High Temperature Top Combustion Hot Stoves of Kalugin Design for Blast Furnaces

B. Prokofyev, M. Kalugina, Y. Murzin, S. Ivlev,
A. Subbotin, KALUGIN JSC, Russia
mail@kalugin.biz

Abstract

Heating of blast has been and remains one of the most important parameters that determine the economic efficiency of blast furnace operation. However, for several decades, the maximum level of blast temperatures remains unchanged at 1,200 - 1,250°C. This shows the limited capacity of conventional hot stoves with internal and external combustion chambers. Kalugin Top Combustion (Shaftless) Stoves make it possible to achieve the hot blast temperature of 1300-1400°C with the use of standard refractory materials (silica, mullite-corundum and fireclay bricks) and provide high economic and environmental performance with service life of 30 years. In Kalugin Shaftless Stoves, gas combustion is performed by pre-chamber type burner with jet and vortex supply of gas and air. The burner is installed at the top of the dome and provides full combustion of gas without flame pulsation before its entrance to the checkerwork and uniform distribution of combustion products over the checkerwork. These stoves have small dimensions leading to a saving of 30 - 50 % on refractory materials. Moreover, they can be used for reconstruction of existing hot stoves and installed in place of old stoves on the same foundation. Kalugin Shaftless Stoves have already been commissioned at iron and steel works in China, Russia, Ukraine, India, Japan, Kazakhstan, Indonesia, Turkey, Brazil and Syria. At present 191 Kalugin Shaftless Stoves are in operation and 44 stoves are being designed and constructed.

Key words: blast furnace; shaftless hot stove; top combustion; checkerwork; burner

Introduction

Heating of blast has been and remains one of the most important parameters that determine the economic efficiency of blast-furnace operation. However, for several decades the maximum level of blast temperature remains unchanged at 1200 - 1250°C. This shows the limited capacity of the existing hot stoves with internal and external combustion chambers.

In the meantime, increased use of injectants through tuyeres such as pulverized coal, natural gas, etc. make it possible to achieve the hot blast temperature of 1300-1400°C. To provide these temperatures, new hot stoves without drawbacks of conventional stoves

and with better engineering, economic and environmental performance are required. We are sure that this can be provided by top combustion hot stoves.

Conventional hot stoves and their drawbacks

The main feature of conventional hot stoves is the presence of a high combustion chamber. In internal combustion stoves, the checker chamber and combustion chamber are located in the same shell. This design appeared 150 years ago and its long-term operation has revealed a number of essential drawbacks. These are "short circuit", "banana" effect, high-temperature creep of refractories, uneven distribution of combustion products over the checkerwork, flame pulsation during combustion, cracking of refractories due to thermal shock.

These drawbacks lead to frequent failures of the combustion chamber and characterize the combustion chamber as the weakest part of the hot stove. During long-term operation, this limits the hot blast temperature to 1200°C and requires frequent repairs of the stoves.

In the external combustion stoves, the combustion chamber is located in an individual metal shell. This eliminates only two drawbacks: "short circuit" and "banana" effect. However, these stoves have a complex dome and a complex system of temperature expansion compensations for the checker chamber and combustion chamber shells. Moreover, these stoves are approximately 30% more expensive and require more space for their arrangement, that present a problem during reconstruction in the existing blast-furnace plants. Nevertheless, these stoves are more reliable than internal combustion stoves and can be installed at big blast furnaces of 3000 m^3 capacity and more. Their maximum hot blast temperature during long-term operation is 1250°C.

Top combustion (shaftless) stoves with burners at the dome top

The main drawbacks of conventional stoves with internal or external combustion chambers can be eliminated if the combustion chamber itself is eliminated, i.e., to develop a top combustion, in other words shaftless hot stove. In Russia, the first top combustion stove of our design was constructed in 1982 for a blast furnace of 1500 $m^3$of Nizhny Tagil Iron and Steel Works. In this stove, gas was burnt in a small annular pre-chamber located at the base of the silica dome and having several dozens of small ceramic burners installed at its bottom. Gas and air were supplied to the burners from the headers located under the shell. This stove provided complete combustion of gas without pulsation. It was tested for operation with the hot blast temperature of 1350°C. The stove was in operation for almost 30 years without major repairs at the temperature of 1200°C in the system with

two conventional stoves and was decommissioned due to shutdown of the blast furnace itself. Examination of the decommissioned stove showed that it was in a very good condition. So, successful long-term operation of this stove paved the prospects for further development of top combustion design.

Despite the fact that this design was successful, it had some drawbacks. First of all, it was impossible to install this stove during one-by-one reconstruction of the existing stove. Its wide dome made it impossible to install this stove in place of the existing one due to little space available. Moreover, to provide complete combustion of gas, it was necessary to provide the same gas-air ratio at each burner. But it was difficult to provide this ratio as due to the collector effect, careful and longtime adjustment of the burners was required. That is why our company hasn't used this design any more.

Kalugin Shaftless Stove (KSS)

Kalugin Shaftless Stove (we call it KSS for short) has become the next stage in development of the top combustion concept. This design is patented in Russia, Japan, China, Ukraine, Turkey and patent applications have been filed in India, Europe, USA and other countries.

The general view of Kalugin Shaftless Stove is shown in Figure 1. In Kalugin Shaftless Stoves, the burner device is located at the top of the dome along the center line of the hot stove. It has a pre-chamber and jet-vortex supply of gas and air. Vortex flows of gas and air in the pre-chamber provide rather intensive mixing and combustion of gas which starts in the pre-chamber and finishes in the middle part of the dome.

The optimum degree of the vortex determined experimentally and confirmed by computer calculations provides complete combustion of gas and uniform distribution of combustion products over the checkerwork (up to 95-97% per cent).

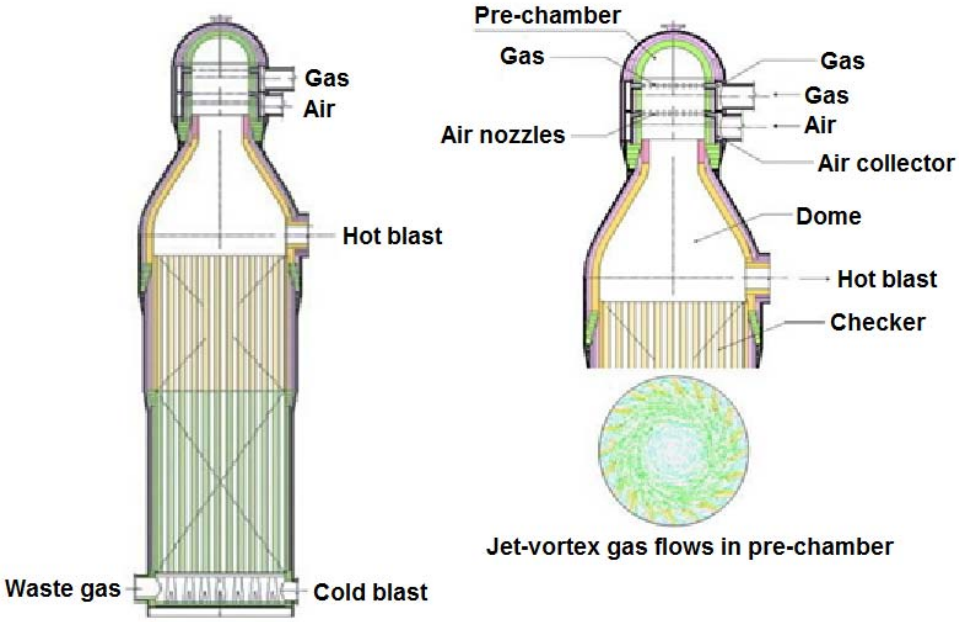

Figure 1 : General view of Kalugin Shaftless Stove

The jet-vortex burner provides concentration of carbon monoxide in waste gas not more than 50 mg/m^3, that is twice less than the European standards (Figure 2).“Short-circuit” is completely eliminated i.e. during the whole period of operation the hot stove remains ecologically clean. Flame pulsation during combustion is completely missing.

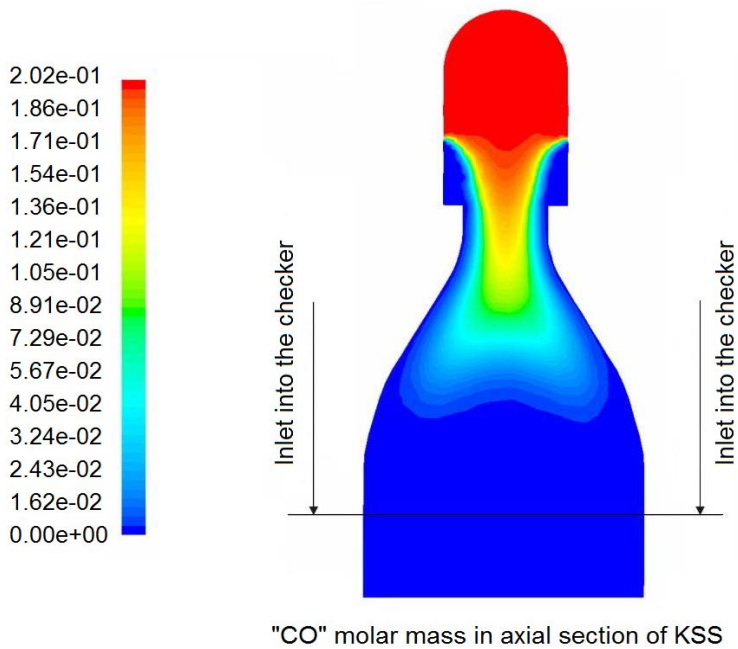

Figure 2 : Location of gas combustion zone in KSS. Carbon monoxide (CO) concentration is given based on computer modeling for full thermal capacity operation.

In KSS, there is no flame impingement against the brickworks and its local overheating, in fact, it provides symmetric distribution of temperature over the dome, checkerwork, lining and shell. As a result, thermal stresses are reduced and durability of the stove is improved.

Exclusively for Kalugin stoves, we have developed hexagonal checker bricks with 30 mm channel diameter (their heating surface is 48m^2/m^3) and 20 mm channel diameter (their heating surface is 64 m^2/m^3). This allows us to decrease dimensions of the checkerwork and entire stove keeping the same heat capacity.

Distribution of zones made of various refractories is calculated in such a way that there are no condition for channel clogging with dust and slag so that during the whole period of operation, the checkerwork with channels of any diameter remains clean. Checker bricks with 20 mm channel diameter have already been used for more than 10 years and they have better performance than other checker bricks. Therefore, at present they are widely used in Kalugin stoves and combustion air preheaters in China, India, Japan, Kazakhstan and Russia at blast furnaces of capacity from 250 m^3 to 5500 m^3.

Elimination of the combustion chamber and application of the new checker design made it possible to significantly reduce the checker height (by 40-50%). At the same time, the cross sectional dimensions of the hot stove remained the same. During construction this enables to save 30-50% on refractory materials in comparison with hot stoves with internal combustion chamber of the same heat capacity.

Moreover, a new design of the checker support was developed for Kalugin stoves. It provides independent support of each grid on its column. As a result, the grids do not influence each other during temperature fluctuation. When this checker support is used, the maximum waste gas temperature is 500°C. This allows, on the one hand, to decrease the required height of the checkerwork and, on the other hand, to increase the waste gas temperature and there by pre-heating of gas and air in the waste heat recovery system up to 200°C.

For waste heat recovery, two systems of heat exchangers are used for KSS: heat pipe heat exchangers and tube recuperators. In practice gas and combustion air were preheated up to 200°C at the maximum waste gas temperature of 450°C at the end of the gas period.

KSS units are equipped with the same standard equipment and automation control system as conventional hot stoves with ceramic burners.

In addition, the stove heating system makes it possible to use gas and air pre-heated to the temperature of 600°C. When Kalugin hot stoves run on blast furnace gas with a low heating capacity, for achievement of the high hot blast temperature of 1250-1300°C, combustion air is pre-heated in two small Kalugin stoves. It is pre-heated up to 1100-1200°C, then it is mixed with cold air in a special mixer to the temperature of 450-600°C and is supplied to the main hot stoves. The main advantage of the system is that small Kalugin stoves as well as main Kalugin stoves have the service life of 30 years without major repairs, which cannot be achieved with other types of heat exchangers. Small Kalugin stoves for combustion air preheating have been installed at 12 stove units in China.

Figure 3 : KSS systems of BF No. 1 and No. 2 with capacity of 5500 m³ in Shougang Jingtang United Iron and Steel Co., Ltd., blast temperature of 1300ºC with combustion air up to 570ºC in small KSS.

Installation of Kalugin Shaftless Stoves

KSS can be used both for greenfield blast furnaces and for reconstruction of the existing hot stoves by replacing them with Kalugin shaftless stoves.

When constructing KSS at a new site, there is an opportunity to reasonably arrange the stove system with installation of heat exchangers, small Kalugin stoves for combustion air pre-heating, fan station and other equipment. This is the main way of using Kalugin stoves.

However, Kalugin shaftless stoves are also widely used for reconstruction of old stoves. Reconstruction of hot blast systems with one-by-one replacement of the existing stoves with Kalugin shaftless stoves has been performed at blast furnaces of various capacities. Both old-fashioned designs of hot stoves with internal and external combustion chambers were replaced.

The most noticeable effect with regard to capital expenditures on refractory materials is achieved during reconstruction of external combustion stoves replaced with top combustion stoves. One example of this reconstruction is Blast Furnace No.5 of 5500 m^3 capacity at Severstal, Russia. Stoves No. 1, 3 and 4 with external combustion chambers were replaced one-by-one with Kalugin Shaftless Stoves (Figure 4). In 2015, they started replacement of Stove No. 2 with Kalugin design. Upon completion of this project the reconstruction of the hot stove unit at Blast Furnace No. 5 will be finished.

Figure 4 : 3KSS at 5500 m^3 BF No.5 of Severstal in Russia

Replacement of old, worn out and outdated stoves with Kalugin Shaftless Stoves provides savings on capital expenditure, increases the hot blast temperature by 100-200°C, makes it possible to move to a new level of blast-furnace smelting technology with coke economy up to 5%, increases blast-furnace productivity up to 6% and improves environmental performance (CO emissions about 50 mg/m^3).

Figure 5 : 2KSS between internal combustion hot stoves at 3000 м^3 BF No.1 ofZSMK in Russia

Application of Kalugin Shaftless Stoves

The advantages of Kalugin shaftless stoves were appreciated by experts from many countries and at present this design is rapidly spreading. 191 stoves are already in operation and 44 more stoves are being designed and constructed. A significant event occurred when Kalugin shaftless stoves were constructed in China for two biggest blast furnaces of 5500 m^{3}of Shougang Jintang United Iron and Steel Co. Ltd., Caofeidian, where the design hot blast temperature of 1300°C was achieved using only blast-furnace gas of low calorific value (750 kcal/m^3). The total fuel consumption (coke + pulverized coal) was about 440 kg/thm. Kalugin JSC performed all calculations and detail engineering for the hot stoves and combustion air pre-heaters.

In Japan, two Kalugin shaftless stoves were commissioned at big blast furnaces of 4300m^3 and 5000 m^3 of JFE Fukuyama instead of the hot stoves with external combustion chamber. Kalugin Hot Stove System was also commissioned in Kurashiki.

We have successfully provided stove to POSCO, South Korea. A hot stove unit for 3800 m^3 blast furnace was constructed in Indonesia. The similar blast furnace with the Kalugin shaftless stove units are being commissioned now in Brazil.

Furthermore, they continue using Kalugin shaftless stoves for big blast furnaces in China. Recently, a Kalugin shaftless stove unit was commissioned at 4747 m^3 blast furnace of Anyang Steel Group Co. Ltd. and at 4350 m^3 blast furnace of Taiyuan Iron & Steel in cooperation with CISDI. KSS units at two 4150 m^3 blast furnaces of Baotou Iron and Steel

Group are already in operation. A KSS unit was commissioned at one of 5050 m^3 blast furnaces of Baosteel in Zhanjiang and one more KSS unit is under construction at the other blast furnace.

Now, we are developing projects for hot stove operation at a temperature of 1400°C with the use of widely applied ordinary refractories such as silica, mullite-corundum and fireclay. We assume that due to this, it will be possible to reduce coke consumption up to 250-270 kg/thm and replace coke with less expensive pulverized coal with consumption of 440-460 kg/thm.

It may also be noted that, in China, some companies spread their copies of shaftless hot stove design previously received from Kalugin JSC on a confidential basis and without the right to use it for other projects. Our company doesn't give any license to third parties, so they don't have our know-how & technology, they don't know calculation methods applied for our hot stoves and they use refractory materials of poor quality to reduce the project cost. As a result, the design performance parameters including the hot blast temperature and service life are never achieved. And the major loss is suffered by the customer due to untimely, premature and sudden failure of the stoves. There have been reported cases of serious emergency at these stoves.

Conclusion

Kalugin shaftless hot stoves do not carry the drawbacks typical of the conventional hot stoves. The dimensions are significantly smaller and it has advantages regarding both savings of capital expenditures and service life without repairs. KSS can be installed in place of existing hot stoves on the same foundation. At present, 191 Kalugin stoves are in operation and 44 Kalugin stoves are being designed and constructed.

The design of our stoves is simple and have the most favorable conditions for refractory service. Therefore, with the use of ordinary refractory materials under acceptable operating conditions, these stoves can provide the hot blast temperature up to 1400°C with the service life up to 30 years, which is impossible for other types of existing hot stoves. KSS provide better economic and environmental performance and provide new opportunities for enhancement of blast furnace performance.