

# Development of a new scheme for the use of heat in the process of dry quenching coke in order to save energy

I S Gordeeva and E G Neshporenko

<sup>1</sup>Department of Electric Power Engineering and Automation, Nosov Magnitogorsk State Technical University, Lenin St., 38, Magnitogorsk, 455000, Russia

E-mail: 5otl@mail.ru, neshporenkoeg@mail.ru

**Abstract.** The process of efficient use of the heat of red-hot coke in order to obtain the annealed concentrate of siderite ore in the coke dry quenching plant, with the allocation of the zone of preliminary technological heat treatment (ZPTO) of siderite ore, is proposed and investigated. Thermodynamic analysis was carried out, in which the shares of heat of incandescent coke consumed for the implementation of the processes of heating and decomposition of  $\text{FeCO}_3\text{MgCO}_3$  with the processes of the bell-Boudoir reaction at 490°C and 650°C, respectively, were determined. The thermodynamic analysis resulted in the construction of a temperature-thermal graph of carbon monoxide cooling in the preheating zone, the heat of which is used to preheat the material to the decomposition temperature of 490°C and a graph of coke cooling in the main zone of material processing (ZMTO) - the zone of the forkamera of the coke dry quenching plant. A comparative table of the mass flow rates of coke and sideriteplezite ore is presented.

## 1. Introduction

The heat of hot coke is a valuable high-potential secondary energy resource.

The use and utilization of hot coke heat is an actual task of coke chemical enterprises from the point of view of both energy saving and environmental protection [1-7].

Efficient use of secondary energy resources allows to replace purchased fuel energy resources, which significantly reduces the energy intensity and cost of production.

For example, the current method of dry quenching in modern coke dry quenching plants, in which coke is cooled by gases, allows to utilize 80 % of the heat carried away by coke from the furnaces, or 40 % of the total heat spent on coking, while, from one ton of extinguished coke, it is possible to obtain 400-500 kg of steam of high energy parameters [8, 9]. Coke, extinguished in this way, is characterized by high strength and less cracking, compared with the wet method of extinguishing it.

Studies have previously determined that it is expedient to allocate a high-temperature area in the dry coke quenching plant, in which it is possible to carry out thermal treatment of various solid process materials [10, 11].

The aim of the work is to find and apply the most effective process of using the heat of hot coke, with the use of sideritoplesite ore in the high-temperature area of the coke dry quenching plant (CDQP), with the possibility of obtaining a larger amount of fired concentrate of siderite ore, which is valuable in the conditions of modern industrial production.



## 2. Materials and Methods

For this purpose, in the thermal scheme it was expedient to allocate a new preliminary area, with the delimitation of the zones of the main and preliminary heat treatment of the process material.

As a source of heat in the preliminary zone, carbon monoxide released from the main high-temperature region was considered at its initial temperature of 1200°C.

The analysis was performed for thermodynamically ideal conditions and processes. Calculations have established that for the full heat treatment of 1 kg of sideritoplesite ore on the heat of hot coke only in the high-temperature region, when it is cooled from 1200°C to 740°C, about 2325 kJ/kg of ore is consumed, while the composition of sideritoplesite ore with a fraction of  $\text{FeCO}_3$  and  $\text{MgCO}_3$  of 73.36% and 22.8%, respectively, was taken into account [5].

Heat consumption of sideritoplesite ore in high temperature area of coke dry quenching plant

$$m_k \cdot \int_{740}^{1200} c_k(t) dt = \sum_{i=1}^n Q_i \quad (1)$$

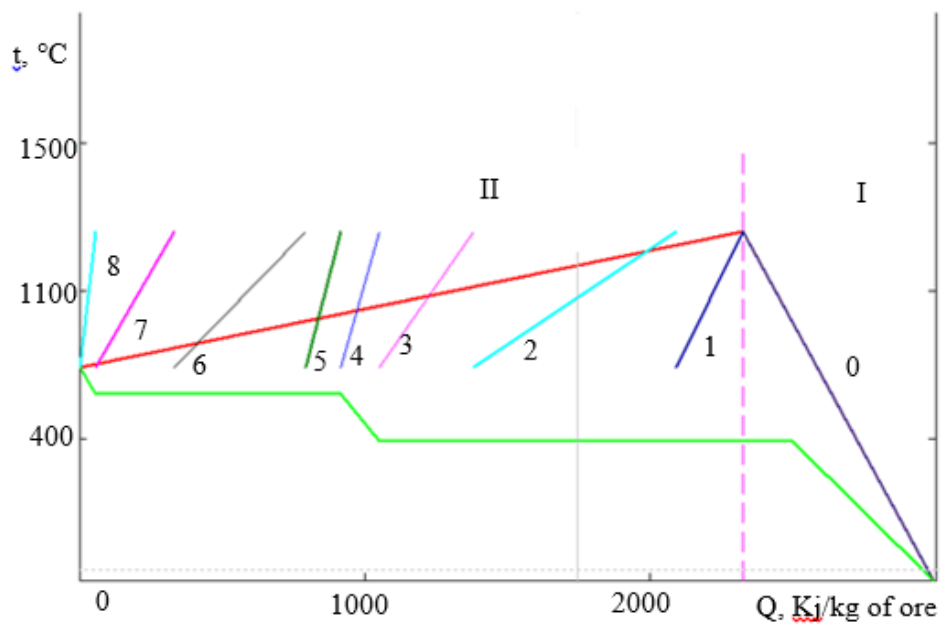
where  $i=1,2,\dots,n$  -the number of elementary areas of heat consumption during the heat treatment of siderite ore in the decomposition processes of  $\text{FeCO}_3$  and  $\text{MgCO}_3$ , ore heating from 490°C to 650°C, bell-Boudoir reactions at 490°C [13-15] and 650°C [13-15] and ore overheating from 650°C to 740°C.

In the study of thermal treatment of siderite ore, it was revealed that in the decomposition of iron carbonate and magnesium carbonate at 490°C and 650°C, about 0.153 m<sup>3</sup> of carbon dioxide is released, followed by their reduction to CO, when interacting with coke carbon by the bell-Boudoir reaction equation, in the volume of 0.307 m<sup>3</sup>/kg of ore at a temperature of 1200°C, the temperature potential of which is used for preheating siderite ore.

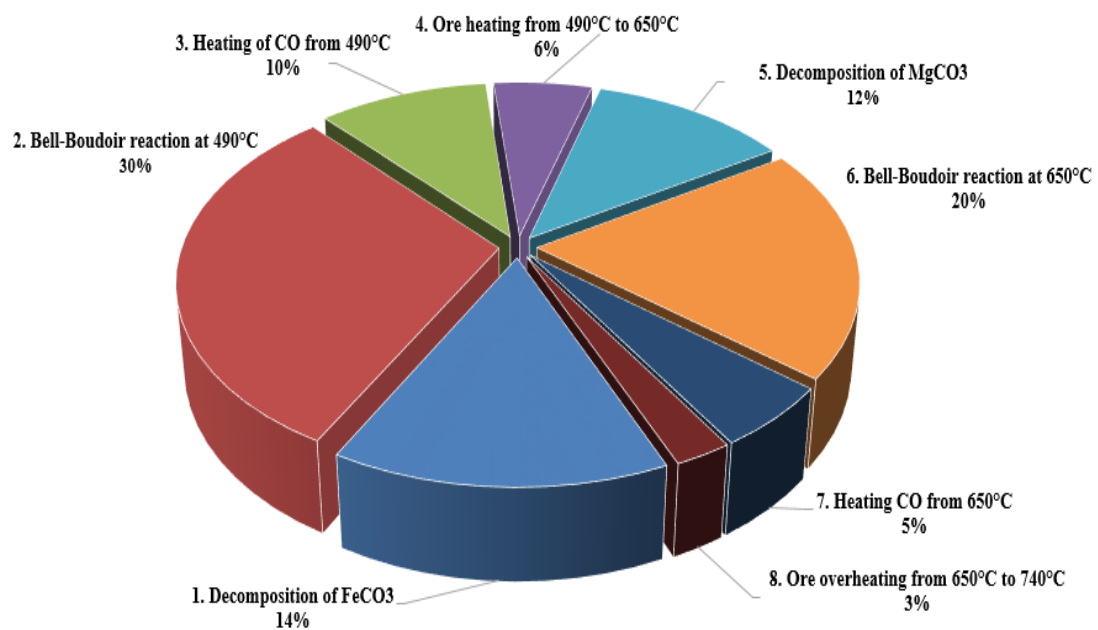
For a more complete visualization of heat consumption in the process of heat treatment of the material in the zones of preliminary and primary technological operations, a temperature-thermal diagram of the cooling of hot coke and heating of 1 kg of ore was constructed, presented in (Figure 1). The figure shows the individual areas in which the heat of coke is spent on the following reactions: 1-the heat of hot coke, spent on the implementation of the reaction of heating carbon monoxide in the counterflow from 490°C to 1200°C when cooling coke from 1200°C to 740°C; 2-the heat spent on the reaction of Bella - Boudoir, at a temperature of 490°C; 3 - the heat spent on the reaction of decomposition of iron carbonate (  $\text{FeCO}_3$  ) at 490°C; 4 - the heat, spent on reheating the ore from 490°C to 650°C; 5-heat spent on reheating carbon monoxide in the counterflow from 650°C to 1200°C; 6-the heat expended on the Bella-Boudoir reaction at 650°C; 7-the heat expended on the decomposition reaction of magnesium carbonate ( $\text{MgCO}_3$  ) at 650°C; 8-the heat expended on reheating the ore from 650°C to 740°C.

The preliminary heating region of siderite ore - zone I, carried out on the physical heat of carbon monoxide when it is cooled from 1200 °C to 20 °C, where 0 is the cooling of carbon monoxide, was also investigated. The study was carried out for 1 kg of siderite ore.

From the analysis it also follows that when cooling coke from 1200°C to 740°C and heat treatment of 1 kg of siderite ore, the bulk of the heat of hot coke in the high-temperature region (forkamera zone) is spent on the Bell-Boudoir reaction processes at 490°C and 650°C, consuming 30% and 20% respectively of the total heat of hot coke, which is determined by the ore composition; about 12% and 14% of the heat of hot coke is spent on the decomposition reaction of magnesium carbonate, iron carbonate in the process of heat treatment and the minimum amount of heat is spent on the site of overheating of the ore from 650°C to 740°C-3% of the total heat of coke and about 6% of heat-on the process of overheating the ore from 490°C to 650°C. No less costly are the processes of heating carbon monoxide from 490°C and 650°C, which is 10% and 5% of the total heat consumption, when cooling coke. The data on the percentages of the consumed heat of hot coke during the heat treatment of 1 kg of sideritoplesite ore are presented in detail by the diagram on (Figure 2).

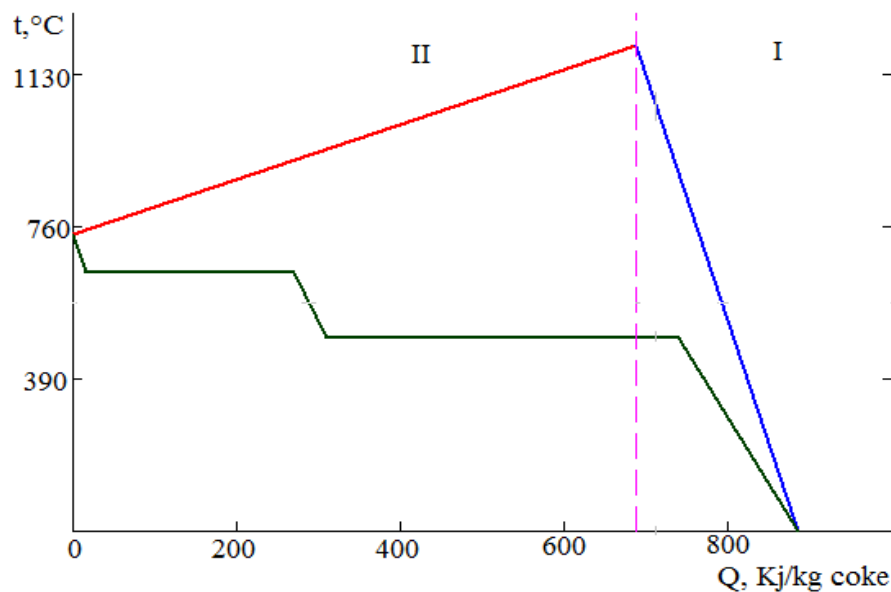


**Figure 1.** Temperature-thermal graph of coke cooling and heating of 1 kg of siderite ore in (ZPTO) and (ZOTO) process material, where I-preliminary region of siderite ore heating on the physical heat of carbon monoxide, II-high-temperature region of heating and decomposition of process material in the zone of coke dry quenching unit forkamera.



**Figure 2.** The structure of the consumed heat of hot coke in the processes of heat treatment of siderite ore in the main technological zone (ZMTO).

The calculations also determined that when cooling 1 kg of hot coke from 1200°C to 740°C in the high-temperature region and cooling carbon monoxide from 1200°C to 20°C in the preliminary heating region, it is possible to carry out a total heat treatment of the process material in the amount of 0.296 kg, taking into account the specific heat consumption per 1 kg of the incoming flow of hot coke. At the same time, the total heat consumption of sideritoplesite ore will be 884.2 kJ/kg of coke. The display of these processes, with the cost of heat for the main processing zones are presented in figure 3.



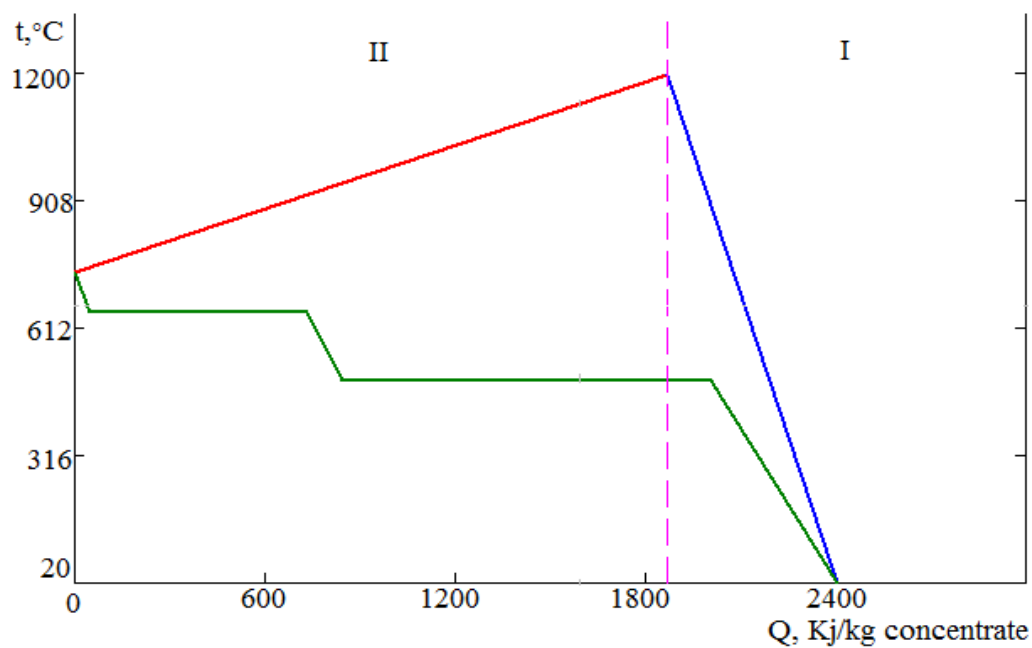
**Figure 3.** Temperature-thermal graph of cooling of 1 kg of coke and heating of 0.296 kg of siderite ore in (ZPTO) and (ZOTO), where I - preliminary area of heating of siderite ore on physical heat of carbon monoxide, II-high-temperature area of heating and decomposition of process material in the zone of forkamera of coke dry quenching plant.

The heat consumption of the process material, taking into account its specific consumption per 1 kg of annealed concentrate of sideritoplesite ore, will be 852.7 kJ / kg of concentrate, shown in figure 4.

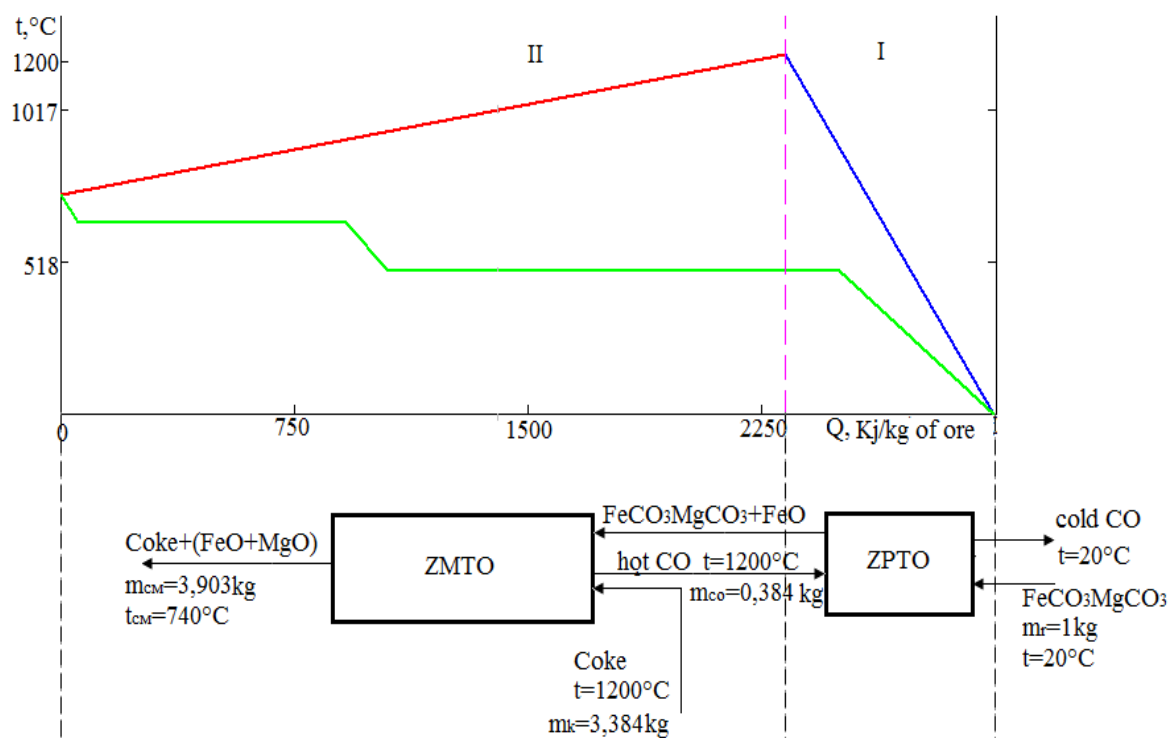
The construction of the proposed thermal scheme of heat use, given to 1 kg of siderite ore and presented in figure 5, was a reflection of the above processes carried out during the heat treatment of ore with the cost of material resources.

This scheme involves the loading of cold siderite ore at a temperature of 20°C into the zone of preliminary technological operation in the amount of 1 kg. Preheating of the process material is carried out on the heat of carbon monoxide in the amount of 0.384 kg/kg of ore, at its initial temperature of 1200°C. Partially fired and heated to 490°C ore enters from the preliminary area into the zone of the main technological operation, where the heat of coke, when it is cooled from 1200°C to 740°C, complete thermal treatment of the ore from 490°C to 740°C.

At the exit from the scheme, according to the results of the process of dry quenching of coke in the zones of the main and preliminary technological operations, a mixture of coke weighing 3,301 kg/ kg of ore and a mixture of annealed concentrate of siderite ore in the amount of 0.602 kg/kg of ore, the mass of the total mixture in this case is 3,903 kg.



**Figure 4** Temperature-thermal graph of coke cooling and siderite ore heating in the zones of preliminary and main technological processing, taking into account the specific ore flow rate per 1 kg of burnt siderite ore concentrate, where I-preliminary area of siderite ore heating on the physical heat of carbon monoxide, II-high-temperature area of heating and decomposition of the process material in the forkamera zone.



**Figure 5.** Thermal scheme of coke dry quenching process.

The results of thermodynamic analysis during the heat treatment of sideritoplesite ore in the zones of preliminary and main technological operations were summarized and presented in table 1.

**Table 1.** Heat treatment of 1 kg of siderite ore in (ZPTO) and (ZMTO).

Sections of the thermal processing of ore	Required heat, Kj /kg of ore	Coke consumption / kg of ore	The mass of ore, kg	The decrease in the mass of ore, kg	The mass of CO, kg
Area of preliminary technological operation: area I					
0. Heating of ore with CO gas	613.819	-	1	-	0.384
Result area I	613.819	-	1	-	0.384
Zone of the main technological operation: area II					
1. Decomposition at 490° C	331.286	0.524	1	-	-
2. Bell-Boudoir reaction at 490 °C	707.677	0.828	0.817	0.182	-
3. Heating CO from 490 °C	236.204	0.373	0.817	-	0.232
4. Ore heating from 490 °C to 650 °C	137.327	0.217	0.817	-	-
5. Decomposition at 650 °C	273.691	0.433	0.817	-	-
6. Bell-Boudoir reaction at 650 °C	459.746	0.727	0.698	0.119	-
7. CO heating from 650 °C	121.917	0.193	0.698	-	0.152
8. Ore overheating from 650 °C to 740 °C	56.919	0.09	0.698	-	-
Result area I	2325	3.384	0.698	0.301	0.384
Result	2938.586	3.384	1	0.301	0.384

### 3. Results

According to the results of the calculations, it follows that for the full heat treatment of 1 kg of siderite ore in the high-temperature region (ZMTO), it is possible to cool 3.384 kg of hot coke from 1200°C to 740°C, while for the heat treatment of the process material, the heat of hot coke 2325 kJ/kg of ore is required.

In the pre-processing zone, when the ore is heated from 20°C to 490°C and partially fired at 490°C, 614 kJ/kg of ore will be spent, while the total heat consumption of sideritoplesite ore, taking into account the preliminary and main technological zones, will be about 2938.6 kJ/kg of ore.

### 4. Conclusion

Thus, it follows from the analysis that the proposed method of cooling coke with the allocation of the preliminary area of heat treatment of the process material, which involves the implementation of pre-heating sideritoplesite ore on the physical heat of carbon monoxide with subsequent heat treatment of the ore in the high-temperature zone on the heat of hot coke will produce 0.178 kg of the finished fired concentrate of siderite ore, spending 0.296 kg of siderite ore per kilogram of hot coke. In the process of heat treatment of the process material will be achieved coke burnout in 2.43%.

The proposed process of using the heat of incandescent coke allows to obtain a valuable material resource (annealed concentrate of siderite ore) and cooled carbon monoxide, with its further possible use in the scheme with a preliminary area of heat treatment of the process material. The resulting re-

source-cooled carbon monoxide opens up new possibilities for use in schemes of its complete after-burning, which thus allows to solve the problem of complete utilization of carbon monoxide.

## References

- [1] Errera M and Milanez L 2000 Thermodynamic analysis of a coke dry quenching unit *Energy Conversion & Management* **41** 109-27.
- [2] Liu H, Zhang X, Xu L and Wang M 2002 Mathematical model for fluid flow and heat transfer in the cooling shaft of coke dry quenching unit *J. of Thermal Science* **11** 65
- [3] Yang Wei-hua, Xu Tao, Chen Guang, Guo Yue-jia, Jia Li-yue and Li Wei 2009 Coke dry quenching and utilization of its waste heat for electricity in iron and steel industry *Int. Conf. on Power Electronics and Intelligent Transportation System* (Shenzhen, China) pp 227-30
- [4] Sun L, Wu J, Xu J and Li Q 2011 Thermodynamic Analysis of a New Coke Dry Quenching Technology *Advanced Materials Research* **225-226** 84-7
- [5] Bisio G and Rubatto G 2000 Energy saving and some environment improvements in coke-oven plants *Energy* **25** 247-65
- [6] Zaitsev S 2001 Vy`bor racional`noj sxemy` suxogo kontaktnogo tusheniya koksa [Choice of rational scheme of dry contact coke extinguishing] *Chernaya Metallurgiya* **7** 23-6 [In Russian]
- [7] Strakhov V 2006 O nekotory`x problemax lokalizacii i obezvrezhivanii vy`brosov v koksovom proizvodstve [On some problems of localization and neutralization of emissions in coke production] *Koks i Ximiya* **3** 47-9 [In Russian]
- [8] Falkov M 2009 E`nergoberezhenie i e`nergoe`ffektivnost` v proektax GIPROKOKSa na predpriyatiyax chernoj metallurgii Ukrainy` [Energy Saving and energy efficiency in Giprokoks projects at the enterprises of ferrous metallurgy of Ukraine] *Koks i Ximiya* **7** 69-72 [In Russian]
- [9] Danilov O and Munts V 2008 *Ispol`zovanie vtorichny`x e`nergeticheskix resursov* [Use of secondary energy resources] (Yekaterinburg: USTU-UPI) [In Russian]
- [10] Kartavtsev C, Gordeeva I, Neshporenko E and Demin Yu 2017 Issledovanie e`nergetiki teploexnologii suxogo tusheniya koksa [Study of energy heat technology of dry coke quenching] *Promy`shlennaya E`nergetika* **5** 38-43 [In Russian]
- [11] Neshporenko E, Kartavtsev S and Gordeeva I 2018 Povy`shenie e`nergeticheskoy e`ffektivnosti teplovoj texnologii processa suxogo tusheniya koks [Improving the energy efficiency of thermal technology of dry coke extinguishing process] *Energetik* **2** 44-8 [In Russian]
- [12] Krupenin M 2017 Temperaturny`e ogranicheniya metasomatoza Bakal`skix sideritovy`x mestorozhdenij po geoximicheskim dannym [Temperature limitations metasomatism Bakal siderite deposits in geochemical data] *Vestnik Permskogo Universiteta* **16(2)** 167-77 [In Russian]
- [13] Glushko V 1962 *Termodinamicheskie svoystva individual`ny`x veshhestv* [Thermodynamic properties of individual substances] (Moscow: Nauka) [In Russian]
- [14] Nikolsky B P 1971 *Spravochnik ximika* [Handbook of the chemist] vol 2 (Moscow: Ximiya)
- [15] Melamud C, Shatsillo B, Yuriev B and Zagainov C 2013 Texnologiya vosstanovitel`nogo obzhiga sy`roj i obozhzhennoj sideritovoj rudy` dlya polucheniya vyustitnogo produkta [Technology of reducing roasting of raw and burnt siderite ore to obtain a vustite product] *Stal`* **2** 8-11 (Moscow) [In Russian]