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Influence of the Properties Raw Coal Materials and Coking Technology on the Granulometric Composition of Coke
Message 2. Granulometric Composition of the Coke as a Function of the Coal Batch Properties

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Abstract

To implement a comprehensive approach to improving the technology of coal preparation in order to improve the quality of coke, it is necessary to study the raw materials and technological factors that determine the distribution of coke by size classes. This determines the possibility of influencing the granulometric composition of coke in its production in order to increase the yields of the most valuable fractions, improve its quality characteristics to achieve high performance blast furnaces. The change in granulometric composition of the coke as a function of the batch properties is analyzed for coke production at ArcelorMittal Krivyi Rig. Analysis of the results indicates that, with no changes in the coking conditions, the granulometric composition depends significantly on the ash content and packing density of the coal batch. Research has shown that the petrographic composition of the coal batch also affects the size of the coke. The closest relationship is established between the magnitude of the fusinized components Σ*FC* and the output of the coke fractions 80-60 mm (correlation coefficient r = 0,8), 40-25 mm (r = 0,8), <25 mm (r = 0,87).

***Keywords**: Coal batch; Technological properties of coal batch; Petrographic characteristics of raw coal materials; Coking technology; Coke; Granulometric composition.*

1. Introduction

The basic requirements of the granulometric composition of blast furnace coke were considered in [1]. To obtain a more uniform granulometric composition, we need to study the influence of the coal batch and the coking technology on the size distribution of the coke and the possibility of modifying the granulometric composition in the course of coking.

The primary granulometric composition of coke is primarily produced in the coke even when semicoke is converted to coke, with shrinkage of the semicoke and coke cake and the formation of a system of cracks in the monolithic mass [2–4].

The formation of the coke's granulometric composition in the oven was studied in [5]. In the formation of semicoke, it shrinks on account of the release of gaseous products and reordering of the structure. Because of the different rates of shrinkage at different temperatures, stress appears, and consequently, the solid monolithic bed is cracked. The crack formation depends on factors determining the stress development (the shrinkage rate and structural relaxation) and resisting crack formation (the strength of the material and the bed thickness).

The shrinkage of the batch is a key factor in the formation of the coke cake and the coke's granulometric composition [3]. As a result of transverse shrinkage, the coke cake moves away from the walls of the furnace chamber. As a result of vertical shrinkage, horizontal cracks are formed. As a result of impermissible longitudinal shrinkage, vertical cracks are formed. These cracks determine the primary granulometric composition of the coke cake.

The size distribution of the coke—that is, its granulometric composition—depends both on the properties of the coal batch and on the design of the coke ovens and the coking technology [4].

The influence of the coal's metamorphic stage (in terms of the mean vitrinite reflectivity *R*o) and petrographic composition (in terms of the content of fusinized components Σ*FC* in the batch) on the yield of different size classes in comparable coking conditions were considered in [4]. In addition, the granulometric composition of a number of coke samples was presented, with variation in the mean vitrinite reflectivity and the content of lean components in the batch.

Thus, with the increase in *R*o from 0.81 to 1.11% (Σ*FC* = 19.0–19.5%), the greatest change in granulometric composition affects the 60–80 and 40–60 mm classes: +10.5 and –8.2%, respectively. With increase in *R*o from 1.11 to 1.27% (Σ*FC* = 21.0–21.2%), these trends continue: the corresponding factors are +8.9 and −9.2%. However, changes are also seen for other classes: +5.3% for the >80 mm class; and –4.4% for the 25–40 mm class. When *R*o = 1.11–1.27% (Σ*FC* =33%), the absolute values decline for all the size classes in the coke. Variation in Σ*FC* for batch with fixed *R*o mainly affects the content of the >80 mm, 60–80 mm, and 40–60 mm classes in the coke. The granulometric composition is seen to depend on the main petrographic parameters with relatively constant technological conditions [4].

The influence of the batch's moisture content on the uniformity and size of the coke produced was considered in [6]. In production conditions, the influence of variation in the batch's moisture content from 8 to 15% on the yield of individual classes of metallurgical coke was studied. It was found that even small changes in moisture content markedly affect the yield of different size classes. That ultimately affects the hydraulic drag of the batch column in the blast furnace. Thus, with the decrease in the batch's moisture content, the yield of the >80 mm, 40–25 mm, and <25 mm classes decline, while the yield of the 80–60 mm and 60–40 mm classes increases. The change in the yield of different coke classes is nonuniform. The greatest change is observed with a decrease in the batch's moisture content from 10.3 to 8.1% [6].

Technological factors also make a significant contribution to the size distribution of the coke. Results obtained at Karaganda metallurgical works were presented in [7]. With coarse crushing of the batch (<80% of the <3 mm class), increasing the content of the <3 mm class from 67.0–68.2 to 75.5–76.2% reduces the content of the >80 mm class in the coke and increases the content of the 60–80 and 40–60 mm classes. With fine crushing (>80% of the <3 mm class), increasing the content of the <3 mm class from 85.4–85.6 to 90.6–92.4% mainly leads to some decrease in the content of the >80 mm class and increase in content of the 60–80 mm class [4, 7].

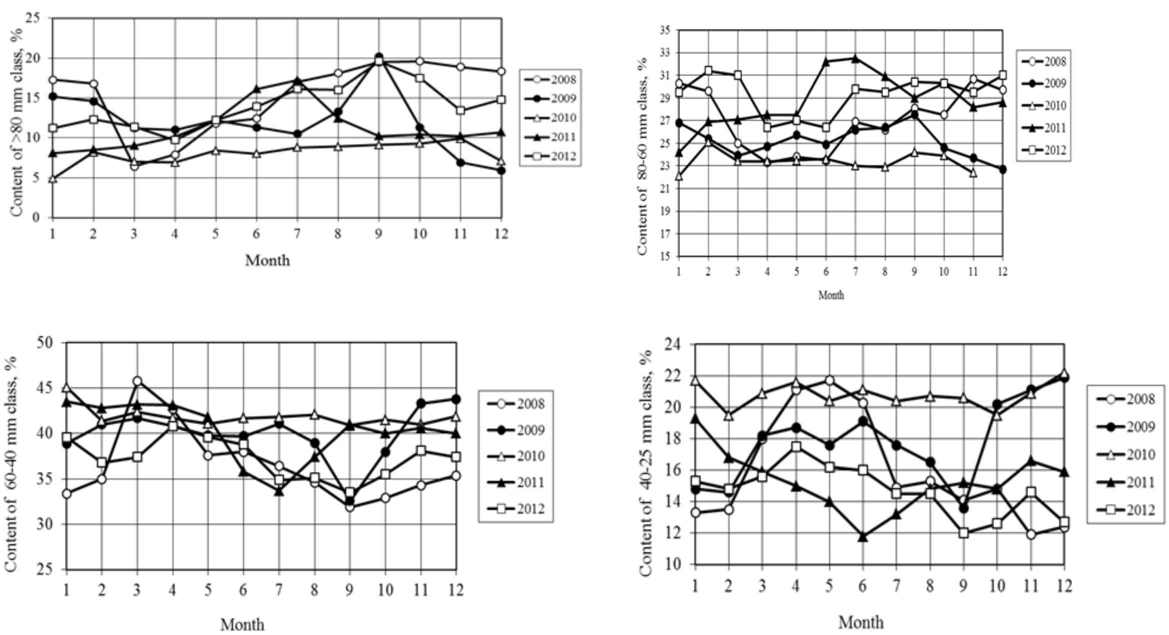
With the finer crushing of the batch, smaller cracks are formed in the coke cake, but they penetrate further into the depth, as noted in [2]. Therefore, the coke pieces obtained are smaller but have fewer cracks. The formation of smaller coke particles with the fine crushing of the batch may further distort the size distribution, with the decrease in the content of >80 mm pieces and an increase in the content of 40–80 mm pieces. The influence of the coking period and final coking temperature before discharge on the coke strength and granulometric composition was noted in [7]. Increasing the coking time at Mariupol coke plant from 13.8 to 15.8 h was found to increase the content of the >80 mm and 80–60 mm classes and reduce the content of the 60–40 and 40–25 mm classes. Experimental coking at Kharkov coke plant showed that reducing the temperature in the axial plane of the coke cake from 1042 to 984°C somewhat increases the piece size of the coke, on account of increase in the content of the >80 and 80–60 mm classes and decrease in the content of the 60–40 and 40–25 mm classes.

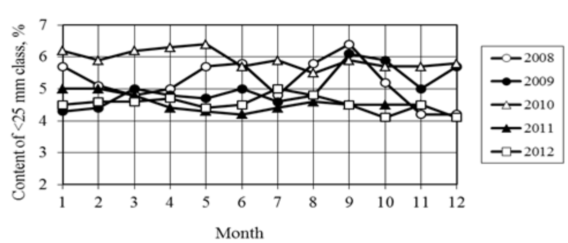
Analogous results were obtained in [8]: with the increase in the coking time, the piece size of the coke increases, on account of an increase in the content of the >80 and 80–60 mm classes. The piece size of the coke changes significantly with an increase in the final coking temperature if that involves an increase in the heating wall temperature and is accompanied by an increase in the heating rate. Thus, increasing the final coking temperature from 950–1000 to 1050–1100°C as a result of increase in the heating wall temperature (without change in the coking period) somewhat reduces the piece size of the coke, on account of decrease in the content of the >80 and 80–60 mm classes and increase in the content of the 60–25 mm classes. The size distribution of the coke becomes more uniform.

An example of the change in properties of coke produced at Krivoi Rog coke plant on the same day from the same batch in normal coking conditions (14 h 10 min) and after furnace deterioration was presented in [9]. In that case, the piece size of the coke increases on account of the increase in the content of the 80–60 and 60–40 mm classes. Thus, the yield of the >80 mm class declines from 8.7 to 6.8%; the yield of the 80–60 and 60–40 mm classes increases, respectively, from 35 to 29.6% and from 34.7 to 41.6%; and the yield of the 40–25 mm and <25 mm classes declines, respectively, from 17.6 to 8.6% and from 4.0 to 3.4%. The strength M_{40} increases from 72.2 to 82.4%, while the susceptibility to wear M_{10} falls from 10.0 to 5.8%. A considerable change in the granulometric composition of the coke is also seen in switching from wet to dry slaking of the coke. Dry slaking significantly increases the content of the most valuable 40–60 mm class in the gross coke and reduces the content of the >80 mm class, which consists of the weakest coke [4, 7].

2. Results and discussions

To study the influence of the batch and the technology on the granulometric composition of the coke produced, we consider the size distribution of the coke produced at ArcelorMittal Krivyi Rig between 2008 and 2012 (Fig. 1). We also analyze the characteristics of the coal batch—the moisture content, ash content, petrographic composition (in terms of fusinized components Σ*FC*), packing density, and content of the ≤3 mm class in the batch—over the corresponding period (Figs. 2–6). The moisture content of the batch from 2008 to 2012 varies widely: from 7.3 to 12.1%. Over the whole observation period, the minimum moisture content is seen in August.





a	b
c	d
e	

Fig.1. Variation in the yield of the >80 mm (a), 80–60 mm (b), 60–40 mm (c), 40–25 mm (d), and <25 mm (e) classes for coke batteries 1–4 between 2008 and 2012

In studying the influence of the moisture content on the size distribution of the coke, we find that for from 11.9% in January 2009 to 9.5% in August 2009 (Fig. 2) is accompanied by decrease in the yield of the >80 mm class from 15.2 to 13.3% and in the yield of the 80–60 mm class from 27 to 26.4%. There is no significant change in the yield of the 60–40 mm class.

The yield of the 40–25 mm class increases from 14.8 to 19.1% in the first six months and then falls to 16.5%. The yield of the <25 mm class is 4.3–5.0% (Fig. 1).

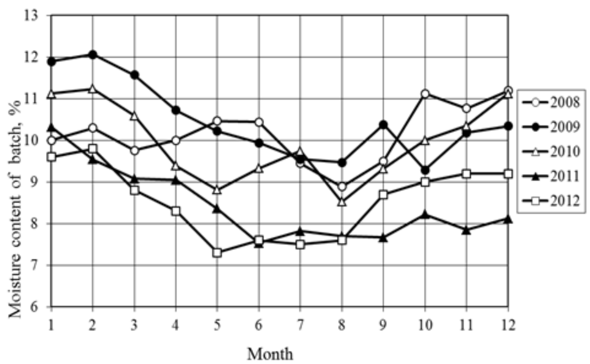


Fig.2. Variation in the moisture content of coal batch at coke batteries 1–4 between 2008 and 2012

The decrease in the moisture content of the batch from 11.2 to 8.8% between February and May 2010 (Fig. 2) is accompanied by decrease in the yield of the 80–60 mm class from 25.1 to 23.5% and decrease in the yield of the 60–40 mm class from 42.4 to 41.1%. The yield of the 40–25 and <25 mm classes increases, respectively, from 19.5 to 20.4–21.6% and from 5.1 to 6.4% (Fig. 1). In both cases, a decrease in the moisture content of the batch leads to a decrease in piece size of the coke, but the change in the yield of different size classes is nonuniform. The increase in the moisture content of the batch between August and December 2010 increases the piece size of the coke, on account of increase in the yield of the >80 mm class from 8.9 to 9.9%, with the corresponding increase from 22.9 to 24.2% for the 80–60 mm class. The yield of the 40–25 mm class rises from 19.5 to 22%, while the yield of the 60–40 mm class falls from 42.1 to 41.9%. The yield of the <25 mm class is 5.5–5.8%.

In 2011 and 2012, the size distribution of the coke changes differently. Thus, the decrease in the moisture content of the batch from 10.3 to 7.5% in the first half of 2011 is associated with an increase in the yield of the >80 mm class from 8.1 to 16.1% and in the yield of the 80–60 mm class from 24.2 to 32.2%. The yield of the 60–40 and 40–25 mm classes falls, respectively, from 43.5 to 35.8% and from 19.3 to 11.8%.

The decrease in the moisture content of the batch from 9.6 to 7.6% between January and June 2012 is associated with an increase in the yield of the >80 mm class from 11.2 to 13.9% and decrease in the yield of the 80–60 mm class from 29.5 to 26.4%. The content of the 40–25 mm class is 15.3–16.0%, while the yield of the 60–40 mm class first falls from 39.6 to 37.4% and then rises to 38.8–40.8%. That may be explained in that the dominant factor in the coke's granulometric composition during this period is the increase in the content of the ≤3 mm class in the batch and the associated decrease in the packing density.

The influence of the batch's ash content on the granulometric composition of the coke arises in that the mineral inclusions differ from coal in terms of the thermal expansion coefficient, have no clinkering properties, and weaken sections within the coke pieces, with the increase in crack formation. The 1.3% increase in ash content of the batch from July to September 2009 is accompanied by increase in the yield of the >80 mm class by 9.7%, in the yield of the 80–60 mm class by 1.2%, and in the yield of the <25 mm class by 1.5%, while the yield of the 60–40 and 40–25 mm classes declines by 8.5% and 4%, respectively.

Analogous changes are noted as a result of the 1.3% increase in ash content between January and May 2010: the yield of the >80 mm class increases from 4.9 to 8.4% and that of the 80–60 mm class from 22.1 to 23.5%. The yield of the 60–40 mm class falls from 45.1 to 44.1% and that of the 40–25 mm class from 21.7 to 20.4%. The decrease in ash content from 10.5 to 9.7% in the first half of 2009 is accompanied by decrease in the content of the >80 and 80–60 mm classes, respectively, from 15.2 to 11.5% and from 26.8 to 24.9%, while the yield of the 60–40 mm and 40–25 mm classes (the most valuable classes) increases, respectively, from 38.9 to 41.7% and from 14.8 to 19.1%.The same trends are observed with decrease in ash content of the batch from 10.7 to 9.1% between September and December 2009: decrease in the content of the >80 and 80–60 mm classes, and corresponding increase in the content of the 60–40 and 40–25 mm classes (Fig. 3).

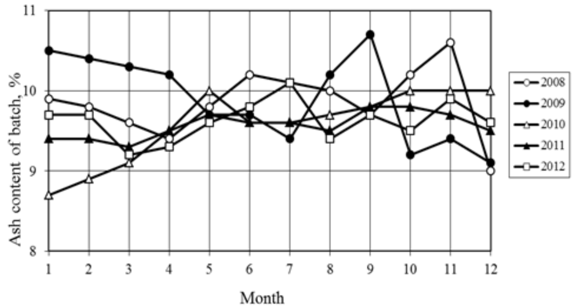


Fig. 3. Variation in the ash content of coal batch at coke batteries 1–4 between 2008 and 2012

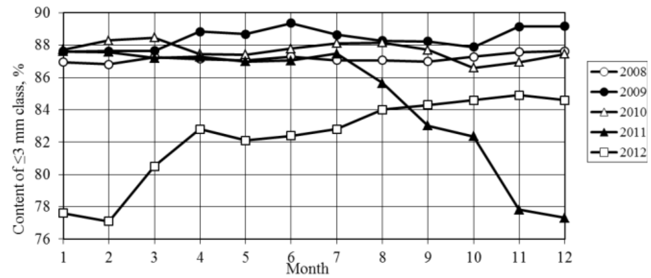


Fig. 4. Variation in the content of the ≤3 mm class in the coal batch at coke batteries 1–4 between 2008 and 2012

Analysis of the results shows that the content of the ≤3 mm class in the batch declines sharply (from 87.5 to 77.3%) between July and December 2011 (Fig. 4), with a corresponding increase in the packing density of the batch from 0.787 to 0.816 t/m^3 (Fig. 5). The granulometric composition changes as follows: decrease in the content of the >80 and 80–60 mm classes, respectively, from 17.2 to 10.7% and from 32.5 to 28.6%; and increase in the content of the 60–40 and 40–25 mm classes, respectively, from 33.7 to 41% and from 13.2 to 16% (Figs. 1a–1d). The content of the ≤3 mm class in the batch increases from 77.1% to 82.8% between February and April 2012 (Fig. 4), with the corresponding decrease in the packing density of the batch from 0.817 to 0.804 t/m^3 (Fig. 5). Correspondingly, we note decrease in the content of the >80 and 80–60 mm classes, respectively, from 12.3 to 9.7% and from 31.4 to 26.4%; and increase in the content of the 60–40 and 40–25 mm classes, respectively, from 36.8 to 40.8% and from 14 to 17.5% (Figs. 1a–1d).

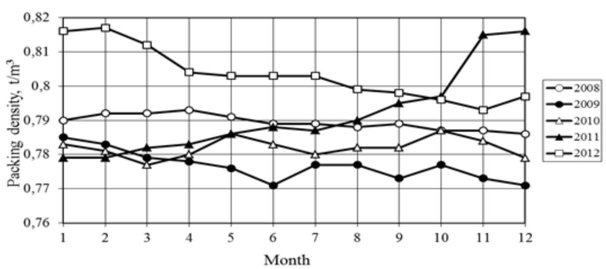


Fig.5. Variation in the packing density of the coal batch at coke batteries 1–4 between 2008 and 2012

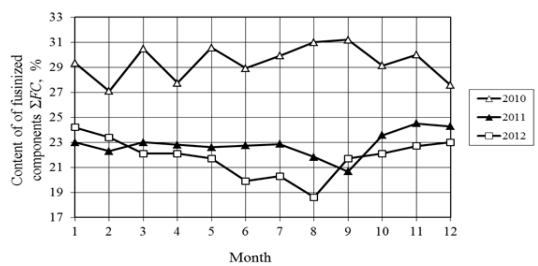


Fig.6. Variation in the content of fusinized components (ΣFC) in the coal batch at coke batteries 1–4 between 2010 and 2012

Further, an increase in the content of the ≤3 mm class in the batch from 82.1 to 84.6% between May and December 2012 is accompanied by a decrease in the packing density of the batch from 0.804 to 0.797 t/m^3. The granulometric composition changes as follows: increase in the content of the >80 and 80–60 mm classes, respectively, from 82.1 to 84.6% and from 27 to 31%; decrease in the content of the 60–40 class from 39.6 to 33.5% and subsequent increase to 37.4%; and, likewise, decrease in the content of the 40–25 class from 16.2 to 12% and subsequent increase to 12.7%.

Thus, when the packing density of the batch is in the range 0.804–0.817 t/m^3, the size distribution of the coke is more uniform. The fluctuation in the batch's content of the ≤3 mm class and its packing density has practically no influence on the yield of the <25 mm class (Fig. 1e).

Data for the petrographic composition (in terms of the content of fusinized components Σ*FC*) indicate values of 27.1–31.2% in 2010, 20.7–24.5% in 2011, and 18.6–24.2% in 2012 (Fig. 6). The closest correlations are observed between Σ*LC* and the yields of the following size classes in the coke (Fig. 7): 80–60 mm (k =0.8); 40–25 mm (k = 0.8); and <25 mm (k =0.87).

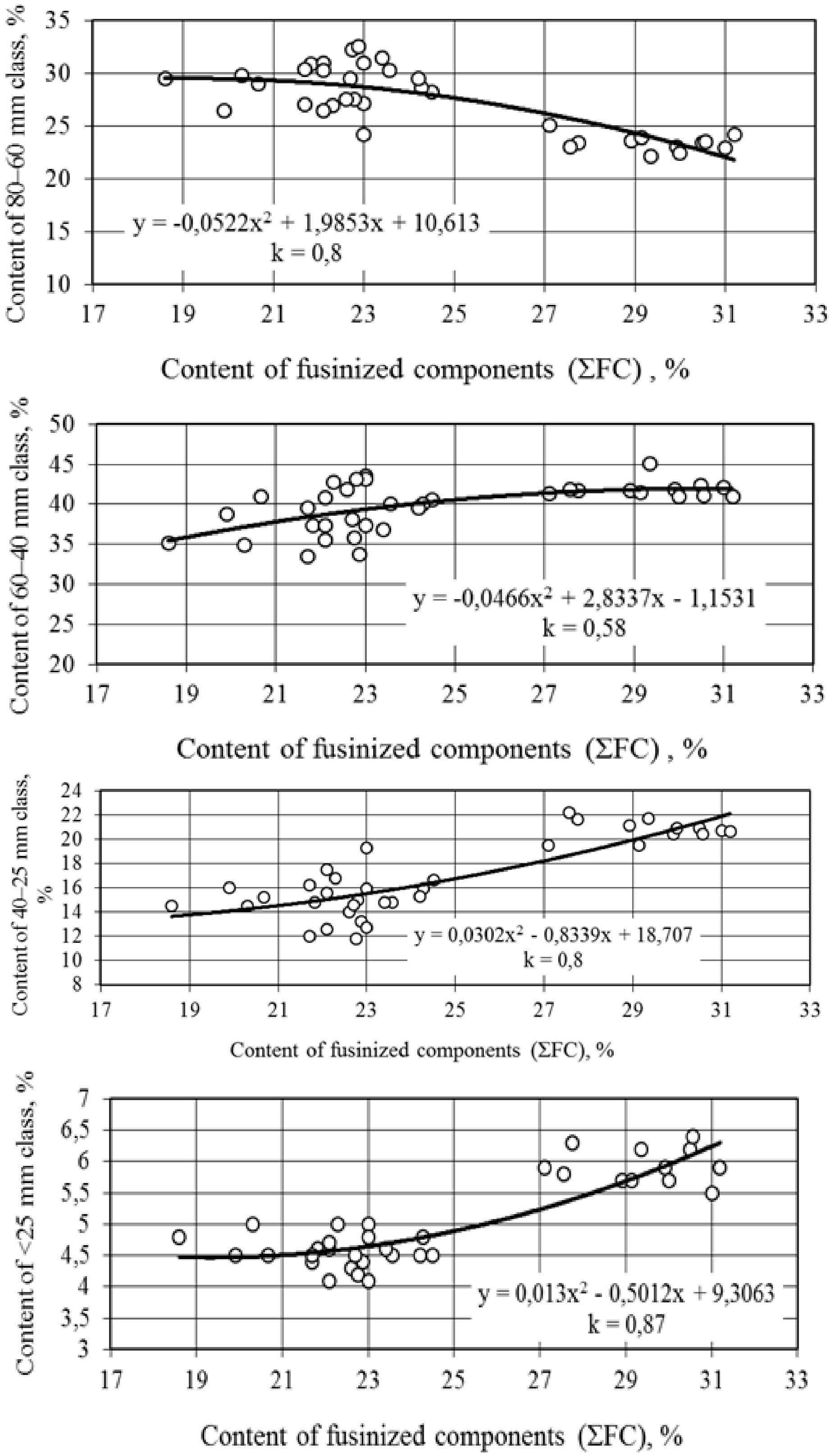


Fig.7. Dependence of the yield of the 80–60 mm (a), 60–40 mm (b), 40–25 mm (c), and <25 mm (d) classes on the content of fusinized components (ΣFC) in the coal batch at coke batteries 1–4 between 2010 and 2012

3. Conclusions

Analysis of the influence of raw materials and technological factors on the distribution of coke by size classes showed the following:

- reducing the humidity of the charge leads to a decrease in the size of coke, but the output of coke of different classes varies unevenly;
- the macerate composition of the coal batch also affects the size of coke. The closest relationship is established between the magnitude of the fusinized components Σ*FC* and the output of the coke fractions 80-60 mm (correlation coefficient r = 0,8), 40-25 mm (r = 0,8), <25 mm (r = 0,87). Thus, as the content of the fusinized components in the coal mixture increases, the coke size decreases, which is accompanied by an increase in the yield of fractions of 40-25 mm and <25 mm;
- when coal ash content is increased by 1%, there is a redistribution of the size classes, which is accompanied by an increase in the outputs of class> 80 mm by an average of 3.5% and a class <25 mm by 1.5% and a corresponding decrease in the outputs of the most valuable classes of 60-40 mm. and class 40-25 mm.
- increasing the uniformity and homogeneity of the granulometric composition of the coke can be obtained when optimal values of the packing density of the coal batch are achieved, which in turn is provided by the optimization of the granulometric composition of the batch, reducing humidity and ash content.

Symbols

M_{10}, M_{25} – indices of resistance of coke abrasion and crushability, respectively, %;
>80 mm, 80-60 mm, 60-40 mm, 40-25 mm, <25 mm – content of particles in coke accordingly, %;
R_0 – mean vitrinite reflection coefficient, %;
ΣFC – sum of fusinized components, %;
W^r_t – water content of the coal batch, %;
A^d – ash content of the coal batch in the dry state, %;
BD^r – packing density of the coal batch, t/m^3.

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