumed constant for any batch, crushing system, and coking conditions). Then, the optimality of the batch composition may be estimated on the basis of the coefficient $K_{opt}$ proposed in [5]. Using $K_{opt}$, we may measure the discrepancy between the actual rank composition of the batch and the baseline (optimal) composition. The formula for $K_{opt}$ is as follows [5]

$$K_{opt} = 100(K_c \cdot K_{co} \cdot K_b),\ \%. \quad (1)$$

where $K_c = [100 - (\Sigma CC - 43) \times 2]/100$ characterizes the optimality of the ratio of clinkering and lean components; $K_{co} = [100 - (\Sigma CG - 37)]/100$ characterizes the optimality of the content of coke-group coal; and $K_b = [100 - (\Sigma B - 23)]/100$ characterizes the optimality of the content of bituminous coal.

With the increase in $K_{op}$t, the coke is stronger, as indicated by the rise in $M_{40}$ and $M_{25}$ [5]. Note also that $K_{opt}$ permits both ongoing and retrospective assessment of how optimal the batch composition is; and also permits prediction of the coke's mechanical strength. This method of optimization has performed well in the coke plant at OAO EVRAZ NTMK [6].

The optimality of the batch composition at Ukrainian coke plants was also assessed on the basis of $K_{opt}$ in [7]. The numerical factors 43, 37, and 23 in the formulas for $K_c$, $K_{co}$, and $K_b$ were retained for Ukrainian coke plants. (Note again that the coefficients are assumed constant for any enterprise, batch, crushing system, and coking conditions, which may seem unlikely). Analysis for Ukrainian coke plants between 2004 and 2006 shows that the mean $K_{opt}$

value declines: from 77.4% in 2004 to 73% in 2005 and 66.9% in 2006. That may be attributed primarily to the decline in $K_c$—in other words, to the growing shortage of clinkering coal. Another finding is that the increase in $K_{opt}$ is associated with a decrease in $M_{10}$ and increase in $M_{25}$. In other words, the coke quality is enhanced, despite the decline in the absolute value of $K_{opt}$.

The coefficients of 43, 37, and 23 used in calculating $K_c$, $K_{co}$, and $K_b$ may be corrected in accordance with the characteristics of the coking coal available at a particular plant, according to [7]. (This casts doubt on the constancy of these coefficients in any coking conditions).

Detailed analysis for Ukrainian coke plants in 2010 and 2011 on the basis of $K_{opt}$ yields the unexpected result that $K_{opt}$ does not correspond to the quality of the coke. That contradicts the finding in [5].

We may offer the following explanation of the findings. First, it is not correct to determine the rank composition of the batch in optimization on the basis of the suppliers' declarations. In addition, it is not correct to assume constant coefficients in the formulas for $K_c$, $K_{co}$, and $K_b$ when determining $K_{opt}$ on the basis of petrographic and reflectogram analysis. Note also that all the all the coal ranks present in the batch according to petrographic analysis must be individually taken into account.

In this context, note the proposal in [8]: specifically, that ongoing and objective formulation of coking batch entails direct optimization of coke quality (such as the mechanical strength).

Hence, the coefficients in optimization must be found from information regarding the production of high-quality coke at the specific enterprises, in specific conditions.

We now propose the coefficient $K_{opt(Vt)}$ on the basis of the proposal in [8] and the method in [5]

$$K_{opt(Vt)} = 100(K_G K_{Zh} K_K K_{OS}) \quad (2)$$

Here $K_G$ characterizes the optimality of the content of vitrinite components with reflectance 0.65-0.89% (G coal)

$$K_G = [100 - (\Sigma Vt_{Ro = 0.65\text{-}0.89} - X_g)]/100, \quad (3)$$

$K_{Zh}$ characterizes the optimality of the content of vitrinite components with reflectance 0.90-1.19% (Zh coal)

$$K_{Zh} = [100 - (\Sigma Vt_{Ro = 0.90\text{-}1.19} - X_{Zh})]/100, \quad (4)$$

$K_K$ characterizes the optimality of the content of vitrinite components with reflectance 1.20-1.39% (K coal) and $K_{OS}$ characterizes the optimality of the content of vitrinite components with reflectance 1.40-1.69% (OS coal).

$$K_K = [100 - (\Sigma Vt_{Ro = 1.20\text{-}1.39} - X_K)]/100, \quad (5)$$

$$K_{OS} = [100 - (\Sigma Vt_{Ro = 1.40\text{-}1.69} - X_{OS})/100. \quad (6)$$

In Eqs. (2)—(6), the coefficients $X_G$, $X_{Zh}$, $X_K$, and $X_{OS}$ characterize the baseline content of the corresponding rank in the optimization of the batch's rank composition. The values of $X_G$, $X_{Zh}$, $X_K$, and $X_{OS}$ are determined on the basis of petrographic analysis of the coal concentrates during a period in which high-quality coke is obtained at a specific coke plant. In our view, their values cannot be the same for all shops and plants.

The values of $X_G$, $X_{Zh}$, $X_K$, and $X_{OS}$ must be corrected (recalculated) if the $M_{25}$ values of the coke deteriorate by more than 1%, say. In addition, the absolute difference between the actual and optimal contents of the components is calculated in the formulas for $K_G$, $K_{Zh}$, $K_K$, and $K_{OS}$ (disregarding the sign of the result), as in the method of [5].

In accordance with the proposed method, we determine the values of $X_G$, $X_{Zh}$, $X_K$, and $X_{OS}$ for the coke plant at PAO ArcelorMittal Krivoi Rog in a period with the production of high-quality coke, for the coal then available [9]. We find that $X_G$ =14, $X_{Zh}$ = 65, $X_K$ =14, and $X_{OS}$ =7. On the basis of Eqs. (2)-(6), we may then plot $M_{25}$ as a function of $K_{opt(Vt)}$ (Fig. 1).

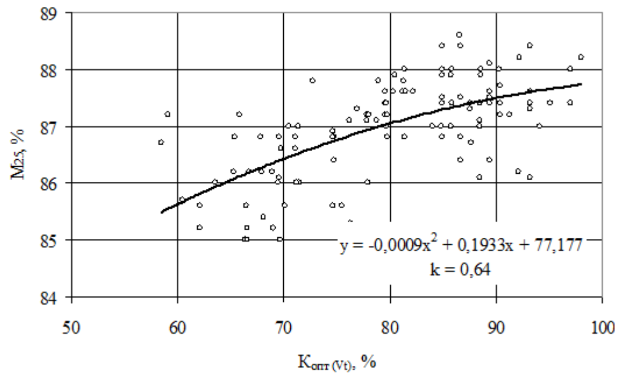


Fig. 1. Dependence of coke strength $M_{25}$ on $K_{opt(Vt)}$

## 3. Conclusions

On the one hand, the relation between $K_{opt(Vt)}$ and the coke strength is closer than for $K_{opt}$. On the other hand, we find that the coke quality increases with increase in $K_{opt(Vt)}$, and the absolute value of this coefficient reaches the level recommended in [5-6].

Thus, our research again confirms the need for petrographic analysis in order to monitor the actual rank composition of the coking batch during optimization. In determining the optimization coefficient $K_{opt(Vt)}$, the baseline content of the various ranks in the coking batch must be established during a period in which high-quality coke is obtained at the specific coke plant. The baseline cannot be the same for all shops and plants.

### *Symbols*

*CRI, CSR – coke reactivity index and coke strength after reaction, %*
*Vt – vitrinite, %;*
*$R_0$ – mean vitrinite reflection coefficient, %;*
*$M_{10}$, $M_{25}$ – indices of resistance of coke abrasion and crushability, respectively, %.*

### References

[1] Romanyuk IV, Sikan II, Mukina NV, et al., Prospective development of the coal resource base of the Arcelor Mittal Krivoy Rog coke chemical production, Uglekhim. Zh., 2016; 3–4: 12–18.
[2] Gainieva GR, and Boyarchikova RL. Reflectogram assessment of the coal reserves of OAO Zapadno-Sibirskii Metallurgicheskii Kombinat, Koks Khim., 2005; 5: 18–22
[3] Chernyshov YuA, Ovchinnikova SA, Podlubnyi AV, et al., Assessing the properties of coal and complex batch at OAO Zaporozhkoks on the basis of petrographic characteristics and new coeffcients, Uglekhim. Zh., 2009; 1-2: 12–20.
[4] Kaftan YuS, Drozdnik ID, Miroshnichenko DV, et al., Scientific principles for batch formulation using coal from different basins, Uglekhim. Zh., 2010; 3-4: 25–31.
[5] Shtark PV, Stepanov YuV, Popova NK, and Vorsina, DV, Optimal composition of coal batch, Coke and Chemistry, 2007; 50(3): 45–49.
[6] Popova NK, and Stepanov YuV. More on the optimization of batch composition, Coke and Chemistry, 2013; 56(5): 165–166.
[7] Ulanovskii ML, and Likhenko AN. Assessing Ukrainian coking batch in terms of optimization of the rank composition, Coke and Chemistry, 2008, vol. 51, no. 7, pp. 256–259.
[8] Stankevich AS, Kruglov VN, Vorsina DV, and Zolotukhin YuA. Model for optimization of coke quality on the basis of the chemical and petrographic characteristics and nonlinear programming, Koks Khim., 2000; 5: 21–29.
[9] Lyalyuk VP, Kassim DA, Lyakhova IA, and Sokolova VP. Coke quality and optimization of the batch composition, Coke and Chemistry, 2012; 55(12): 448–452.

*To whom correspondence should be addressed: Dr. E. O. Shmeltser, Kryvyi Rig Metallurgical Institute, Ukraine National Metallurgical Academy, 50006, Kryvyi Rig, Ukraine, shmelka0402@gmail.com*