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HIGH-TEMPERATURE SHAFTLESS HOT STOVES FOR BLAST FURNACES[1]

Iakov Kalugin[2]

Abstract

Increase of BF blast heating temperature is one of the most important ways to increase economic efficiency of BF production. Existing structures of hot stoves with internal and external combustion chambers do not allow for this. The Kalugin shaftless hot stove makes it possible to heat BF blast up to 1,300°C-1,400°C while using standard refractory materials (silica, mullite-corundum, and fireclay) and provides high economic and ecological values. It provides the possibility of carrying out reconstruction of existing aging hot stoves with increase of blast heating temperature and substantial savings in capital expenditures. This construction is fast spreading at the blast furnaces of 250-5,500 m³ volume in several countries (Russia, China, Ukraine, India, and Japan). 149 Kalugin hot stoves are in operation, and 52 more are in the process of designing and construction. Kalugin hot stove systems have been commissioned at two 5,500 m^3 blast furnaces in China (Shougang Jingtang United Iron and Steel Co., Ltd., Caofeidian), hot blast temperature of 1,300°C has been achieved. Replacement of the hot stoves with external combustion chamber for shaftless ones has started at big blast furnaces: commissioning of the hot stoves at blast furnaces of 4,300 m³ and 5,000 m³ volume at JFE Steel Corporation, Fukuyama, Japan has been completed; hot stoves at the 5,500 m³ blast furnace of "Severstal" Company, Cherepovets, Russia are being modified.

Key words: Blast furnace; BF hot stove; Burner system; Checker.

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[2] *Doctor of Engineering, Director General, Kalugin JSC, Yekaterinburg, Russia.*

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1 INTRODUCTION

Blast heating has been and remains one of the most important parameters, which define economics of BF production. However, during several decades maximum level of blast temperatures 1200-1250°C remains without any changes. It speaks for the limits of potentials of existing hot blast stoves with internal and external combustion chambers.
Meanwhile, use of prepared raw materials (coal dust, natural gas, etc.) enables application of blast with the temperature of 1,300-1,400°C. To provide such temperature new constructions of hot stoves shall be applied which are free from disadvantages of existing hot blast stoves and ensure better economic and ecological values.

2 DEVELOPMENT

2.1 Existing Hot Stoves and Their Disadvantages

Main feature of existing hot stoves is a tall combustion chamber. It is located at the hot stoves with internal combustion chamber along with the checker chamber within the same shell. Its long service has revealed a number of essential drawbacks: «short circuit», banana effect, high-temperature creeping (creep) of refractory, non-uniform distribution of combustion products along the checker work, pulsating combustion, refractory spallings on thermal stability due to temperature fluctuation.
Indicated drawbacks, first of all characteristic of the combustion chamber, lead to frequent failures and characterize the combustion chamber as the weakest element of the hot stove. It limits hot blast temperature during long-term operation at the level of 1,200°C and requires frequent repairs of the hot stove.
At the hot stoves with external combustion chamber the latter is put into its own steel shell. In so doing, only two disadvantages are eliminated: «short circuit» and «banana» effect, but these hot stoves have a very complicated dome design and difficult system of thermal expansion compensation of checker chamber and combustion chamber shells. These units are costlier by about 30% and require for its installation more space. It causes problems while carrying out reconstruction in operating workshops. Nevertheless, these units are a more reliable construction and are installed at the big blast furnaces of more than 3,000m³ volume. Maximum hot blast temperature during long-term operation is 1,250°C.
Existing hot stoves with combustion chambers have exhausted its potential on the increase of blast heating temperature, for with the increase of blast heating temperature their stability essentially comes down.

2.2 Shaftless Hot Stoves with the Burners at the Base of the Dome

Combustion chamber is not principally necessary part of the hot stoves and main disadvantages of existing hot stoves with the combustion chambers (shafts) may be eliminated if the combustion chamber itself is eliminated, that is a shaftless hot stove is developed.
In Russia the first shaftless hot stove of our construction was built in 1982 at the blast furnace of 1,500m^3 capacity at Nizhny Tagil iron & steel plant, refer to Figure 1a. At this hot stove gas is burnt in a small annular prechamber situated at the top of the dome, in the bottom part of which several dozens of ceramic burners of a small size

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are installed. Gas and air are supplied into the burners from collectors located under the shell. The hot stove provides full combustion of gas without pulsations. It was tested at the hot blast temperature of 1,350°C, and had been in operation for 27 years without repair at the temperature of 1,200°C and is still in a good condition. Its operation has shown promising outlook of shaftless hot stoves and possibility of their operation up to 30 years without any repair.
However, at a later date such construction of the hot stove was not applied as there were some disadvantages. In the first place, a wide dome did not allow installing such hot stoves instead of existing ones due to not enough space for reconstruction of a hot stoves system. In the second place, to provide complete burning out of gas the same relation gas-air at each burner was required, but they are supplied from collectors and due to collector effect it is difficult to maintain this relation. Despite preliminary fine-tuning of uniform distribution of the streams from each collector per burners at the stands, this relation could not be maintained at the real hot stove in cold condition. Long-time tests and fine-tuning of the streams' distribution at the real hot stove was required before it could be commissioned. Combustion of gas in all the burners was good; carbon monoxide content «CO» in the waste gas did not exceed 20 mg/m^3. However, at the wide distribution of such construction a lengthy and fine adjustment of the burners for each hot stove hardly seems to be possible and without it reliable operation of such hot stoves cannot be guaranteed. Besides, "short circuit" may occur in such hot stove when not burnt gas from the channels may come to the checker through cracks in the brickwork and will be further emitted into the atmosphere and negatively impact ecological values.

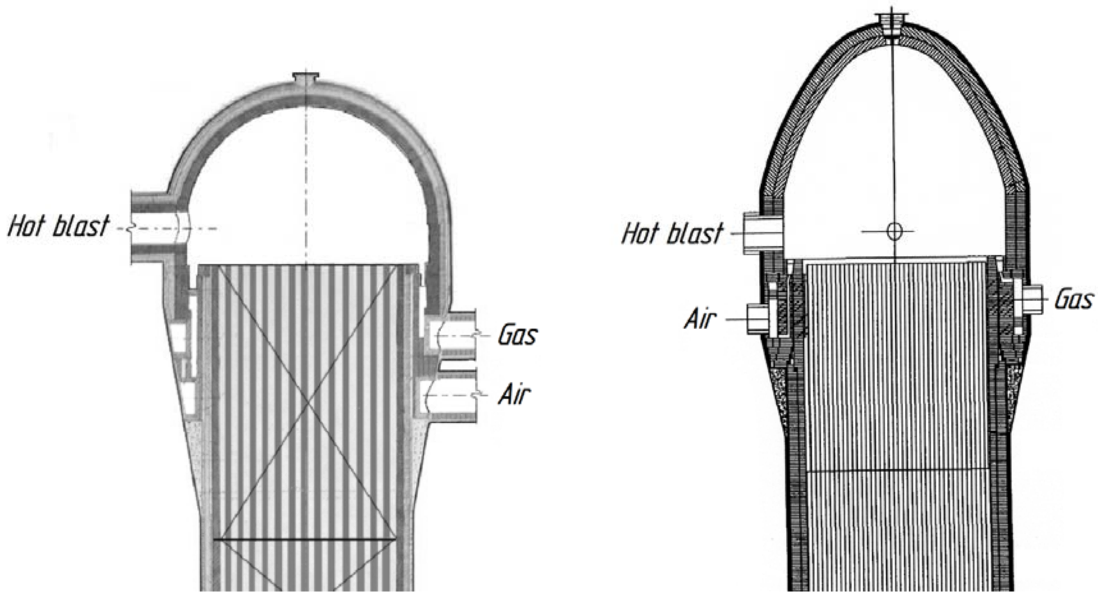

Figure 1. (a) First shaftless hot stove with small annular prechamber 1982 (Russia); (b) similar construction of the hot stove, China [1].

In China a similar construction of the hot stove made its appearance, refer to Figure 1b, and several patent applications has been filed, for instance.[1] It has been already applied at many plants.[2] However, disadvantages of the structure could not be eliminated. Patent analysis shows that a constant search for uniform distribution of streams per burners is going on. Our experience shows that flow distribution by streaming in real channels from refractory brickwork considerably differs from calculated ones and even from experimental data. As a matter of fact, a huge under

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burning of gas in the burners may be in such hot stoves and large emission of carbon monoxide «CO» with waste gas into the atmosphere. As the ecological requirements are getting constantly tougher it may lead to considerable fines and thus application of this construction will be questioned.
A big quantity of narrow channels may lead in the course of time to their clogging with dust or split off brickwork parts of the burners or the dome as well as to their closing when the brickwork moves. As a result heat capacity and blast heating temperature will decrease in the course of time.

2.3 Kalugin's Hot Blast Stove

Kalugin's shaftless hot stove (KSS for short) has become a further stage of development of shaftless hot stoves, refer to Figure 2. KSS construction has been patented in Russia, China, and Ukraine; it is being patented in Japan, India, Europe, USA and other countries.
Burner device is located on the top of the dome along the axis of the hot stove; it has a prechamber and a jet-vortex supply of gas and air. Jet-stream vortex of gas and air in the prechamber provides intensive mixing and combustion of gas which starts in the prechamber and is over in the middle part of the dome, refer to Figure 3.
Optimum degree of stream's vortex defined experimentally and proved by computerized calculations provides full combustion of gas and uniform distribution of combustion products along the checker, non-uniformity makes ± 3-5%. For the hot stoves of different capacity and sizes distributions of streams and their vortex may be different and the burners of each hot stove are thoroughly calculated at computers during engineering stage.

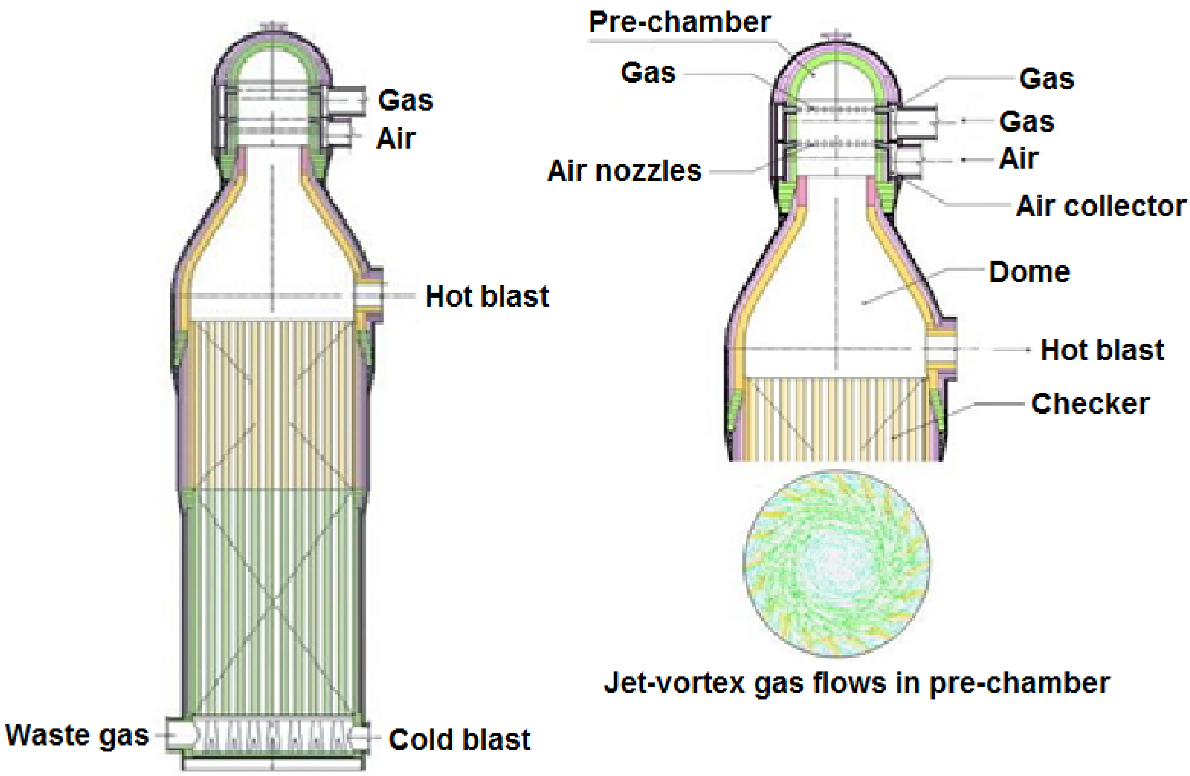

Figure 2. General view of Kalugin's Shaftless Stove

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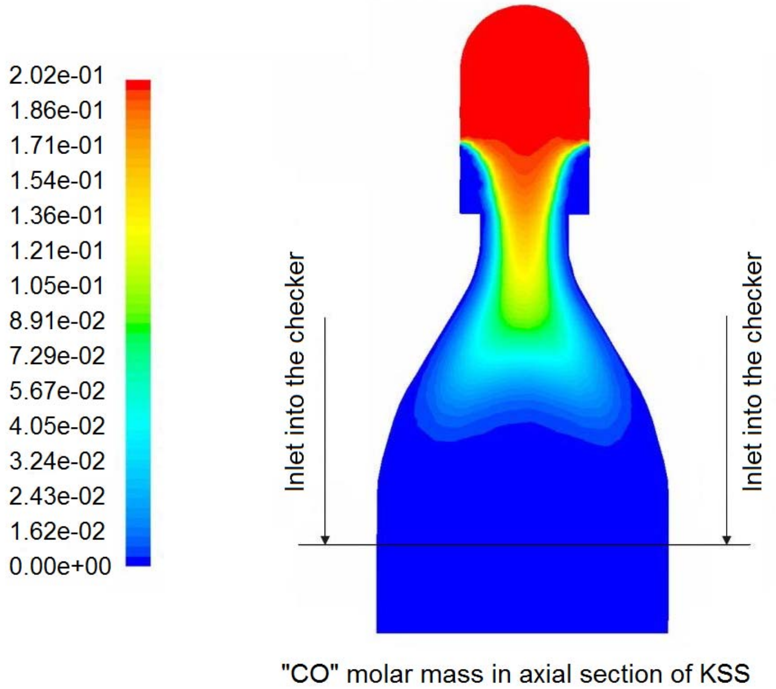

Figure 3. Location of gas combustion zone in KSS. Carbon monoxide (CO) concentration is given based on computer modeling for full thermal capacity operation.

Jet-vortex burner provides concentration of carbon monoxide in waste gas not more than 20 mg/m³; it is five times less than European norms. As the «short circuit» in KSS is completely excluded the hot stove will remain during the whole period of operation ecologically «clean», it provides essential ecological advantages to a considerable degree decreasing emission of harmful substance CO into the atmosphere.

Pulsating combustion is completely lacking.

There is no blow of the flame to the brickwork and no local overheating; it ensures symmetrical temperature distribution along the dome, checker, prechamber and shell. As a result temperature stresses decrease and stability of the hot stove improves.

Thin-walled hexahedral checker blocks with the channel diameter of 30 mm, heating surface 48 m²/m³ and with channel diameter of 20 mm, heating surface 64m²m³ have been developed for shaftless hot stoves. It makes it possible to reduce overall dimensions of the checker and of the hot stove while preserving its heat capacity.

Distribution of zones of different refractory bricks along the checkerwork is calculated in such a manner that there is no conditions for dust and slag clogging of checker channels, so that during the whole period of operation the checker with the channels of any diameter stays clean. The checker with 20 mm channel diameter has the best values and has started its wide application in KSS and preheaters of combustion air in China, India and Russia. It is used at KSS for blast furnaces with capacity from 250 m^3 up to 5,500m³.

In China impregnation of the upper part of the checker by suspensions [3] has become widespread. It increases blackness grade of the channel walls from 0.5 up to 0.9 and according to the calculations made by the authors (Zhou Hui-min, etc.) it should increase hot blast temperature by 15-20°C. In accordance with our calculations [4] such increase of the blackness grade of the wall leads only to a minor rise of the mentioned blackness grade in the system «gas-wall» and to a small increase of heat-

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transfer factor through radiation, that provides a very insignificant ~1ºC rise of the blast temperature. It is explained by relatively small grade of blackness of radiation gases and small effective ray length at small size of the channels' flow area.
Elimination of the combustion chamber and application of the new structure of the checker made it possible to considerably, by 40-50%, increase checker height having the same lateral dimensions of the hot stove. It has made the KSS compact and enabled saving of resources by 30-50% on refractory materials for its erection compared with a hot stove with internal combustion chamber of the same heat capacity.
A new construction of the checker supporting grid has been developed for the KSS with independent support of each grid on its column. It eliminates impact of the grids on each other at temperature fluctuation. Maximum temperature of waste gas at such checker support makes 500°C. It makes it possible, on the one hand, to decrease required height of the checker, on the other hand, to increase waste gas temperature and rise preheating of gas and air in the waste heat recovery system without application of additional heating. At the KSS system the same typical equipment and the same automation control system is applied as is the case at the conventional hot stoves with ceramic burners.
For heat recovery of parting waste gases two systems of heat exchangers are applied in the KSS system: heat exchangers on heat pipes (thermosyphons) and tubular recuperators. Preheating of gas and combustion air up to 200ºC has been achieved practically at the maximum waste gas temperature of 450°C in the end of gas period.
KSS checker support enables increase of maximum waste gas temperature up to 500ºC. In connection with this temperature of preheating of gas and combustion air in the waste heat recovery systems may be increased up to 250°C. Heat recovery systems have been installed at the most KSS systems.
KSS heating system makes it possible to use gas and combustion air preheated up to 600ºC. When KSS operates on BF gas with low combustion heat 3,000-3,100 kilojoule/m³ and without addition of gas with high combustion heat for achieving of high hot blast temperature 1,250-1,300°C a scheme is realized with preheating of combustion air in a specially constructed battery of two small KSS. Combustion air is preheated in this battery up to the temperature of 1,100-1,200ºC, and then it is diluted in a special mixer by cold air up to 450-600°C and is supplied to the main KSS. One of advantages of this scheme is that small KSS as well as main KSS have their campaign life of 30 years without repair; it cannot be achieved with other types of heat exchangers. Small KSS for preheating of combustion air are installed at 10 KSS systems in China.
Many KSS systems utilize both systems: heat recovery system and system of preheating of combustion air in small KSS. For obtaining hot blast temperature of 1,300ºC at low combustion heat of gas and without addition of high calorific gas preheating of gas up to 200°C is required at the expense of waste gas heat in heat exchangers on heat pipes and combustion air up to 570ºC in small KSS. Such scheme has been already implemented at the KSS systems of BF No. 1 and No. 2 with capacity of 5500 m³ of Shougang Jingtang United Iron and Steel Co., Ltd., Caofeidian, PRC (Figure 4) as well as at the hot stoves systems of other blast furnaces in PRC. For achieving hot blast temperature of 1,400°C it is possible to use small KSS for preheating of both: BF gas and combustion air.

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Figure 4. KSS systems of BF No. 1 and No. 2 with capacity of 5,500 m^3 in Shougang Jingtang United Iron and Steel Co., Ltd., blast temperature of 1,300ºC with combustion air up to 570ºC in small KSS.

3 RESULTS AND DISCUSSIONS

3.1 Erection of Shaftless Hot Stoves

KSS application is possible in both cases: at construction of new blast furnaces on new sites (greenfield) and at overhaul by way of replacement of existing units by the shaftless ones.

When a KSS is erected in a greenfield there is a possibility to rationally deploy the KSS system with installation of heat exchanging units of the heat recovery system, small KSS for combustion air preheating, fan station and other equipment. It is the main way of KSS application.

However, reconstruction (overhaul) of hot blast stoves is also widely applied. Overhaul of existing HS systems with one by one replacement of aging structures of hot stoves by KSS has been carried out at the blast furnaces from 350m^3 up to 5,500n^3 capacity in different countries (Figure 5). Aging hot stoves both with internal and external combustion chamber were being replaced.

There are a great many blast furnaces in China with aging structures of the hot stoves which provide a low hot blast temperature about 1,000ºC and emit huge amounts of carbon monoxide into the atmosphere up to 5,000 mg/m^3. It is sensible to conduct their repairs with simultaneous reconstruction for small-size KSS.

Replacement of old, physically and morally outdated constructions of the hot stoves for KSS makes it possible to save on capital expenditures, increase hot blast temperature by 100-200ºC, switch over to a new technological level of BF melting with coke saving by 5%, increase productivity of blast furnaces by 6% and improve ecological values - «CO» emissions about 20 mg/m^3.

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Figure 5. 2 KSS between in internal hot stoves of .№1 BF 3000 м3 in OAO ZSMK in Russia

3.2 Application of Shaftless Stoves

Advantage of KSS has been appreciated by the experts from many countries, and for the time being there is a wide spread of this structure. 149 units are in operation; additionally more than 52 hot stoves are in the process of design and construction. Especially many KSS are applied in China, in this country there are more than 90 units. A very meaningful event was erection of KSS systems at two biggest blast furnaces in China with 5500m³ capacities at Shougang Jintang United Iron and Steel Co., Ltd., Caofeidian. JSC Kalugin has carried out all the calculations and detail engineering of the hot stoves and combustion air preheaters. At this plant KSS batteries having at their disposal only BFG with low calorific value 750 kcal/m³ provide design hot blast temperature of 1,300°C. Total consumption of carbon fuel, coke + pulverized coal, reached about 440 kg/t of hot metal.
KSS application at big blast furnaces in China continues. At the present time and on the joint project with CISDI a KSS system has been commissioned at the 4,747 m³ BF of Anyang iron & steel plant, KSS systems for two 4,150 m³ blast furnaces of Baotou iron & steel plant are being designed, a KSS system at 4350 m³ BF at Taiyan iron and steel plant is under construction.
2 KSS have been commissioned in Japan at the big blast furnaces with capacity of 4,300 and 5,000 m³ at JFE Corporation, Fukuyama.
In Russia a step by step reconstruction of a hot stoves system is going on with replacement of the hot stoves with external combustion chamber for KSS at BF No. 5 of OAO «Severstal», volume of the BF is 5,500 m³, refer to Figure 6. The checker

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with 20 mm channel diameter is applied. A KSS battery has been commissioned at the 3800 m³ BF at Novo Lipetsk iron & steel plant (NLMK).

It should be noted that in the PRC some entities practise to spread project copies of shaftless hot blast stoves obtained earlier at JSC Kalugin on conditions of confidentiality and without the right of application at other objects as their own development. These entities do not own our licence, do not possess methods of technical calculations of such units and use refractory of poor quality. Cases of major accidents have become known to public at such hot stoves. The Customers who implement such projects incur a considerable risk.

Figure 6. 2 KSS in.№5 BF 5500 м3 in OAO Severstal in Russia.

In recent time many patents (PRC, Japan) relating to the KSS structure have appeared. Reasonability of solutions being offered very often gives rise to doubts and it should be proved. KSS structure is well tested. All the elements are being very thoroughly calculated at the engineering stage for the blast furnaces with capacities from 250 m³ up to 5,500 m³. A thorough technical supervision is being conducted during erection activities. It guarantees successful KSS operation; it has been always proved by experience.

Therefore at present time we study real KSS projects for operation under hot blast temperature of 1,400°C with application of widely used normal refractories (silica, mullite-corundum, and fireclay). According to our evaluation it will enable us to reduce coke consumption up to 250 – 270 kg/t of hot metal and replace it by more cheap coal dust having their total consumption at the level of 440 – 460 kg/t of hot metal.

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4 CONCLUSIONS

Kalugin's shaftless hot stoves are free from most of disadvantages that existing hot stoves have. They have considerably smaller dimensions and huge advantages regarding saving of capital expenditures and campaign life without repair. They can be installed in the course of modification of existing hot stoves at their footprint. There already are 149 units in operation, next 52 units are being designed and constructed.

KSS have a plain structure and the most comfortable conditions for refractory. Therefore under observation of admissible tolerances for normal refractories (silica, mullite-corundum, fireclay) KSS make it possible to obtain hot blast temperature of 1,400°C, campaign life without repairs of 30 years. It is not possible to reach with other types of existing hot stoves. They provide better economic and ecological values and new opportunities for development of BF production.

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