MASTERING OF FERROSILICON MANGANESE MELTING WITH HIGHLY REACTIVE REDUCING AGENT

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ABSTRACT

There has been a report of development and mastering of new type of special reducing agent at Yasinovsky Coking Plant, with the use in the burden for coking of highly reactive low-metamorphosed gas coal. The coke produced from the above mentioned coal preserves high reactivity from a genetic standpoint, as evidenced by investigation of its metallurgical properties and test melts of silicon manganese at Nikopol Ferroalloy Plant; however, manganese recovery into alloy is increased by 8-10% and specific power consumption is reduced by 70-170 kWh/t. In 2014, Nikopol Ferroalloy Plant consumed over 40 thousand tons of special highly reactive reducing agent produced by Yasinovsky Coking Plant.

When melting the ferroalloys in the electric furnaces, the completeness and kinetics of pivotal components recovery from ore materials into alloy, the structure of furnace work space, the speed of burden descent and, as a consequence, the main electrical characteristics of ferroalloy stage are mainly determined by the quality of used reducing agents **/ 1, 2 /.**

Note that, as shown in the paper **/ 2 /**, the intention of technicians – ferroalloy producers to maximize electrical resistance of the burden, when melting the alloys using continuous method, is explained by the need to reduce the fraction of burden conductivity current and increase the fraction of current passing through the electric arc – high-temperature heat source. Herein, the primary condition is that in the areas of low and moderate temperatures typical for upper levels of the furnace bath (top) the main types of burden materials (ores, fluxes) are actually electric insulators, the conductivity of which is lower in comparison with the used carbon reducing agents (the exception is metal chips used in the separate technological processes). In other words, it is possible to suppress undesirable processes relatable to the current passage through the burden and its overheating in the area of furnace top, first of all, by increase of specific electrical resistance (SER) of the reducing agent, as the most conductive burden component.

The development of target production of special coke with high reactivity and increased SER based on the coking of wet low-sintering burden is constrained by its low sintering limit. The investigations of Ukrainian State Research Institute of Coal Chemistry and Yasinovsky Coking Plant demonstrated that as much as 30% of deficient strongly coking coal of grade Zh in the coke burden is required to overcome the above described situation.

In 2006-2007, the investigations were carried out and the possibility to produce special types of coke for ferroalloy production from low-sintering high-volatile coal of low metamorphism stage was found at Yasinovsky Coking Plant, where the equipment and technology of preliminary thermal treatment of the burden are available. In such a case, the increase in coke battery productivity as compared to the wet burden can be up to 50% and more, and the efforts at the coke cake pushing from the furnace comply with regulatory ones.

As shown in our papers **/ 3, 4 /**, under the industrial conditions of Nikopol and Stakhanov Ferroalloy Plants, these special types of carbon reducing agents were used for production of silicon manganese and 65% of ferrosilicon instead of coke nut. However, these tests were of short-term nature (only three days at Nikopol Ferroalloy Plant) and needed processing within longer period of time.

In 1 half of 2013, a new, more representative batch of special reducing agent with the weight over 2 thousand tons was developed at Yasinovsky Coking Plant with subsequent shipment to Nikopol Ferroalloy Plant, where, after storing, it was prepared for melting according to the standard schedule applicable at the plant for preparation of screened coke.

The coke was delivered to the four-roll crusher and then to the screen with mesh of 10×10 mm. After screening, the undersize fraction of 10-0 mm was delivered for use as sinter fuel at the sinter shop of Nikopol Ferroalloy Plant, whereby the top size fraction (screened coke fraction of +10 mm) through the system of intermediate hoppers and conveyors was delivered to the furnace hoppers for proportioning.

The particle size distribution of standard coke nut supplied by various sellers, before its preparation at Nikopol Ferroalloy Plant (screening), is characterized as follows (averaged data): coke nut fines content (10-0 mm) is up to 6%, large-sized coke nut content (+25 mm) is up to 20%.

In accordance with the plant's process instruction, the composition of screened coke nut delivered to the melting shop shall meet the following requirements: 5-0 mm fraction content is max 15%; +25 mm fraction content is max 10%, i.e. the desired fraction (25-10 mm) content shall be at least 75%. Usually, as a result of screening, the fractional yield after sorting and screening is as follows: 5-0 mm fraction is 14%; 25-5 mm fraction is 86%.

The special coke produced by Yasinovsky Coking Plant and delivered to Nikopol Ferroalloy Plant, based on the incoming analysis data, was described by the following parameters: coke fines content (10-0 mm) is 2.9%; coke lump fraction (+25 mm) is 18.8%. After screening, the particle size distribution of special coke was characterized by the following data: 5-0 mm fraction content is 6-10%; +25 mm fraction content is up to 5%, which fully complies with the above described requirements outlined in the plant's process instruction.

After crushing and screening, the fractional yield during the special coke sorting was as follows: 5-0 mm fraction content is 14%, 25-5 mm fraction content is 86%, which conforms to the typical data as well.

When delivering the special coke to Nikopol Ferroalloy Plant (incoming control) and, subsequently, during the test campaign at the proportioning unit of the furnace No. 6, the samples of special coke were taken for chemical analysis and screening.

The results of special coke quality incoming control are presented in Table 1.

Thus, the data represented in Table 1 demonstrate that ash content in the special coke was 10.61%, average volatile content in special coke is 1.7%, sulphur content in the ash is 1.3%, and solid carbon content is 86.4%.

As reported by Nikopol Ferroalloy Plant, the average moisture content was 4.9%. However, as shown in Table 1, substantial variations in the special coke moisture were observed in some periods. This can be reasonably explained by the climatic conditions of Nikopol and Donetsk, when storing the coke at outdoor storage. The test melts showed that variations in the special coke moisture did not affect the parameters of its use during the ferrosilicon manganese melting at Nikopol Ferroalloy Plant.

Table 1. Quality of special coke produced by Yasinovsky Coking Plant based on the incoming control data of Nikopol Ferroalloy Plant

Batch No.	**Special coke**			**A,%**	**V,%**	**S,%**	**W,%**	**C_{solid},%**	**SER, Ohm·m**
	Batch No.	**Batch weight**	**Dry weight**						
1	K-18	167.35	153.46	11.30	2.00	1.30	8.30	85.40	1.624
2	K-19	169.30	154.06	11.80	2.10	1.20	9.00	84.90	1.739
3	K-35	87.20	78.83	10.30	1.60	1.40	9.60	86.70	1.200
4	K-42	334.40	313.67	11.10	1.80	1.40	6.20	85.70	1.596
5	K-46	305.65	292.51	11.40	2.00	1.30	4.30	85.30	1.774
6	K-47	230.05	214.87	10.10	1.60	1.30	6.60	87.00	1.189
7	K-48	45.90	43.61	11.30	2.00	1.30	5.00	85.40	1.370
8	K-49	275.60	266.51	9.90	1.70	1.30	3.30	87.10	0.935
9	K-54	172.85	167.84	9.80	1.60	1.20	2.90	87.40	1.115
10	K-66	248.50	243.03	10.10	1.20	1.30	2.20	87.40	1.242
11	K-73	131.75	129.12	10.50	1.30	1.30	2.00	86.90	1.137
12	K-76	156.35	152.75	10.10	1.70	1.30	2.30	86.90	1.041
13	K-91	180.00	172.26	10.50	1.60	1.30	4.30	86.60	1.168
Average value		**2 504.90**	**2 382.50**	**10.61**	**1.7**	**1.30**	**4.9**	**86.4**	**1.3396**

According to the data of screened coke particle size distribution determination on a shift basis it has been established that fines content (5-0 mm) in the reducing agent delivered to the furnace No. 6 was stably at the level of 5-10% (at maximum permitted value of 15%).

At Nikopol Ferroalloy Plant the ferrosilicon manganese was melted at the furnace No. 6, the parameters of which are presented in Table 2.

Table 2. Parameters of furnace No. 6 at Nikopol Ferroalloy Plant

Parameter designation	**Parameter value**
Type of furnace	RPZ-63I1
Design features	Ore-smelting, sealed furnace with stationary rectangular bath and transformer installed capacity of 63 MV·A
Transformers, pcs.	3
Nominal capacity of 1 transformer, kV·A	21000
Primary voltage, kV	154
Secondary voltage, V	238-130
Number of transformer stages, pcs.	33
Maximal electrode current, kA	119.2
Electrodes, pcs.	6
Electrode type	Self-sintering, of rectangular cross-section
Electrode dimensions in section, mm	750 x 3000
Distance between electrodes axes, mm	3600
Melting chamber dimensions, mm	
length	23000
width	8200
height	4500
Electrode movement speed, mm/min	300-600
Maximal electrode travel, mm	1200
Tap-hole height under the hearth, mm	500
Tap-holes, pcs.	3
Tap-hole diameter, mm	105

The actual power utilization of the furnace No. 6 in 2013 is characterized by the following data: 33.13 MV in May (preceding period), 32.73 MV in June (test period), 33.76 MV in July (test period), and 33.88 MV in August (after test campaign completion). Thus, during the test period the actual power utilization of the furnace No. 6 more or less met the standard parameters given as a norm (hereinafter referred to as the basic parameters).

During investigations in the test period, as in the basic period, the production program of the furnace No. 6 supposed melting of ferrosilicon manganese with phosphorus content of 0.25%.

Accordingly, the burden composition was calculated with provision for alloy production with phosphorus content of 0.25%, which was achieved with the use of imported ore and charge slag from high-carbon ferromanganese melting in the burden. The chemical composition of raw materials is presented in Table 3.

Table 3. Chemical composition of manganese and ore raw materials during ferrosilicon manganese melting at Nikopol Ferroalloy Plant with the use of special coke

Type of raw materials	**Composition of components, % wt**							
	Mn	**SiO_2**	**CaO**	**MgO**	**Al_2O_3**	**Fe**	**P**	**$W_{moist.}$**
Sinter AMNV-2P	38.1	21.2	8.9	5.5	–	2.3	0.11	–
Ore (RSA), KK37	37.2	6.3	15.8	3.3	0.7	6.6	0.023	3.4
Ore (RSA), KK42T	43.4	4.9	7.3	1.1	0.6	13.4	0.039	1.8
Ore (Australia), KK49NZh	52.6	6.8	1.0	0.9	0.9	3.2	0.032	3.0
Ore (Ghana), MK28	28.5	12.8	6.5	4.6	2.2	1.3	0.067	2.8

It should be noted that composition of ore burden was dramatically changed for a variety of organizational reasons (availability and supply of imported raw materials) during the test campaign. Thus, when baking manganese sinter AMNV-2, in the beginning and in the middle of campaign various types of raw materials (Table 4) were used, which affected stability of its quality indicators.

The analysis reveals that it is reasonable to examine three separate sub-campaigns with regard to ore materials used in that period, considering changes in the types and quantities of the used raw materials (both sinter and directly in the furnace burden):

Sub-campaign 1: Manganese sinter AMNV-2P and ore from Republic of South Africa KK37 and of Republic of South Africa KK42;

Sub-campaign 2: Manganese sinter AMNV-2P together with greater (as compared to the sib-campaign 1) weighed portion of ore from Republic of South Africa KK37 and additional charging of iron ore;

Sub-campaign 3: Manganese sinter AMNV-2P and imported ore – Australia KK49NZh and Ghana MK28.

Table 4. Composition of ore sinter burden for baking of sinter AMNV-2, %

Designation of raw materials	Campaign opening (by 02.07)	Campaign closing (by 02.07)
Ore from Ghana (28% Mn)	69.2	64.4
Concentrate, 2 grades, Ordzhonikidze Mining and Processing Enterprise (34% Mn)	13.3	10.6
Ore from Gabon (47% Mn)	9.7	-
Ore from Brazil (49% Mn)	-	15.5
Grade PShM	7.8	9.5

Another point to be made here is that significant quantity of secondary materials (grades SShMS, VMS and SGM) was charged during the first sub-campaign.

The ratio of reducing agent, ore components and quartzite in the test period was calculated to maintain C_{solid}/Mn = 0.44-0.47 and SiO_2/Mn = 0.95-1.0 in the charged burden. However, in accordance with the technology adopted at Nikopol Ferroalloy Plant, 15% of the inserted solid carbon was provided with the use of anthracite in the burden and 85% owing to the special coke.

The parameters of furnace operation during the test period in respect of the above described sub-campaigns 1-3 are presented in Table 5; the parameters of test campaign are integrally presented in Fig. 1.

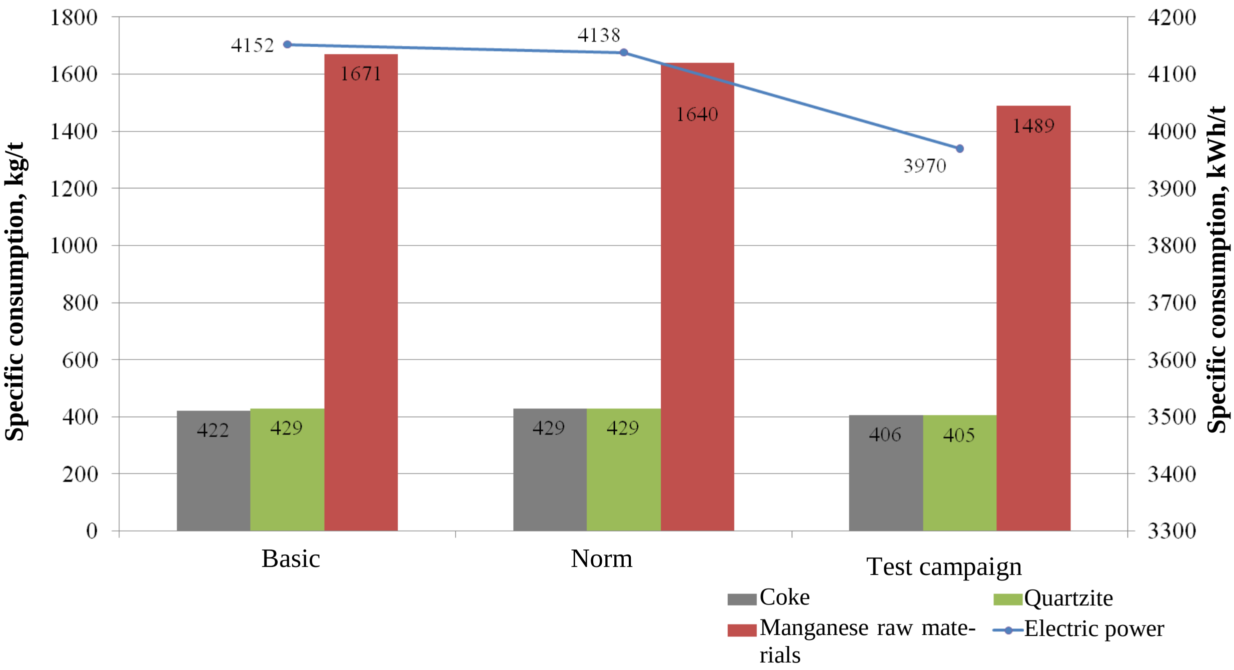

Fig. 1. Consumption of burden materials and electric power per melting of 1 basic ton of SiMn during the test period as compared to the basic period and norm (consumption of manganese raw materials is expressed in terms of basic raw materials, 48%Mn)

The furnace operation with the use of special reducing agent during the test period, as a whole and for individual sub-campaigns, is characterized by stable gas and electric conditions, satisfactory tapping and lack of troubles with tap-hole assembly maintenance. The electrode slipping conditions were also near-optimal; during the campaign, the electrodes were slipped uniformly (by all phases) and the slipping was 31 mm per 100 thousand kWh of electric power take-off.

Table 5. Process parameters of ferrosilicon manganese melting with the use of special coke (by Yasinovsky Coking Plant) as reducing agent

Sub-campaign No.	**Furnace capacity, basic tons/days**	**Specific power consumption, kWh/basic tons**	**Content in alloy, %**			**Mn content in slag, %**	**Slag ratio, units**
			Mn	Si	P		
1	200.53	3987	71.30	17.63	0.22	11.22	1.44
2	202.10	3972	67.33	18.25	0.19	12.40	1.35
3	194.20	3934	72.66	18.40	0.20	13.50	1.42

Actual manganese and silicon content in the finished ferroalloy met the requirements set out in DSTU 3548-97 (DSTU 3548-97. Ferrosilicon manganese. General Specifications).

However, during the second sub-campaign, relatively low (but within the norm prescribed by the plant's process instruction) manganese content of 35.16% was observed in the ore burden. This was attributed to the iron ore addition in the burden (Fig. 2).

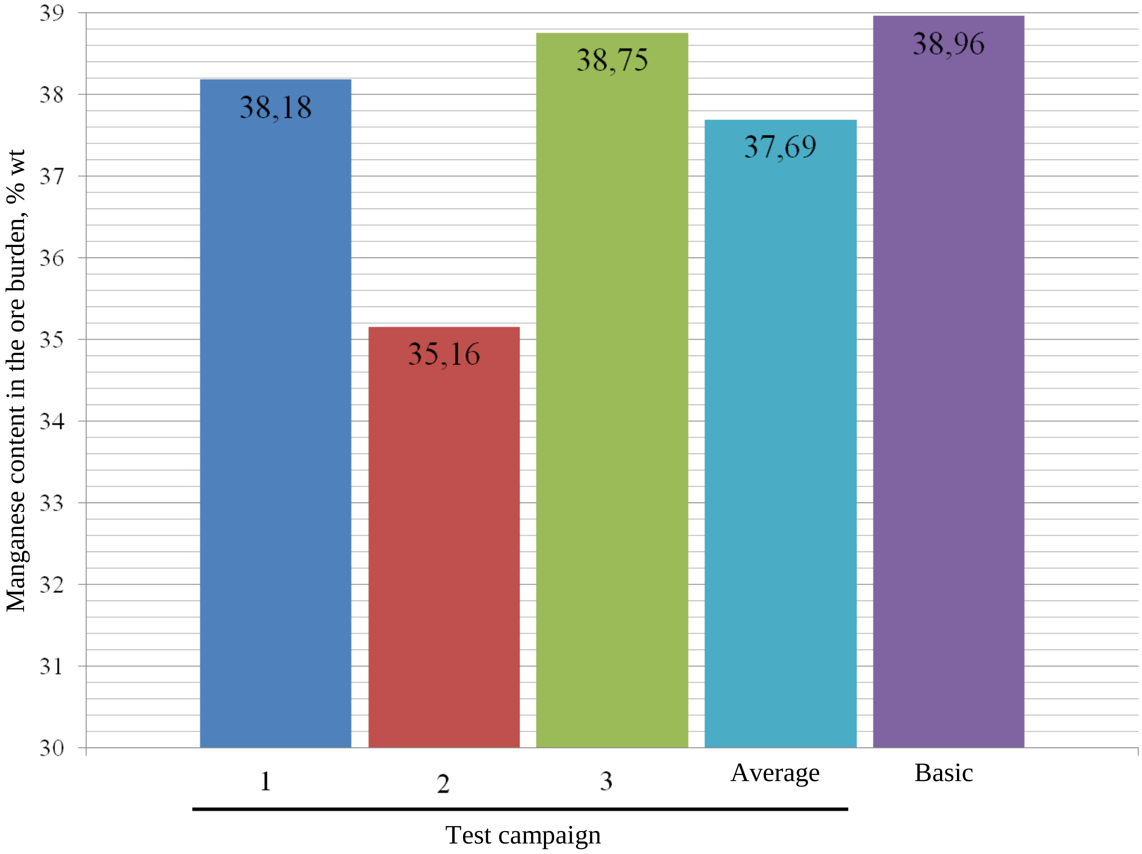

Fig. 2. Manganese content (% wt) in the ore burden during the test and basic periods

At the same time, well-known positive influence of iron on completeness and kinetics of manganese oxides reduction and decrease in manganese activity in alloy at its iron dilution was largely responsible for the fact that manganese content in alloy was 67.33% in the sub-campaign 2 as compared to 71-72% of manganese in the sub-campaigns 2 and 3, manganese recovery was increases and slag ratio was reduced to 1.35 as compared to 1.42-1.44 (Fig. 3.).

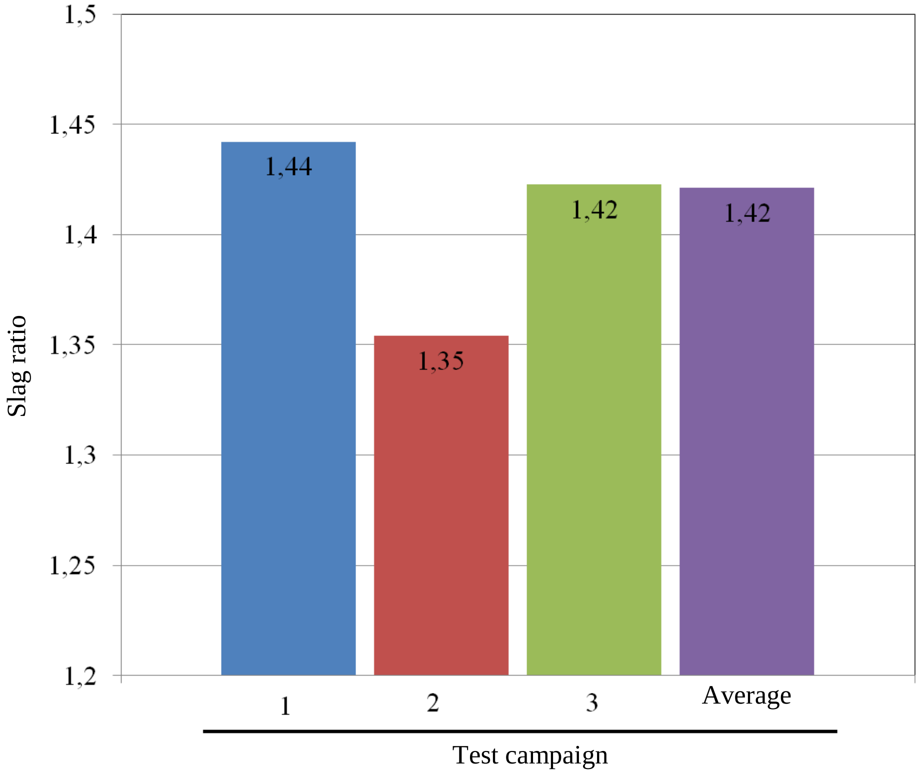

Fig. 3. Slag ratio in the sub-campaigns Nos. 1-3 of silicon manganese melting test campaign and average weighted slag ratio over the entire campaign

During the test campaign (Fig. 1), actual reduction of manganese raw materials (by 10.9%) and electric power (by 4.4%) was generally observed as compared to the basic parameters; and in the first sub-campaign the decrease in reducing agent consumption by 8.3% occurred.

Actual reduction of specific power consumption during the test period as compared to the basic period (the norm) was 168 kWh/basic ton, and actual specific consumption of manganese raw materials, coke and quartzite was decreased by 32; 21.2 and 23.9 kg/basic ton respectively. Manganese recovery during the test campaign was increased by 7.42% (from 83.7% to 91.12%).

In total, 5.603 thousand tons of ferrosilicon manganese was melted within 28 days (from 12 June till 10 July 2013) during the test campaign carried out at Nikopol Ferroalloy Plant.

Moreover, the difference in quantity of used metalized waste during the basic (norm) and test periods (extra 84 kg of waste/basic ton) required the adjustments of actual parameters, considering this factor. In addition, the above described difference in manganese content in the ore burden required the adjustments as well.

As shown in the paper **/ 5 /**, technical and economic parameters of ferrosilicon manganese melting significantly depend on this factor: when manganese content is increased by 1% in the ore burden, manganese recovery into alloy grows by 0.7%, electric power consumption is reduced by 50 kWh/t and furnace capacity is increased by 13 basic tons/day.

In our case, as shown above, manganese content in the ore burden was changed in the sub-campaigns during the test period and differed from basic value (Fig. 2). The average weighted manganese content in the ore burden during the test period was 37.69% as compared to 38.96% in the basic period (according to the calculated norms).

It is easy to calculate that difference in the specific power consumption of 63.5 kWh/basic tons, consumption of raw materials of 12 kg/basic tons and manganese recovery of 0.9% conforms to the difference of 1.27% in manganese content in the ore burden.

The changes in technical and economic parameters (TEP) adjusted on the basis of these data, considering actual manganese content in the ore burden and use of metalized waste, are represented in Table 6.

Table 6. Adjusted TEP of ferrosilicon manganese melting with the use of special reducing agent at Nikopol Ferroalloy Plant (shown by manganese content in the ore burden and waste utilization).

Parameter designation	Norm (basic period)	Actual test period	Calculated test period (considering manganese content in the burden and waste utilization)	Deviation from basic data by calculated parameters
Consumption per 1 basic ton				
- of manganese raw materials (48% Mn), kg	1640	1608	1612	- 28
- of coke, kg	429	419	424	- 5
- of quartzite, kg	429	425	425	- 4
- of electric power, kWh/basic ton	4138	3970	4070	- 68
- manganese recovery into alloy, %	83.7	91.1	92.0	+ 8.3

Thus, as shown in Table 6, based on the adjusted data, the reduction of specific power consumption with the use of special coke was 68 kWh/basic ton and manganese recovery into alloy was increased by 8.3% with proportional consumption reduction of manganese raw materials, coke and quartzite.

The calculations (based on the adjusted data) demonstrated that economic effect from the use of special coke per 1 basic ton of silicon manganese is 92 UAH and in equivalent of 1 ton of special reducing agent produced by Yasinovsky Coking Plant, possible saving will be 257 UAH.

SUMMARY:

The production of new type of special reducing agent for ferroalloy manufacture has been mastered at Yasinovsky Coking Plant, with the use in the burden for coking of highly reactive low-metamorphosed gas coal. It has been demonstrated that coke produced from the above mentioned coal preserves high reactivity from a genetic standpoint, as evidenced by investigation of its metallurgical properties and test melts of silicon manganese at Nikopol Ferroalloy Plant.

As shown by the test melts (2013) of silicon manganese in the furnace No. 6 at Nikopol Ferroalloy Plant, when using special coke, manganese recovery into alloy was increased by 8-10% and specific power consumption was reduced by 70-170 kWh/t.

In 2014, Nikopol Ferroalloy Plant used over 40 thousand tons of special highly reactive reducing agent produced by Yasinovsky Coking Plant, which replaced about 20% of coke nut consumed at Nikopol Ferroalloy Plant. The volume of test reducing agent utilization, in opinion of the plant's technological departments, could be considerably larger (up to 100% of standard coke nut replacement with it), but was limited only and exclusively by the possibilities of the supplier located in the east of Ukraine and experiencing difficulties with deliveries of coal for coking since the middle of last year. After recovery of Yasinovsky Coking Plant operation (the plant was almost completely shutdown in January 2015), it is assumed to continue implementation of the program on special reducing agent production for ferroalloy manufacture.

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