

# *Evaluation of the Coking Capacity Indicator of Coking Coal Concentrates Based on the Research of Non-volatile Residue Strength Via Determination of the Coking Chemical Products Yield*

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**Abstract –** In modern conditions, one of the most acute problems for the coking industry include deterioration of raw material base for coking and coking coal deficit. The negative impact of the deterioration of the raw material condition on the yield and quality of coking products can be compensated by the increase in the level of coal blending quality management, which is primarily based on the chemical and technological properties of coal. Therefore, for the analysis of the above parameters, it is necessary to make a full use of the potential of all available coal properties valuation techniques. In the course of this work, the quality indicators of coal concentrates of the Kuznetsk Basin were defined and the strength properties of non-volatile residue obtained in determining the yield of chemical products of coking were studied. Based on the analysis of the obtained results, the experimental dependences of the reviewed parameters were built.

**Keywords –** coal, volatile matters, chemical products of coking, non-volatile residue, non-volatile residue strength.

## I. INTRODUCTION

Currently, the issues of improving coke quality are of particular relevance due to lower specific coke consumption for iron smelting, increased volume of blast furnaces and the introduction of technological measures to intensify the blast furnace performance. The importance of these problems is further compounded by the deterioration of the coking raw material base due to the instability in the grade composition of the supplied coal and coal concentrates, and the inconsistency of their quality parameters [1] [2]. The negative effect of coal concentrate grade composition deterioration can be compensated by an increase in the level of coal blending quality management which is primarily based on the chemical and technological properties of raw materials [3] [4]. Therefore, a comprehensive study of coal used in the coking process is an urgent task.

## II. MATERIALS AND METHODS

In order to evaluate the coal concentrates coking indicators on the basis of the research of non-volatile residue strength via the determination of the chemical products yield in the coking, the researches were conducted in the facilities of the department of "Chemical technology of solid fuel" of the Institute of Chemical and Petroleum Technology of T. F. Gorbachev Kuzbass State Technical University together with the specialists of OAO "Koks" (Kemerovo) aimed at studying the yield of coking chemical products from the coal of the Kuznetsk basin. The studies were conducted at the installation for determination of the yield of coking chemical products according to GOST 18635-73 "Coals bituminous. Method for determining the yield of coking chemical products" [5]. This method is accurate, reproducible and correlates well with the technological indicators of the yield of coking chemical products [6] [7]. In the course of studies, the yield of the basic coking chemical products was determined: coke, tar, ammonia, total pyrogenetic moisture and water, hydrogen sulfide, carbon dioxide, unsaturated hydrocarbons, benzene and crude coke oven gas. However, according to this method, the coke residue produced during the experiment is not subject to further research.

Based on the analysis of the published data [8], we concluded that in order to determine the coal coking capacity one can use the method of evaluating the strength of non-volatile residue received after determination of the rheological properties of coal in accordance with GOST 1186-87 "Coal bituminous. Method for determination of plastometric indicators" [9]. Based on this technique, we have researched the strength properties of the non-volatile (coke) residue obtained in the determination of the coking chemical products yield.

It should be noted that the process of producing non-volatile residue was performed in a strictly regulated mode [5]. However, in contrast to the size of the sample used in the plastometric test of 1.6 mm, in in the study of the yield of

coking chemical products we used coals with the particle size of 0.2 mm.

The mechanical properties of non-volatile residue were investigated in accordance with the procedure described in [8] with the changes that take into account the nature of the method of its preparation. According to this technique, the resulting non-volatile residue was dissipated by size classes in the round sieves with 10 mm and 1mm diameters. Oversize 10 mm sieve product was weighed and subjected to mechanical testing in the drum (used when determining the sintering properties in accordance with GOST 9318-91 "Coal bituminous. Method for determination of Roga caking capacity" [8]. After the test, the sample was sieved by the 1 mm dia sieve. The weight ratio of the 1 mm screen undersize product to the mass loaded in the drum presents abrasion bead (IR).

TABLE I. Qualitative Characteristics Of Coal And Coke Residue For Determination Of The Yield Of Coking Chemical Products

Sample name	Grade	V <sup>daf</sup> , %	H <sub>ben</sub> , mm	y, mm	R <sub>o</sub> , %	V <sub>t</sub> , %	SIR	RI	Coke yield , %	IR, %	A <sup>d</sup> coke, %	V <sup>daf</sup> coke, %
CCPP* "Berezovskaya"(“Site”Koksovyy”)	K	21.0	39	13	1.267	54	5	45	83.9	5.8	-	-
CCPP "Berezovskaya" (open-pit mine “Sergeyevsky”)	K	24.0	94	13	1.044	54	5,5	50	79.56	3.6	-	-
CCPP "Berezovskaya"	KO+ KC	21.8	9	10	1.046	41	2	37	78.26	10.3	-	-
CCPP "Berezovskaya"	GZh+ KO	30.0	89	16	0.806	77	7	71	73.31	12	-	-
CCPP "Berezovskaya"	GZh+ KO+KC	29.5	68	15	0.807	75	4	68	73.67	6.2	-	-
CPP** "Mezhdurechenskaya"	OC	19.8	40	12	1.335	51	3	20	82.05	47.2	-	-
CPP “Antonovskaya”(1)	GZh	33.8	123	19	0.758	86	7.5	71	70.67	18.6	-	-
CPP “Antonovskaya”	GZh+Zh	34.0	132	24	0.79	89	8	76	72.11	25.8	-	-
CPP “Taybinskaya”	K	19.0	44	13	1.155	62	3.5	30	83.43	11.2	11.5	2.8
CPP “Taybinskaya”	OC	18.8	32	12	1.274	50	3	42	81.4	49.1	-	-
Open-pit mine “Site Koksovyy”	K	20.4	67	15	1.375	48	6	43	81.15	7.9	9.4	2.4
CPP “Severnaya”	K	24.2	37	13	1.064	58	3	45	78.44	5.5	11.1	1.8
CPP “Koksovaya”	K	18.0	44	14	1.434	58	4	41	83.25	9.2	9.5	2.3
Mine “Dzerzhinsky”	K	21.6	54	14	1.222	25	5	32	79.84	7.3	12.1	2.1
Open-pit mine “Apsatskiy”	K	26.1	92	17	1.144	64	6.5	65	77.28	13.9	13.1	2.2
Mine “Butovskaya”	KO	20.6	20	12	1.269	50	1	18	79.90	27.6	12.6	2.2
Mine “Anzhero-Yuzhnaya”	KO	15.0	7	11	1.311	13	1	16	85.36	34.1	10.8	2.5
Open-pit mine “Site Koksovyy”	KC	18.9	15	11	1.351	40	1	18	81.51	32.6	7.7	2.0
CPP “Abashevskaya”(1)	GZh	33.8	127	24	0.787	92	7.5	79	69.31	22.3	10.9	2.1
CPP “Abashevskaya”(2)	GZh	34.3	119	18	0.79	83	6.5	27	70.08	20.1	11.0	2.6
CPP “Raspadskaya”	GZh	34.2	121	20	0.853	89	7.5	82	72.23	35.8	11.5	2.2
Mine “Uskovskaya”	GZh	33.2	111	17	0.856	82	6.5	75	70.05	24.0	6.9	2.3
Mine “Tihova”	Zh	31.2	149	37	0.931	76	9	80	77.41	13.8	13.6	2.8
CCPP “Berezovskaya” (mine “Karagailly”)	Zh	31.4	134	24	0.828	78	9	78	72.80	32.8	13.6	2.4
CPP “Antonovskaya”(2)	GZh	37.8	122	19	0.821	86	6.5	-	68.49	20.1	12.6	2.5

\*CCPP -central coal preparation plant,

\*\* CPP – coal preparation plant.

After determining of the coking residue strength, its technical analysis was performed.

### III. RESULTS AND DISCUSSIONS

The results of the technical analysis of coke residue, its strength parameters, as well as the characteristics of raw coal, from which it was received are presented in Table 1.

The yield of non-volatile residue depends on the properties of the original coal, namely volatiles content determined for coke and bituminous coal in accordance with GOST6382-2001 at 900°C (Fig.1). From the analysis of presented dependence it can be concluded that with an increase in the yield of volatile substances in the coals the coke yield decreases [11-13].

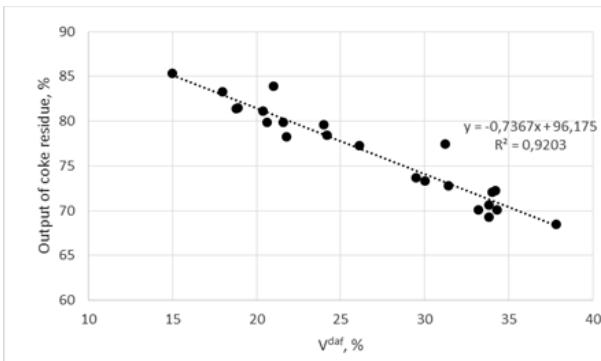


Fig. 1. The impact of the coal volatiles yield on coking residue yield

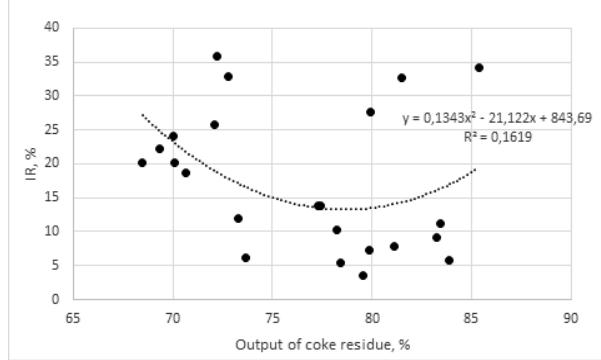


Fig. 2. The impact of non-volatile residue yield via determination of coking chemical products yield on the IR for the reviewed coals

The yield of non-volatile residue is an important parameter of coal quality assessment, which is confirmed by the schedule presented in Fig. 2. From the analysis of this dependence it can be concluded that the rate of abrasion of coal non-volatile residue is minimal at the yield of non-volatile residue of 75 – 81%. This corresponds to the yield of volatile matters  $V^{daf}$  equal to 27 – 37%, which indicates the optimum quality of coal concentrates at which the improvement of the strength properties of non-volatile residue is observed, which is consistent with the data presented for the coke residue after the determination of the rheological properties of coal in accordance with GOST 1186-87 [9].

The properties of any product in a greater or less extent are determined by the characteristics of the raw material from which it is obtained. The plastic layer formed when coal is heated, is a complex heterogeneous system. This system consists of organic macromolecules passing into the liquid state, solid organic or inorganic inclusions in the liquid phase, and the gases released during heating. Increasing the thickness of the plastic layer does not always mean an increase in the sintering ability and, especially, for the coking coal [8]. Fig. 3 shows the dependence of the strength of coke residue IR on the thickness of the plastic layer.

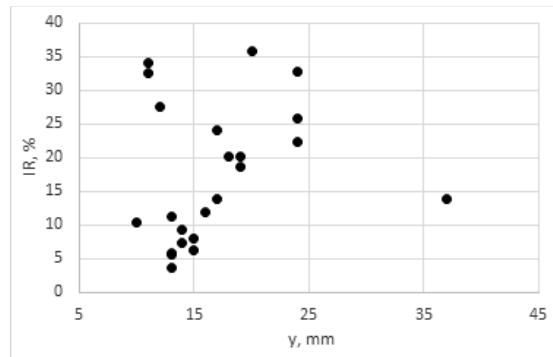


Fig. 3. Dependence of coke abrasion index on the plastic layer thickness

As can be seen from this graph, we have not achieved the correlation between these indicators. This may be due to the insufficient number of coal samples studied. However, the dependences were constructed between the coke residue abrasion index and Roga caking index (Figure 4), the crucible swelling index (Fig. 5) and swelling index in IGI-DMetI apparatus (Fig. 6), which showed good correlation between the parameters studied that proves once again that caking is a complex process, and a set of methods is required for its study [14-16].

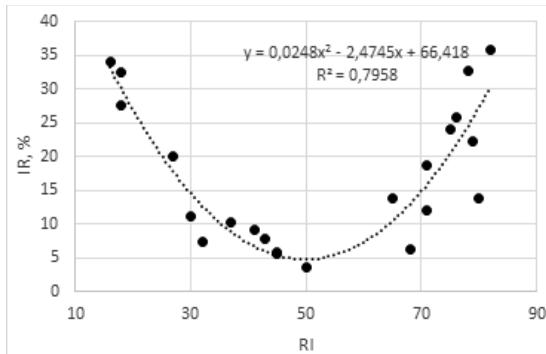


Fig. 4. Dependence of coke abrasion index on the Roga caking capacity

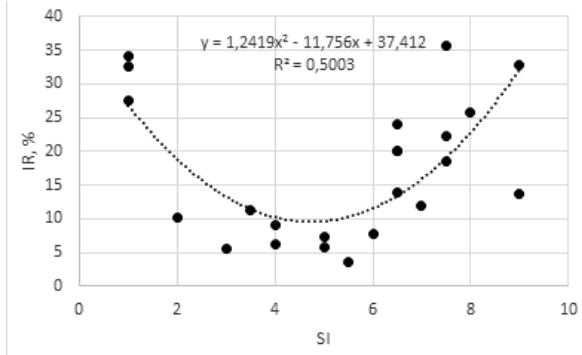


Fig. 5. Dependence of the coke residue abrasion on the swelling index in the crucible

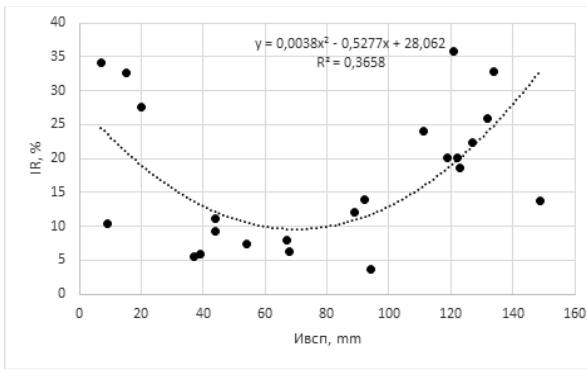


Fig. 6. Dependence coke residue abrasion on the swelling index in the device IGI-DmetI

According to the research data [8], the release of gases during the caking of beads contributes to the increase in its porosity and reduces the strength. The dependence of the non-volatile residue abrasion IR on  $V^{daf}$  is presented in Fig. 7.

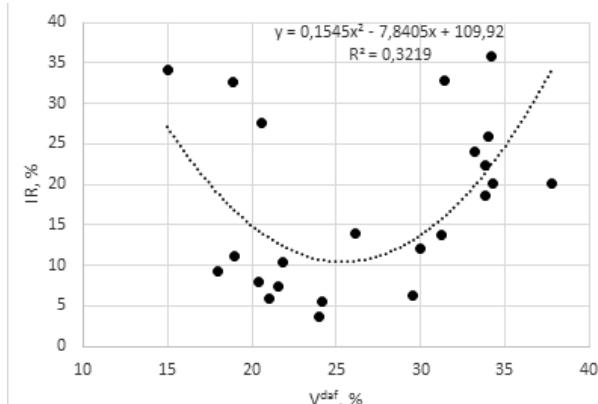


Fig. 7. Dependence coke residue abrasion on the volatiles yield

The best strength characteristics of the non-volatile residue are obtained at sufficient caking properties and the least possible yield of volatile matters. However, in most cases, due to the nature of coals, the volatiles yield and the caking parameters increase simultaneously. The exception is coals at the low stage of metamorphism [17-19]. The graph in Fig. 7 shows that with an increase in the yield of volatile matters to 25 %, there comes a decrease in IR (coal caking index increasing), and when  $V^{daf}$  is over 30 %, the mechanical properties deteriorate. In this range, typically, with the growth of volatiles the coals caking capacity decreases [8] [20] [21]. The findings are consistent with the research data [8] obtained for the coke residue after the determination of the rheological properties of coal in accordance with GOST 1186-87[9].

Also, the researchers [8][22] identified that in order to achieve good mechanical properties of the coke residue, the raw coals or their blend should have a vitrinite reflection index 1.0 - 1.1. The dependence presented in Fig. 8 of the non-volatile residue abrasion on the vitrinite reflection index of raw coal, or mixtures thereof, confirms the data received for determination of the yield of coke chemical products.

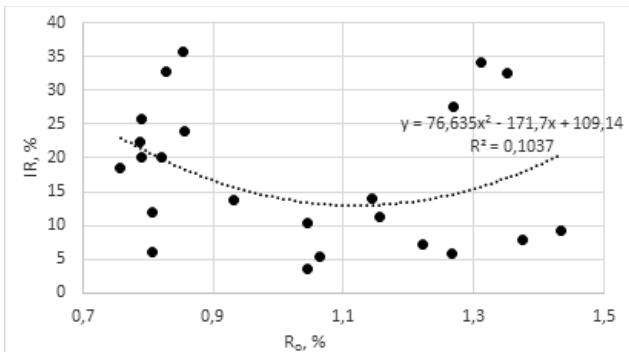


Fig. 8. Dependence of non-volatile residue abrasion via definition of coking chemical products yield on the vitrinite reflectance index

#### IV.CONCLUSION

The dependences of the strength of non-volatile residue in the definition of the yield of chemical products in coking on various factors (yield of volatile matters, reflectance index of vitrinite, the thickness of the plastic layer, the free swelling indicator in the crucible, the swelling index in the instrument IGR-DMetI, Roga caking index) that characterize the nature of the studied coals, are consistent with the correlations obtained by E.N. Stepanov, D.A. Mezin, I.V. Osipova [8] for the strength of the non-volatile residue in determination of plastometric indicators according to GOST 1186-87. Therefore, we can conclude that the proposed method based on an assessment of the quality of non-volatile residue of the yield of chemical products of coking, can be used for a preliminary assessment of the coke quality of the investigated coal concentrates.

Based on the above, the conclusion can be made that the evaluation of the coking index of coal concentrates on the basis of the research of the strength of non-volatile residue from determination of the yield of coking chemicals allows us to determine their technological value[23-25], to study coking capacity of pilot coal blends in order to find the optimal composition.

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