Performance and Recently Orders of Top Combustion type Hot Stove with Metallic Burners

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Summary

NIPPON STEEL ENGINEERING CO., LTD (here in after called "NSE") started to supply hot stoves from the 1960s and we have constantly improved both external and internal combustion types. For the external combustion type hot stove, we developed NSE original type with stable refractory design. For the internal combustion type hot stove, we improved the refractory design to adopt in large size blast furnaces over 5,000 m^3.
On the other hand, in recent years, large-capacity and compact hot stoves have been aimed, and since the 2010s, the top combustion type hot stoves with ceramic burner for large blast furnaces have started to spread in Russia and China.
However, with the method of installing the ceramic burner at the top of the hot stove, there are some problems with regard to initial cost, and the long-term service life time as a refractory structure, etc. For these reasons, NSE had developed the top combustion type hot stove with metallic burner which has low initial cost and stable refractory structure, after actual burning test with actual size metallic burner in 2009, this technology was adopted in a commercial blast furnace in Japan in 2014. NSE have received evaluation about the following some points from customers delivered the hot stove. The ability to blow air as planned equivalent to the conventional type has been achieved stable operation is possible without trouble. The hot stove is compact and low cost and has excellent maintainability. The ratio of unburned CO and NOx is extremely small, BFG exclusive combustion is also possible, and the flammability and environment are excellent etc.
Because of this reference, NSE has received many orders for this hot stove in 2018 for large blast furnace. NSE will continue to strive to disseminate excellent hot stoves in the future.

Key Words
Hot Stove, Hot Blast Stove, Top Combustion, Metallic Burner, CO, NOx, Nippon Steel, Blast Furnace

1. Introduction

As seen in COP21, the world concerns about global warming and reduction of the greenhouse gas, especially CO_2. It is estimated that steel industry is responsible for the 15 % of the CO_2 emission in the world, and ironmaking process is responsible for 70 % of the CO_2 emission by steel industry. Since the CO_2 emission mainly depends on the energy efficiency of the plant, the blast furnace with high energy efficiency is required more than ever.
Also, under the circumstance of the price increase of raw materials and fuels such as iron ore and coke, while price decrease of steel due to over-supply, reduction of production cost with 'high energy efficient blast furnace' is essential.
The biggest factor of the energy consumption is, obviously, coke, and reduction of coke consumption or Reducing Agent Rate (hereinafter called "RAR") is essential. RAR is an index showing the consumption of coke and pulverized coal. The RAR can be reduced by improving quality of raw material and gas flow, etc. and one of the ways is to increase the blast temperature, and it is known that with temperature increase of 100 °C, a large effect of RAR reduction of 10 kg/ton-pig is possible. But due to limitation of existing hot stove's specification, the blast temperature is generally around 1,200 °C, and in order to increase the blast temperature, the increase of hot stove capacity is necessary.
This paper explains the latest order received record and features of the Top combustion type hot stove with metallic burner technology that is capable of higher blast temperature to reduce RAR at minimum cost and long life.

2. Outline of Hot Stove

Hot stove is a facility that continuously supplies heated air at the temperature around 1,200 °C to blast furnace. Requirements of hot stove are following 3 points;

(A) Low capital investment cost:
Hot stoves are very large facilities (3 to 4 hot stoves are required for each blast furnace), which makes it one of the largest investments in iron-making facilities. So, it is necessary to be low cost in both renovation and new construction of hot blast furnaces.

(B) High performance and high energy efficiency:
Hot stove is one of the very important facilities for deciding energy consumption of blast furnace system, for example, Such as improvement of blast temperature of hot blast furnace leads to reduction of RAR of blast furnace, etc.

(C) Long life and high reliability:
Because a trouble of hot stove causes shutdown of blast furnace, hot stove must be high reliable and high long life.

3. History of Conventional Hot Stove

3.1 History of Hot Stove

Hot stove typically, has evolved from internal combustion type to external combustion type, furthermore to top combustion ceramic burner type. Figure 1 shows the outline of different types of Hot Stoves (Internal combustion type, External combustion type and Top combustion ceramic burner type).

3.1.1 Progress for Longer Life

Before 1960s, internal combustion type hot stove was mainstream. In the internal combustion type, the combustion chamber and checker chamber are adjacent to each other in the same shell and the burner is a ceramic burner made by grid of burner bricks. Since combustion and checker chambers are adjacent to each other, the internal combustion type has a large diameter dome. For blast furnaces larger than 4,000 m^3, the refractories in the dome become unstable which led to shorter life. However, most of the blast furnaces had volume less than 4,000 m^3 and therefore the internal combustion type became widespread.
In 1970s, the size of the blast furnace increased in order to rationalize operations, and furnaces bigger than 5,000 m^3 were built. Since internal combustion type had issues about unstable refractory inside of the dome, the external combustion type was developed. The external combustion type has separate combustion chamber and checker chamber and the burner is the same ceramic burner as the internal combustion type. With this structure, the dome diameter became smaller and the refractory issues were solved, and long Hot Stove life with furnaces over 5,000 m^3 was achieved. Since the external combustion type was the only Hot Stove that could cope with blast furnace over 5,000 m^3 at that time, they became popular as the furnace size increased. However it was an expensive investment due to the bigger size of hot stove.

3.1.2 Progress for Lower Cost

During 1980s and on, enlargement of blast furnace was needed in order to reduce the capital and operational expenditure as the steel market saturates. Furthermore, increasing demand and installation of energy saving technology were caused by environmental restrictions. As a result, the demand for lower cost and high efficient hot stove capable of responding to the larger blast furnace increased. Top combustion Hot Stoves with ceramic burner that could cope with less unburnt CO and less expenditure compared with internal combustion and external combustion type for large blast furnace became widespread in 1990s~2010s especially in Russia and China.

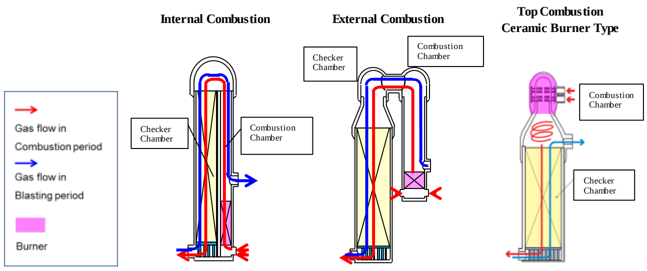


Figure 1: Outline of different types of hot stoves

3.2 Issues with the Conventional Hot Stove

Hot stove has made big progress from internal combustion type to external combustion type, and to top combustion ceramic burner type in terms of ‘longer life’ and ‘lower cost’. In terms of ‘energy saving’, however, there has not been much progress especially by means of increasing the blast temperature that lead to reduction of RAR, other than installing waste gas heat recovery system, Because there was a problem with balance of long life and energy efficiency of the hot stove.

4. Top combustion type hot stove with metallic burners

For the purpose of balancing the low cost, high performance and long life, NSE has developed Top combustion type hot stove with metallic burners as shown in the Figure 1. [1] Instead of conventional ceramic burner, the new hot stove is equipped with metallic burner with high combustibility installed at the top of the hot stove. The first new hot stove as first actual commercial plant was installed at Kokura No.2 blast furnace in Yawata Works, Nippon Steel Corporation in December 2014, and has been operating smoothly since the start-up. [2]

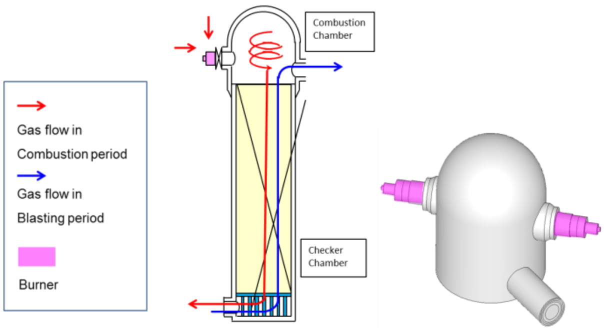


Figure 2: Top combustion type hot stove with metallic burners

Summary of appealing points of NSE standard specification top combustion type hot stove with metallic burners is as follows.

Table 1: Feature of top combustion type hot stove with metallic burners

(A) Low capital investment cost
・Up to existing maximum diversion possible by original design (at the time of renovation) ・Hot Stove weight reduction is possible by original design (at the renovation and new construction) ⇒ Reduction of initial cost of Hot Stove
(B) High performance · High energy efficiency
・New checkered support realize high exhaust gas temperature ・The Metallic burner realize coexistence of the low NOx concentration and the high dome temperature ⇒ As a result, it is possible to further increase the heat storage amount and to increase the capacity of the hot air furnace (increase the air temperature or raise the air flow rate) ⇒ Reduce RAR in blast furnace (Reduce running cost).
(C) Long life · High reliability
・SCC iron crack problem solving by application of anti-SCC plate (called WELACC™) ・Due to low NOx property, SCC avoidance existing facility (Hot blast main, etc.). ・Refractory structure stabilized by unique refractory design ⇒Maintaining stable operation of blast furnace and hot stove

The NSE top combustion type hot stove with metallic burner can achieve both (A) + (B) + (C) at the time of renovation or new construction. Especially at the time of renovation, it is the greatest feature that both high performance (energy saving) and long life can be compatible while maximizing the use of any type of existing equipment (including foundation, shell, etc.) including those made by other companies. We will describe three technical advantages of the NSE top combustion type hot stove with metallic burner.

5. Technical Advantages Top Combustion type Hot Stove with Metallic Burners

5.1 (A) Low Capital Investment Cost

5.1.1 New Building the Top Combustion type Hot Stove with Metallic Burners

Figure 3 shows the size comparison of each type of hot stove. The furnace top combustion metallic burner type hot stove can reduce the construction cost (weight reduction, merit of shortening the construction period) because "no combustion chamber is present" and "burner is small and lightweight". It is about 30 % cheaper than the external combustion type, about 20 % cheaper than the internal combustion type, about 10 % cheaper than the furnace top burning ceramic burner formula. In 2018, we received an order for a renewal project (New building case) to the NSE top combustion type hot stove with metallic burners from an internal combustion type hot stove for the large blast furnace of 4000 m^3 crass. It is possible to increase hot stove capacity inexpensively and the operating performance compared with any of the conventional methods (by reuse foundation etc.).

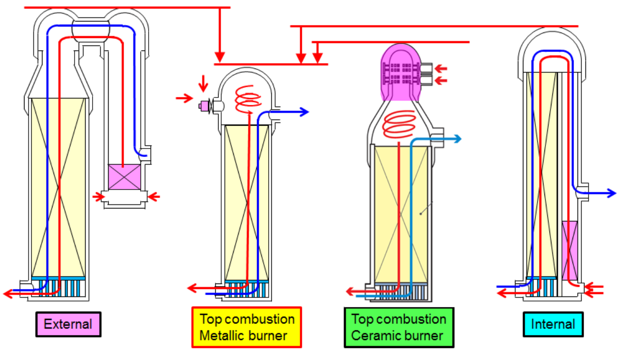


Figure 3: Size comparison of the each type of hot stove

5.1.2 Renovation to Top Combustion type Hot Stove with Metallic Burners

Figure 4 shows the Modification concept from the each conventional type of hot stove to NSE top combustion type. Top combustion type hot stove with metallic burner is able to reduce the construction cost (Reduced weight and shortened construction period) due to ‘no combustion chamber’ and ‘small burner’. The construction cost will be 30 % less in comparison against external combustion type, 20 % less against internal combustion type, and even 10 % less against top combustion ceramic burner type.
In 2018, we received an order for a renovation project from an external combustion type hot stove to the NSE top combustion type hot stove with metallic burners for the blast furnace of 5000 m^3 crass. It is possible to increase hot Stove capacity inexpensively without limiting the layout (without limited by the existing shell diameter), while maximizing the existing foundation and partial iron shell etc.

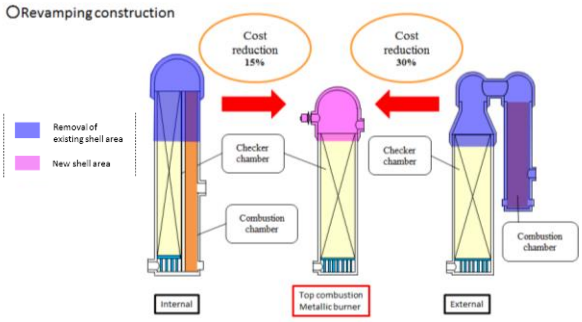


Figure 4: Modification of old hot stove to top combustion type hot stove with metallic burner

5.2 (B) High Performance and High Energy Efficiency

5.2.1 Break through the conventional limit

Figure 5 describes issues of the conventional hot stove. Since conventional stove has temperature limitation at the dome and waste gas, the storage of heat in the checker bricks are limited. As a result, the blast temperature is generally around 1200 °C.

(1) Dome Temperature Limitation:
With conventional hot stove, the dome temperature limitation is generally thought as 1400°C because the generation of the NOx dramatically increases from dome temperature above 1400 °C. An increase in the amount of NOx is caused by the occurrence of SCC and therefore hinders long life.

(2) Waste Gas Temperature Limitation:
With conventional hot stove, typically, the waste gas temperature is limited to 400 °C because of the low heat resistance of the checker support.

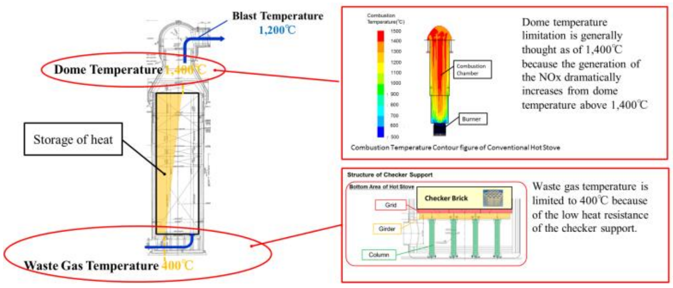


Figure 5: Issues with the conventional hot stove

In order to solve the conventional problem that it is difficult maintaining both the long life and raising the blast temperature. As for the solution to the conventional this problem NSE has been researching development “The improvement of burner flammability for higher dome temperature” and “The improvement of heat resistance of materials for checker support materials”.

5.2.2 Increase of Dome Temperature

In general, the generation amount of NOx, called Thermal NOx, drastically increases between 1450 °C and 1500 °C. In terms of hot stove operation, the increase of the amount of NOx generation leads to higher possibility of SCC on the shell, and therefore the dome temperature is controlled so that large amount of NOx would not be generated. The ceramic burners installed in the conventional hot stove have low mixing property of fuel gas and combustion air.
Because of that, when the hot stove is operated with temperature of higher than 1400 °C, few dozen centigrade lower than theoretical figure, local high-temperature regions are generated in combustion chamber resulting in a large amount of NOx as shown in Figure 6. For this reason, the dome temperature is limited to 1400 °C.

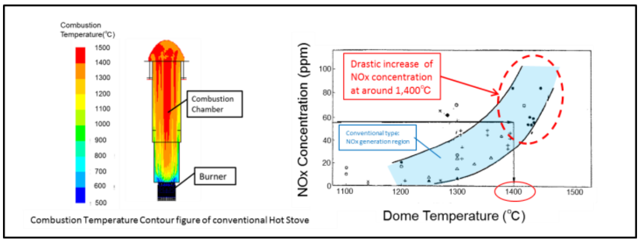
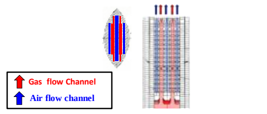
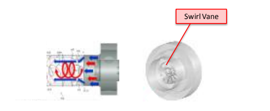
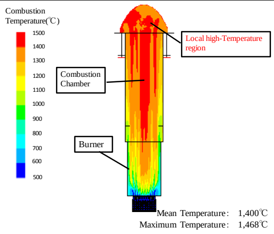
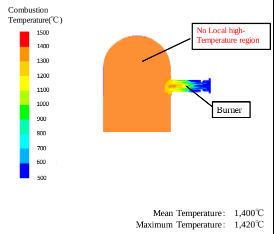


Figure 6: Combustion temperature contour figure and correlation between dome temperature and NOx concentration of conventional hot stove

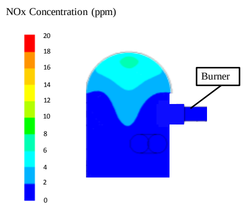
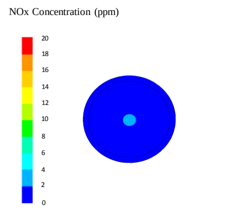
The reason for this occurrence is the configuration of the conventional burner. The burners for internal and external combustion type hot stoves are slit type burner made of refractory and it has strong straight flow causing low mixing property of fuel gas and combustion air. Therefore, a mixed gas with high concentration of fuel gas is partially generated and with combustion, local high-temperature regions are generated. As a result, even when the dome temperature is low, a large amount of NOx is generated. In order to reduce the generation of NOx and achieve the dome temperature higher than 1400 °C, NSE has developed new metallic burner for hot stove with improved mixing property of fuel gas and combustion air.
Table 2 shows the structural comparison between the ceramic burner and the new metallic burner, and contour figure of combustion temperature based on combustion analysis. The new metallic burner, unlike the conventional burner, is three port burners with swirl vane. With swirl vane, rotational flow is generated and mixing property of the fuel gas and combustion air has improved. As a result, the Top combustion type hot stove with metallic burner made uniform combustion temperature without any local high-temperature regions possible.

Table 2: Structural comparison between ceramic burner and metallic burner and contour figure of combustion temperature

	Ceramic Burner	Metallic Burner
Configuration		
Material	Refractory	Metallic
Structure	Slit Type	Three Port Type
Gas Flow	Straight Flow	Rotatinal Flow (Due to Swirl Vane)
Combustion Temperature (Burn Analysis)		

Also, as shown in Table 3, the result of NOx concentration analysis under the operational condition of No.3 Hot Stove of Kokura No.2 blast furnace, the NOx concentration of 2 ppm was attained with dome temperature of 1400 °C due to no local high-temperature regions.

Table 3: NOx concentration contour figure under the operational condition of No.3 hot stove of Kokura No.2 blast furnace

	Vertical section of Dome	Horizontal seciton of upper Surface of Checker brick
NOx Concentration Contour Figure		

Based on this analysis result, further dome temperature rise test was carried out in the No.3 hot stove of Kokura No.2 blast furnace, the actual measurement of dome temperature and NOx generation shown in Figure 7 and Figure 8 proves followings;

- The generation of NOx doesn't increase drastically even at the dome temperature of 1430 °C.
- In the new hot stove, the amount of NOx generation is 20 ppm even when the dome temperature is 1430 °C.
- The NOx generation is 1/3 of the conventional hot stove (20 ppm vs 60 ppm) even with the comparison to the dome temperature limit of 1400 °C of conventional hot stove.

As a result, the new top combustion type hot stove with metallic burner made it possible to increase the dome temperature to 1430 °C, 30 °C higher than that of conventional hot stove.
In addition, this result has the potential for further dome temperature rise (thermal storage capacity improvement = hot stove capacity improvement) beyond 1430 °C while maintaining the long service life of the NSE top combustion type hot stove with metallic burners suggested things.

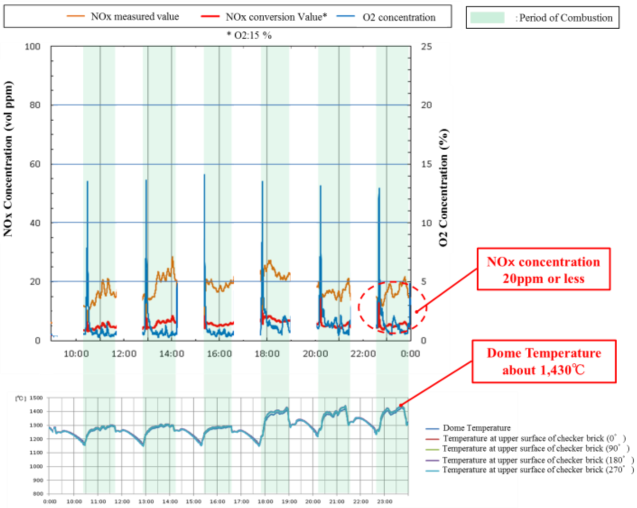


Figure 7: Trend data of NOx concentration and dome temperature of No.3 hot stove of kokura No.2 blast furnace (8th, December, 2015)

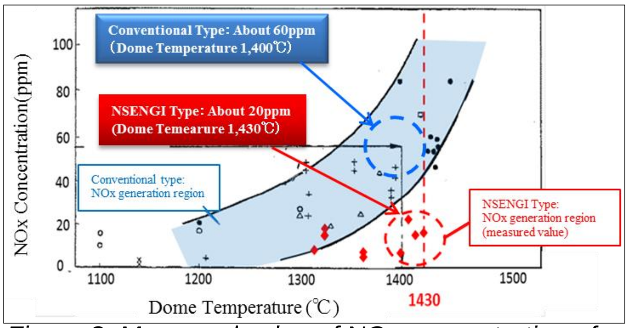


Figure 8: Measured value of NOx concentration of No.3 hot stove of kokura No.2 blast furnace

5.2.3 Increase of Waste Gas Temperature

With the conventional hot stove, temperature limitation of the waste gas temperature is caused by the low heat resistance of checker support. Figure 9 shows the structure of checker support. The checker support is installed at the bottom part of the checker chamber, and composed of 'Girder and Grid' that receive the checker bricks, and 'Column' that supports them.

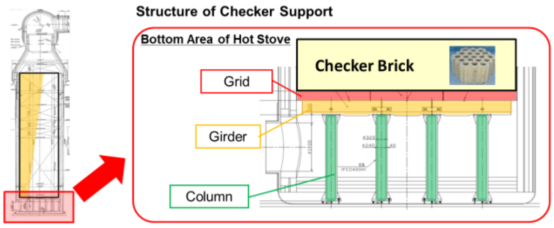


Figure 9: Structure of checker support

Generally, cast iron such as FCD400 is used as a material for checker support. ASME (Boiler & Pressure Vessel Code) is usually referred for structural material strength under high temperature

region and the maximum allowable temperature is determined by design stress under this code, which is, lower of ‘1/4 of maximum high-temperature tensile strength’ or ‘stress that cause creep rate of 10-5 %/h. The maximum operating temperature for hot stove checker support is generally 400 °C due to the fact that generated stress reaches approximately 4kgf/mm2. In this design stress, ‘stress that cause creep rate of 10-5 %/h is determining factor.
In order to increase the heat resistance of the checker support material, NSE has developed a new material for the checker support with improved creep strength based on NSE casting know-hows.

Figure 10 shows the experimental result of ‘high temperature tensile strength’ and ‘creep strength’ of the new material. In comparison with FCD400, both values show significant improvement. In case of design stress of 0.39 MPa (≒4 kgf/mm^2), the increase of waste gas temperature to over 500 °C, about 100 °C higher than conventional limit, is possible by adopting the new material.

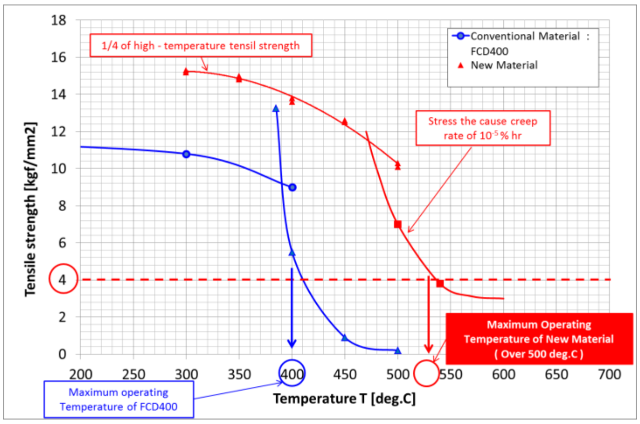


Figure 10: Experimental result of ‘high temperature tensile strength’ and ‘creep strength’ of the new material

5.2.4 Effect

By adopting the metallic burner with higher combustibility, the operation with lower amount of NOx generation became possible even with the higher dome temperature by 30 °C. In addition, the new material for checker support with higher heat resistance makes it possible to operate with higher temperature of waste gas by approximately 100 °C. As a result, as shown in Figure 11, blast temperature of 1,300 °C increased by about 100 °C becomes possible due to increasing storage of heat resulting from the higher temperatures of dome at 1,430 °C and waste gas at 500 °C. This has effect of lower RAR by approximately 10 kg/ton-pig, and merit for operation with blast furnace size of 5,000 m^3 would reach to energy saving of approx. 715,000 GJ/year, reducing CO_2 effect of 38,000 ton/year, furthermore cost saving of 4.9 million dollars per year, which also considers the increase of combustion gas.

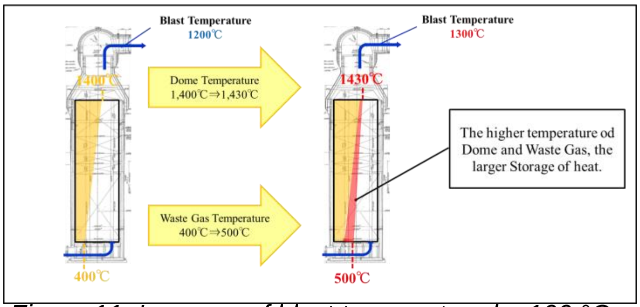


Figure 11: Increase of blast temperature by 100 °C due to increasing dome temperature and waste gas temperature

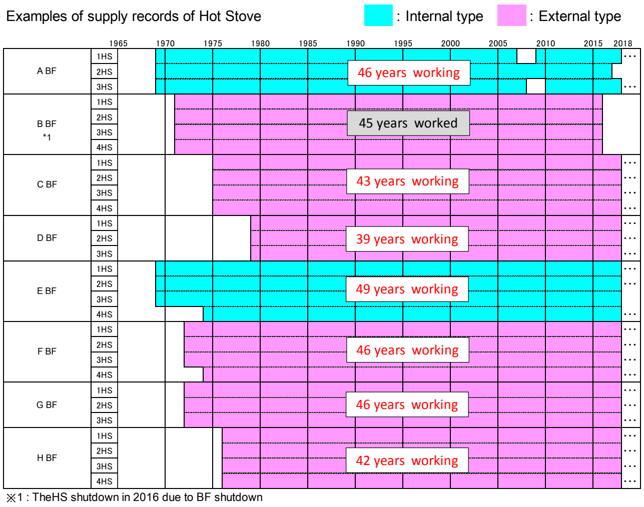
5.3 (C) Long life and High Reliability

5.3.1 Hot Stove Stabilization and Hot Stove Protection Technology

NSE has supplied at least 74 hot stoves throughout the world by 2018. Based on these experiences, NSE acquired the following own know-how and technology that enable the NSE hot stoves to reach life of 40 years or more.

(1) Refractory Design:
NSE owns its unique know-how of refractory design improved based on abundance of data and experiences, through its integrated work from the selection of refractory all the way to brick work on site.
(2) Hot Stove Shell:
Since 1981, anti-SCC plate manufactured by Nippon Steel Corporation, called WELACC^{TM}, has been adapted to the hot stoves, and occurrence of SCC which cause damages of hot stove was significantly reduced. As a result, thermal insulation, stress relief annealing on the site and acid-resistant coating are not necessary, and all of those hot stoves have been operating in good condition after the start-up.
As shown in Table 4, hot stoves designed by NSE have long life more than 40 years.

Table 4: Examples of supply records of the NSE hot stove



The NSE top combustion type hot stove with metallic burners has following technical advantages and is superior over the other hot stoves.

Conclusion

The following is a summary of appealing points of NSE standard specification top combustion type hot stove with metallic burners.

(A) Low capital investment cost

- In the new building case, with the compactness, the initial investment cost can be reduced; in comparison with the other type can be less than max.30 %.
- In the renewal case, with the compactness and maximum diversion effect existing, the initial investment cost can be reduced than repair to same type less than max.30 %.

(B) High performance and High energy efficiency

- It is possible to increase the temperature of dome by 30 °C, waste gas by 100 °C, which makes increase of blast temperature by 100 °C. As a result, RAR of blast furnace can be reduced by 10 kg/ton-pig.

(C) Long life and High reliability

- By adopting NSE own refractory design know-how and anti-SCC plate, WELACC™, it is able to obtain longer life of at least over 40 years.
- By low NOx property, it is possible to avoid SCC of existing iron shell (hot blast main pipe etc.).

In the near future, it is thought that not only new hot stoves will be built in the world, but also large-scale repair of iron skins of hot stoves will occur. NSE will spread the technology of top combustion type hot stove with metallic burners satisfying the cost, performance and life to the world.

Abbreviations

NSE: Nippon Steel Engineering Co., Ltd
CO: Carbon Monoxide
CO_2: Carbon Dioxide
NOx: Nitrogen Oxides
BFG: Blast Furnace Gas
BF: Blast Furnace
COP: Framework Convention on Climate Change Conference of the Parties
SCC: Stress Corrosion Cracking
FCD: Ferrum Casting Ductile
WELACC™: Trademark of anti-SCC plate manufactured by Nippon Steel Corporation

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