A study of the process of smelting ferrosilicon manganese with the use of high ash rock coals as a reducer instead of traditional coke was carried out. The physicochemical properties of coke from high-ash coals of the Kuu-chek deposit have been studied. The fundamental possibility of its application for the production of standard ferrosilicon manganese in large-scale laboratory conditions has been shown.

**Keywords:** melting, ferrosilicon manganese, ore thermal furnace, coke, reducing

**INTRODUCTION**

Currently, ways of using of various carbonaceous reducing agents for the electrothermy of ferroalloys is known [1 - 5]. However, the reducing agents that are used in the production of ferroalloys are either unstable in their physicochemical properties and therefore do not satisfy the specifics of the process, or are limited in terms of production. Typically, ferroalloy factories cover their needs for reducing agents at the expense of scarce blast furnace coke and the waste generated during its sorting. One of these wastes is coke nut, which is the main type of carbonaceous reducing agent used in the production of ferroalloys.

Nevertheless, the one and the other, possessing high mechanical strength, have low reactivity and electrical resistivity. The results of numerous studies and factory practice indicate that when smelting ferroalloys in electric furnaces, especially silicon ferroalloys, the course of the technological process differs significantly when using different carbon-reducing agents, even with the same carbon content in them.

This is due to the variety of properties of carbon materials, on the one hand, and the complexity and specificity of the reduction process in the production of various alloys, on the other. Kazakhstan has large reserves of mineral raw materials, in particular, manganese ores and coal, as well as the necessary production capacities [6,7]. Thus, the purpose of this work was to research on the use of high-ash coke from coal from the Kuu-chek deposit instead of coke nut for ferrosilicon manganese smelting.

**RESEARCH METHODOLOGY**

The high-ash coals of the Kuu-Chek deposit are poorly sintered. Coal coking was carried out in a laboratory shaft furnace with a volume of 0.04 m³ by the thermal-oxidative pyrolysis method [2,8]. The process of obtaining coke proceeded in the autothermal mode, in which high-speed thermal-oxidative treatment of the coal charge was provided, due to selective combustion in a layer of volatile substances. The duration of coking depended on the height of the coal charge, this in a laboratory installation reached 400 - 600 mm. In this case, in contrast to layer coking, a charge consisting of fractionated coal with a particle size of 40 - 60 mm is subjected to thermal-oxidative pyrolysis, and the initial coal size is practically preserved in the resulting coke, which, as a rule, has a higher reactivity with sufficiently high lump strength indicators. Switch over to coking mode in the laboratory installation is consisted in a gradual rise in temperature in the coal bed to 900 - 1 000 °C due to the heat from the combustion of volatile substances. An experimental 600 kg of coke batch was produced.

To assess the behavior of high-ash coke under conditions of ferrosilicon manganese electric smelting, large-scale laboratory tests were carried out in an “RKO-0.2 MVA” ore-thermal furnace. This is a single-phase ore thermal furnace with a transformer capacity of 0.2 MVA. The furnace is designed to simulate the processes of ore electrothermia. Two transformers in the furnace with 100 kVA capacity are connected in parallel, provide a power of 200 kVA at a maximum voltage of 49,0 V and a current load of up to 4 000 A. The electric furnace is equipped with four stages of secondary voltage regulation - from 18, 24, 36 and 49 V. Arc discharge temperature 2 500 - 4 500 °C. The furnace has two electrodes with a diameter of 150 mm, and the lower electrode is rigidly coked in a hearth made of a conductive packing. The upper electrode is fixed in a copper contact jaw placed on a current-insulated suspension. Moving the electrode in the vertical plane is done manually. The electrical mode is monitored through an ammeter connected to the high side of the furnace transformer. The furnace bath is stationary and has one tap-hole equipped with a graphite tap-hole block. The furnace is of the open type and is equipped with an exhaust
hood located at a height of 700 mm from the upper cut of the furnace body. The process gas removal system is equipped with a cyclone and a bag filter for dust collection. The surface of the hearth is inclined at an angle of 5°-7° in the direction of the tap hole, which facilitates the exit of metal from the recovery zone. For opening and piercing the taphole, a piercing system with a graphite electrode 30 mm of diameter was installed. The lining of the furnace is made of refractory bricks. Clay plugs are used to close the tap hole. Melting in the furnace is carried out continuously, with periodic loading of charge materials as they are melted. The release of smelting products is periodic, every 2 hours.

RESULTS RESEARCH

To determine the physicochemical properties and strength characteristics of Kuu-check coke, a general representative sample weighing 40 kg was taken from the batch produced in accordance with GOST 23083-78. The granulometric composition of the finished coke was determined by sieving into four fractions. They are 0 - 5, 5 - 10, 10 - 25 and 25 - 40 mm. The results of the granulometric analysis of coke are presented in Table 1. Technical analysis of coke ash by fractions (25 - 40, 10 - 25, 5 - 10 and 5 - 40 mm) are shown in Table 2.

Chemical analysis of the average fraction ash 5 - 40 mm coke / %: SiO₂ - 62,01; Al₂O₃ - 22,32; CaO - 6,12; MgO - 0,62; Fe_{total} - 6,18; S - 0,23; P - 0,02. The reactivity of coke and its strength after the reaction is determined according to GOST P 54250-2010 (ISO 18894:2006). The coke reactivity index CRI / % by weight is 26 %. The coke strength after the CSR reaction is 43 %. The strength of the coke body (structural) was assessed by the yield of + 1 mm class, formed in a steel cylinder with a volume of 50 cm³ from coke of 3 - 6 mm class according to GOST 9521-74. The strength of the coke body is high, 86 %. The porosity of the coke was established according to GOST 10220-82. The porosity is amounted 33 %. The porosity of the coke was established according to GOST 10220-82. The porosity is amounted 33 %.

The composition of the charge was / kg: Esymzhal ore – 9,0; Bogach ore – 8,0; Arman ore – 2,0; coke Kuu-check – 5,4; lime – 1,8; quartzite – 1,2. This composition of the charge was subject to correction based on analyzes of the slag and metal to achieve the optimal basicity of the slag in (CaO + MgO) / SiO₂, at the level of 0,6. According to the known practical data [9], this basicity creates favorable conditions for the reduction of manganese and provides sufficient fluidity of the slag to exit the furnace. It should be noted that the high ash content of Kuu-check coke is more than 30 % and the ash content of over 60 % of silica can significantly reduce the specific consumption of quartzite, which can be up to 400 kg / t of metal [9]. During a stable period, all indicators (current load, electrode fit, top temperature and condition, charge descent, metal and slag temperature, etc.) of the furnace were within the normal range for this process. The oven was running stably, with no signs of deviations from normal operation.

The furnace productivity in this period was close to the calculated one and averaged 4,8 kg / hour or 9,6 kg per outlet. Slag multiplicity slightly exceeded the calculated value and averaged 1,05. If at the initial stage the average content of manganese and silicon was 53 % and 11 %, respectively, then within the stable period these indicators reached 69 % and 18 %, respectively, which fully meets the requirements of GOST 4756-91 for grade MnSi17.

The main indicators of the pilot campaign are shown in Table 4. The productivity of the furnace, the specific consumption of raw materials, the quality of the metal, achieved using Kuu-check coke as a reducing agent, are not inferior to the parameters of industrial furnaces. The extraction rates of manganese and silicon were 87,2 % and 38,9 %, respectively. This exceeds the known practical data.

CONCLUSION

Coke Kuu-check has a satisfactory technical and chemical composition. In terms of particle size distribu-

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**Table 1** Granulometric composition of Kuu-Chek coke

<table>
<thead>
<tr>
<th>Fractions / mm</th>
<th>25 - 40</th>
<th>10 - 25</th>
<th>5 - 10</th>
<th>0 - 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output / %</td>
<td>23,06</td>
<td>69,64</td>
<td>5,24</td>
<td>2,06</td>
</tr>
</tbody>
</table>

**Table 2** Technical analysis of coke by fractions

<table>
<thead>
<tr>
<th>Fractions / mm</th>
<th>W (moisture)</th>
<th>A (ash)</th>
<th>V (volatile matter yield)</th>
<th>Cs (solid carbon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 - 40</td>
<td>1,27</td>
<td>32,23</td>
<td>1,28</td>
<td>65,11</td>
</tr>
<tr>
<td>10 - 25</td>
<td>1,41</td>
<td>32,16</td>
<td>1,05</td>
<td>65,38</td>
</tr>
<tr>
<td>5 - 10</td>
<td>1,34</td>
<td>45,35</td>
<td>2,26</td>
<td>41,05</td>
</tr>
<tr>
<td>5 - 40</td>
<td>1,35</td>
<td>33,90</td>
<td>1,32</td>
<td>63,42</td>
</tr>
</tbody>
</table>
tion and mechanical strength indicators, coke is a high-quality carbonaceous material for smelting ferrosilicon manganese and fully meets the requirements for reducing agents in ferroalloy production. High-ash coke Kuu-cheek has a high electrical resistivity and contributes to the improvement of the furnace stroke, deep electrode fit, and high extraction of leading elements. Ash of Kuu-cheek coke contains more than 60 % silicon dioxide, which is a positive sign of this material, as it allows to reduce the consumption of quartzite used in industrial smelting of ferrosilicon manganese. The alumina content of more than 20 % in coke ash leads to increasing in the temperature of the slag formation on-set and the formation of relatively refractory alumina slags. This will lead to an increase in the temperature of the process. This favors the intensification of the electrothermal process of smelting ferrosilicon manganese.

As a result of large-scale laboratory tests a pilot batch of ferrosilicon manganese was obtained. The slag ratio was 1.05. The chemical composition of the metal / %: Mn - 69.59; Si - 18.09; Fe - 0.11; S - 0.018; C - 2.2. This composition corresponds to ferrosilicon manganese grade MnSi17 in accordance with GOST 4756-91. The extraction rates of manganese and silicon were 87.2 % and 38.9 %, respectively.

Thus, according to the results of the provided studies, the fundamental possibility of using Kuu-cheek high-ash coke for smelting ferrosilicon manganese was shown.

REFERENCES


Note: The responsible translator for English language is Nataliya Drag, Karaganda, Kazakhstan