Low NOx Combustion Technologies For Lignite Fired Boilers

Takanori Yano

Kenji Kiyama

Kazuhito Sakai

Babcock-Hitachi K.K., Japan

Pauli Dernjatin,

Kati Savolainen,

Enprima Engineering Ltd., Finland

Hirofumi Okazaki

Hitachi, Ltd., Japan

Summary

For the purpose of improving the load range and NOx emission level of lignite fired power plants, the new combustion technology called the NR-LE burner (NOx Reduction - Load Extension) has been developed in co-operation between Babcock-Hitachi (BHK) and Enprima. A single burner combustion test was performed in Japan with the NR-LE type burner by using Czech lignite, adapting the Flame Stabilizing Ring and special Additional Air nozzle.

The first commercial full scale application of the NR-LE burner was implemented to the IPP power producer in Czech Republic, Sokolovská Uhelná, a.s. at Vresová Unit2. The boiler has been retrofitted with the NR-LE and completed with the successful result of the test runs in October 2001. In 2002, it has been again retrofitted with the improved OFA (Over Fire Air) system. The boiler is now in commercial operation with the successful results of 30% minimum load and lower NOx emission.

Introduction

It could be said that the history of super low NOx burners for coal combustion started in early 1980's by BHK in Japan. Then "rapid ignition" phenomenon was first time introduced. The first installation was to the 200 MW power plant Toyama Shinko in Japan, where the existing dual register burners were replaced with the Hitachi - NOx reduction (HT-NR) burners and as a consequence NOx emissions reduced drastically with increasing combustion efficiency. This was the starting point of the NR burner series (Figure 1).

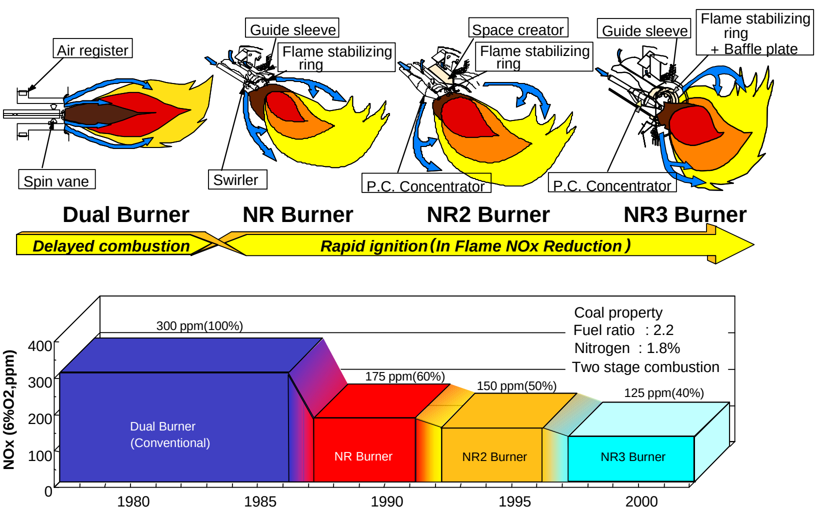


Figure 1. History of Babcock-Hitachi's Low NOx Burners

Toyama Shinko was the first full scale demonstration of the NOx reduction mechanism using hydrocarbon radicals at high temperatures and it was a scientific evidence that NOx decomposition exists in the flame with hydrocarbon intermediates under fuel rich condition (Figure 2). To achieve the high temperature flame, the NR burner is equipped with Flame Stabilizing Ring (FSR) at the end of coal nozzle and a guide sleeve for outer air with high swirl.

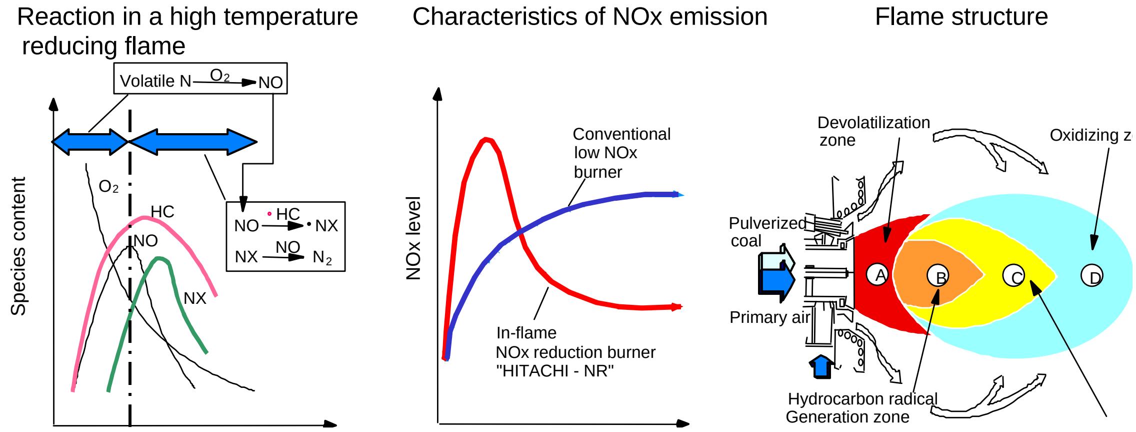


Figure 2. Mechanism of In-Flame NOx Reduction

This type of burner was used in opposed and single wall coal firing units and due to good results it soon became very popular. world wide. Several existing boilers both in Japan and in a lot of countries have been retrofitted by replacing the conventional burners with the NR type low NOx burners. Also the NR type burners have been applied to new boilers supplied by BHK.

Co-operation between Babcock-Hitachi K.K. and Enprima Engineering Ltd. (Enprima) started late in 80’s with the modification of Inkoo Power Plant’s one unit with NR type burner. Inkoo Power Plant, which is owned by Fortum (Enprima’s mother company), is located in Finland and it consists of 4 identical units (4×250 MWe). Because of successful project and good results in the first unit, later on the NR2 burners (two units) and also NR3 burners (one unit) were installed to the remaining units of Inkoo Power Plant.

In addition of installing the NR type burners to Fortum-Enprima’s own power plants, Enprima decided to start the marketing and delivering the NR type burners to Eastern European Countries under the license from BHK. At the same time Enprima started to develop and expand the "high temperature" technology also to the tangentially firing bituminous coal fired boilers(*). First modification was implemented 1994 at the Suomenoja power station in Finland. This was the starting point of the RI-JET burner (Rapid Ignition JET-burner), which is the low NOx burner using the same concept of NR type burners for tangentially fired boiler developed by Enprima(*). After this successful modification, Enprima has installed RI-JET burners for almost 20 boilers in the four different countries. The concept of RI-JET burner is presented in Figure 3. Note (*) : under the license from Babcock-Hitachi

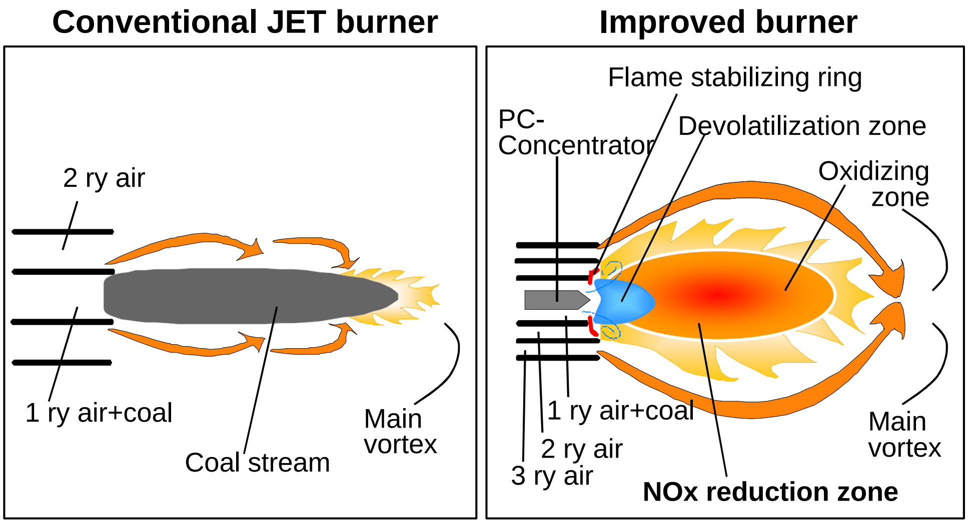


Figure 3. Concept of conventional burner and Fortum's RI-JET burner(*)

In Figure 4 is presented the supply products of Babcock-Hitachi and Enprima in the field of burners. The products for wall fired boilers have been developed and patented by Babcock-Hitachi & Hitachi and the products of RI-JET for tangential fired boiler have been developed and patented by Enprima based on NR burner patent.

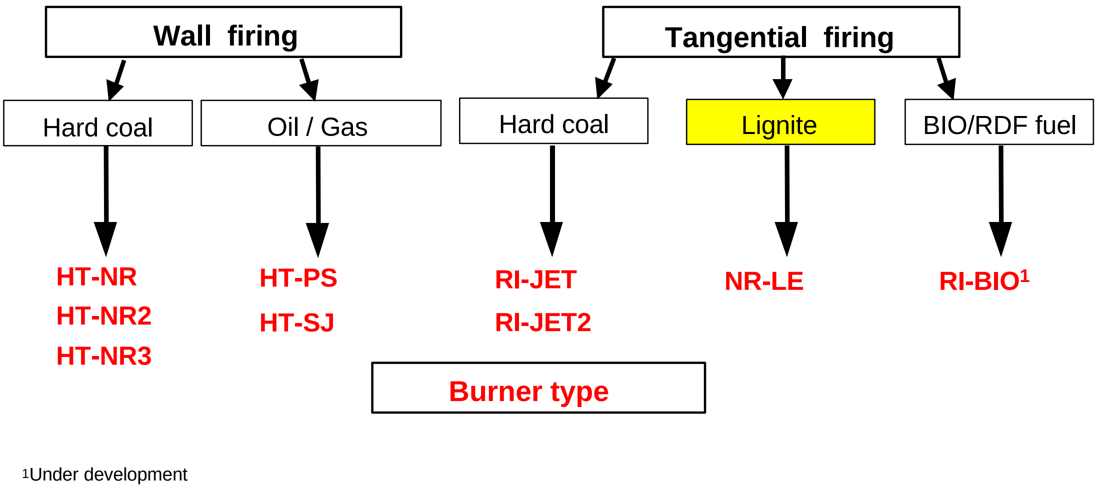


Figure 4. Burner lineup for Boiler and fuel types

Conventional lignite firing system

Most lignite coal firing units in Europe are equipped with tangential firing combustion system with jet burners, where flame is stabilized in the central fireball instead of individual vortex burners. Normally lignite has high moisture content (20 - 70 %) and the ash content varies from 1 to 40 %. Because of its high moisture content, lignite firing boilers are equipped with special drying and grinding system. For grinding, the hammer type or fan type of mills are normally used, and for drying, instead of air the mixture of hot flue gas (800-1000 ^oC) and air are used. Because high amount of hot flue gas and only low amount of air regarding to safety condition are used for drying lignite, the O_2 content in the carrier gas is low. Typically the O_2 content of the carrier gas is 8-15 %, which is significantly lower compared to bituminous coal firing systems. The final moisture content of lignite after drying is about 7-20 %, which is also higher than bituminous coal firing units. Low O_2 content of carrier gas and high moisture content of fuel has a negative effect on coal ignition causing low combustion efficiency and high NOx emission.

Existing lignite firing units applies very simple burners, which are actually not burners but coal injectors. This means that lignite coal ignites very far from coal nozzle, normally after 2-4 m from the nozzle in the central fireball. Then because the O_2 content of the carrier gas must be low, the ignition and flame stabilization is inferior with such a jet burner. This causes narrow operation range for boilers, typically 50-100 % and in the low load operation it is necessary to use oil or gas for flame stabilization and for safe boiler operation.

New combustion system for lignite

Today also lignite firing units have to change their operation mode from "base" power producers to "regulatory" power producers. This means that power plants have to extend the boiler load range from existing 50 - 100% to 30 - 100%. It is not possible by applying the conventional lignite burners to achieve this target. This is the reason, why Babcock-Hitachi and Enprima decided to develop a totally new concept for lignite firing, including new type of low NOx burners named as the **NR-LE** (NOx Reduction - Load Extension) burners applying "high temperature" philosophy. The basic feature of this new combustion system is the stable flame, which makes it possible to reduce the boiler load. At the same time NOx emissions are reduced significantly, because a sub-stoichiometric zone is formed very close to the burner nozzle, and the two-stage combustion is carried out by means of a single burner flame. This single burner staging technique combined with staging in the main vortex by OFA(Over Fire Air) is very effective in reducing NO_x emissions.

In order to reduce slagging of the lignite firing power plants, the furnace corners, where the burners are sometimes installed, are modified in a two ways. Firstly, the vertical distance between burner levels is increased to reduce the burner zone heat release rate related to temperature in the burner zone. Secondary, the corner geometry is changed so that the flame impingement to the furnace wall is prevented. This concept also includes the OFA system. In Figure 5, the principle of the new combustion system has been presented. Furthermore, the **NR-LE** burner can control the flame pattern from wider to narrow construction by adjusting the distribution of primary to tertiary air/gas flow around burner nozzle. Thus it makes possible to avoid the high temperature influence on slagging to furnace corner walls.

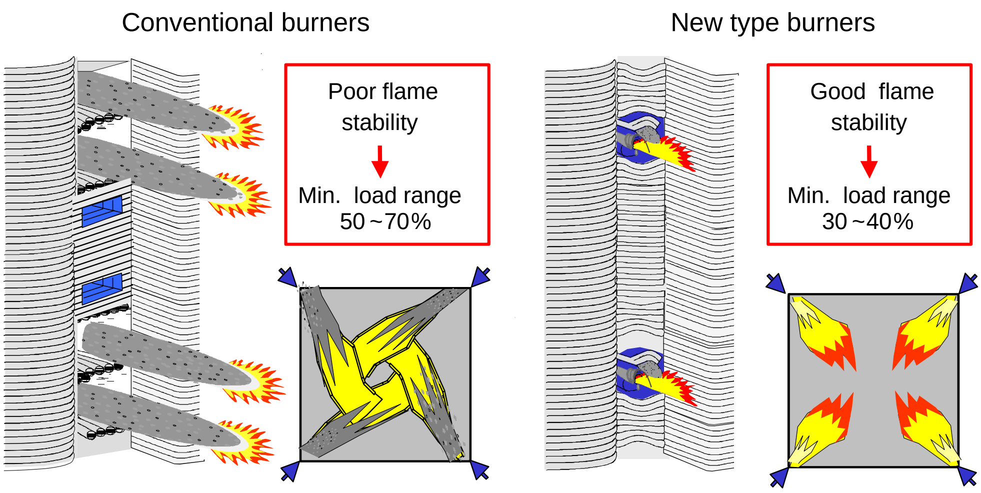


Figure 5. New combustion system for lignite boilers

For developing and finalizing the structure of new lignite burner, three months combustion tests were carried out using Babcock-Hitachi's test rig at Kure Division.

Combustion test arrangements

For the combustion tests 100 ton of Eastern European lignite was shipped from Czech Republic to Japan. The properties of the lignite that was used in tests are presented in Table 1.

Table 1. Raw lignite coal properties

Item \ Coal		Unit	Czech lignite	
			For test	Actual range
LHV as received	(Q_{ir})	MJ/kg	12.8	11.0-12.0
Moisture in raw coal	(W_{ir})	%	37.75	36.0-38.0
Fixed carbon dry ash free basis	(FC)	%	42.7	
Volatile matter dry ash free basis	(VM)	%	57.3	
Ash dry basis	(A_d)	%	24.8	29.2-33.2
Total sulfur dry basis	(S_d)	%	0.74	1.8-2.9
H dry ash free basis	(H_{daf})	%	4.9	6.1-6.5
C dry ash free basis	(C_{daf})	%	75.2	70.45-72.10
S dry ash free basis	(S_{daf})	%	0.8	2.61-4.22
N dry ash free basis	(N_{daf})	%	1.1	0.80-0.90
O dry ash free basis	(O_{daf})	%	18.0	19.8-22.85

Tests were carried out using Babcock-Hitachi's 25 MJ/h single burner test furnace. The flow diagram of the test facilities is presented in Figure 6. Grinding and drying of lignite was made by using a roller type mill under special operating conditions to meet the particle size distribution of actual boilers. After milling, the lignite was stored in the storage bin and from there it was supplied to the test furnace by using the flue gas, which was produced by separated hot gas generator, where LPG was used as a fuel. The O_2 content of the flue gas was possible to be changed from 8 to 21 vol-%.

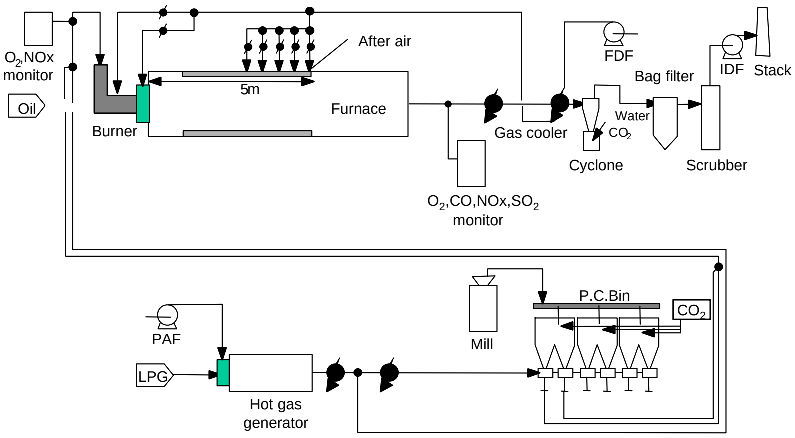


Figure 6. Flow diagram of single burner test furnace

After pre-evaluation, which included CFD-modeling (Computational Fluid Dynamics) of single burner and cold models, three different burner constructions were selected for the test. In addition, each different type of burner was modified slightly during the tests based on the results. Tests were carried out from November 2000 to January 2001.

In these tests, the lignite was ground by the roller type mill instead of fan or hammer type mill that are normally used for grinding lignite. The mill was operated with extremely low loading pressure and low rotating classifier speed, in order to produce the expected fineness for the lignite. By using such conditions of mill, similar fineness of the lignite was obtained as in actual lignite plants. In Figure 7, the size distribution of the pulverized lignite is shown.

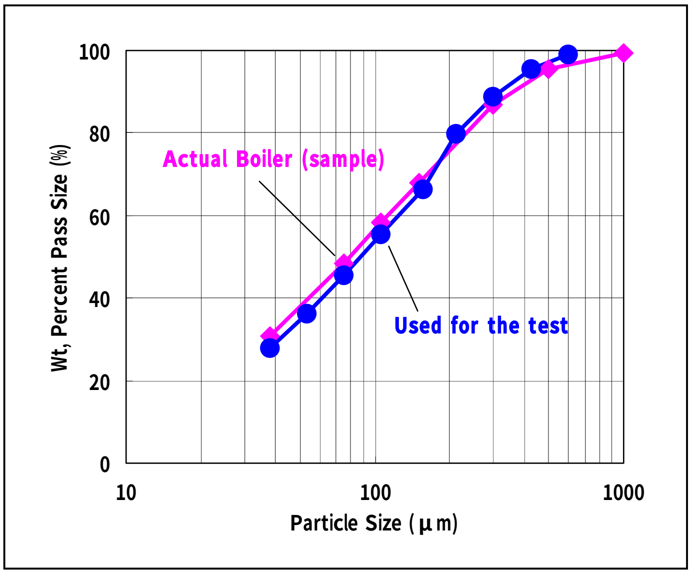
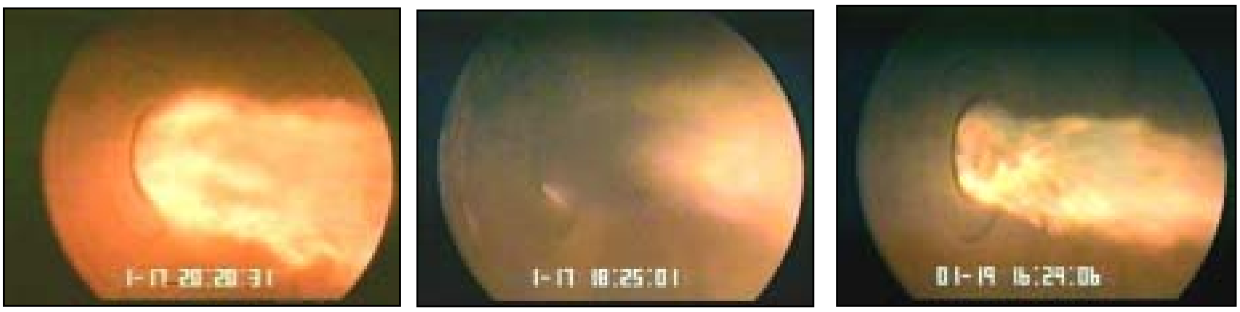


Figure 7. Particle size distribution of pulverized lignite

Test results

By using the best construction of the **NR-LE** burner, it became possible to achieve very stable and bright flame with high burner turn-down ratio (50-100 % burner load). Due to the geometrical structure of the burner, a recirculation zone was formed near the burner and hot flue gas contributed to stabilize the flame. This 50 % burner load represents lower than 50 % boiler load (30-40 % boiler load), because of cutting off the proper number of mills corresponding to the decreased boiler load. The Figure 8 shows the test flame in each burner load.



100% Burner load | **100% Burner load (Blow-off)** | **50% Burner load**

Figure 8. Lignite combustion test flame

Also the tests showed that the O_2 content of the carrier gas was very important parameter to achieve stable flame as well as low NOx emissions. Especially in a low burner load, stable flame was not able to be obtained due to low O_2 conditions. In order to get stable flame and low NOx emissions under the low O_2 content (< 15 %) in the carrier gas, the fresh air was supplied to the burner using special nozzles invented by Babcock-Hitachi. This function of supplying fresh air assisted the initial ignition around the flame stabilizing ring and the stable and high temperature flame for reducing NOx emissions.

Concept of **NR-LE** burner

Based on the three months tests, the structure of the **NR-LE** burner was finalized. Lignite coal and the carrier gas, which O_2 content is typically 8-15 %, enters the inlet elbow of the **NR-LE** burner and flows through the coal pipe. At the end of the coal pipe the flame stabilizing ring is fixed, which promotes the rapid ignition. The combustion air to the **NR-LE** burner is divided into core, additional, secondary and tertiary air. The secondary and tertiary air that is swirled using axial swirl vanes enters into the furnace. The additional air and/or the core air are supplied respectively to the flame stabilizing ring and to the burner centre for adjusting a flexible (stable/blow-off) flame. In a centre of the coal pipe the swirler is equipped.

Figure 9 presents the **NR-LE** burner structure and the calculated temperature, O_2 and flow velocity fields of the **NR-LE** burner. A calculation was carried out by using the combustion simulation model which had been developed by Hitachi.

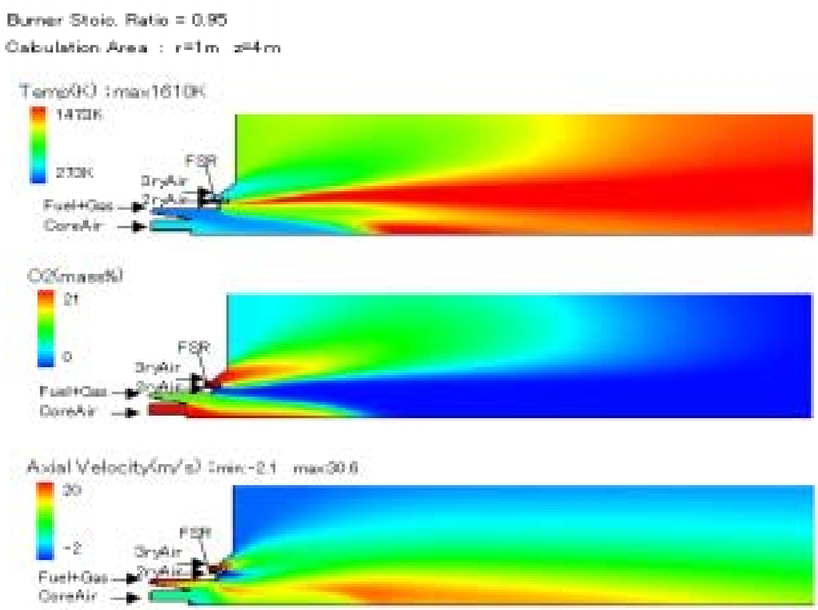


Figure 9. Calculated temperature, O2 and flow fields of NR-LE burner

<u>Application in full-scale boiler</u>

Modification at CHP Vresová, boiler K2

The first commercial application of the **NR-LE** burner was implemented to the actual boiler of Sokolovská Uhelná, a.s. Unit 2 at Vresová in Czech Republic.

The capacity of the boiler is 325t/h of steam and four (4) mills supply the lignite to each corner. Original four (4) jet burner nozzles at each corner were changed to two(2) **NR-LE** burners. The fuel pipes from the fan mills to burners and part of the wind box were also modified. The existing OFA ports remained without modification. The actual burners were scaled-up from the test rig burner and it is five times bigger than the test burner.

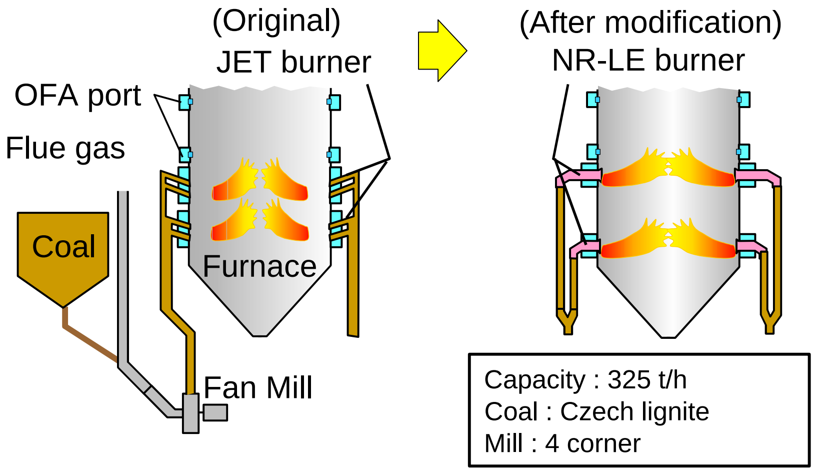
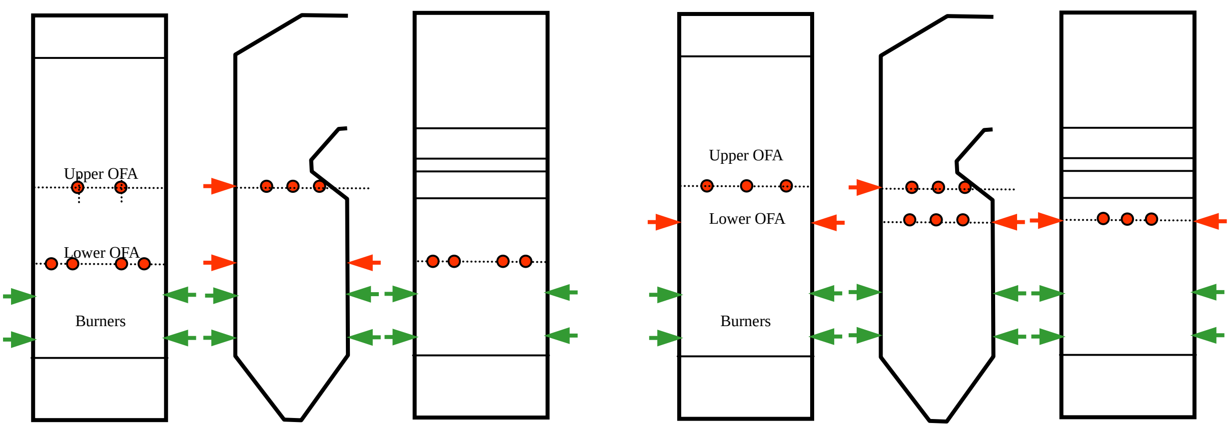


Figure 10. Burner modification (Czech/Vresová Unit2)

Once the burner modification has completed with the successful result, the OFA arrangement has slightly been modified to establish a longer residence time in a sub-stoichiometric condition, as shown in Figure 11 below. The configuration and arrangement of OFA system has been studied by CFD.



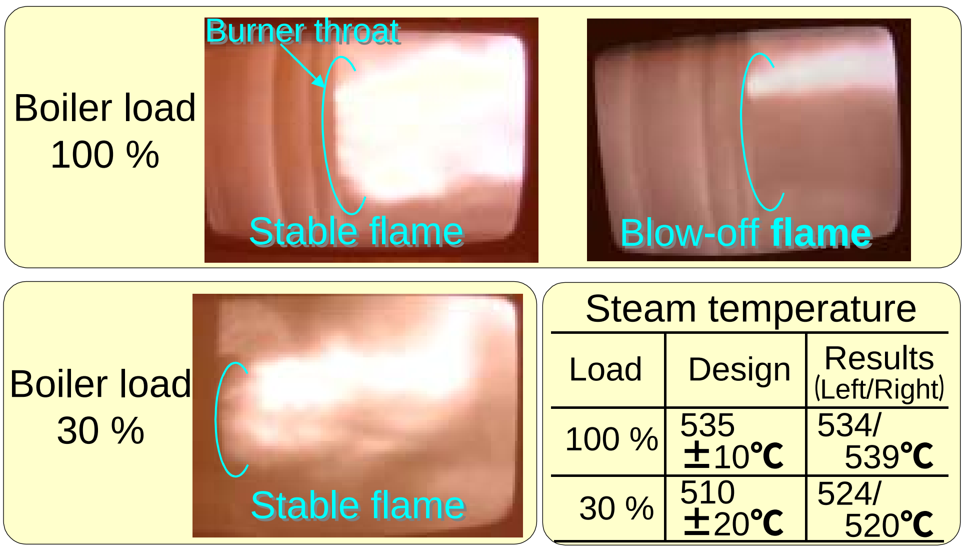
before modification after modification

Figure 11. OFA modification (Czech/Vresová Unit2)

Result

Flame stability

The commissioning of the **NR-LE** burners was carried out from September to October, 2001 in cooperation with Sokolovská Uhelná, a.s.. Figure 12 shows the flame for each boiler load without support fuel. Before the burner modification, boiler minimum load was approximately 50% by the reason of flame stability. The **NR-LE** burner performed very stable flame from the burner throat at high and low boiler load conditions. Also at 100% boiler load, both stable flame and blow-off flame were obtained by adjusting the burner air conditions. Furthermore, the originally designed steam temperatures, with the boiler load range 30-100%, were attained within the range of the required values. Thus the boiler minimum load of 30% was stably achieved with a satisfactory boiler performance.



Load	Design	Results (Left/Right)
100 %	535 ±10℃	534/ 539℃
30 %	510 ±20℃	524/ 520℃

Figure 12. Vresová operation results

NOx emissions

Figure 12 shows NOx emission results of the **NR-LE** burner at the Vresová commissioning test. After the burner and OFA modification, NOx level was reduced compared with the original burner and OFA. Due to the allowable pressure loss of the OFA system, the stoichiometric ratio of the burners has remained in the similar range as it used to be operated. According to the result obtained, it can be said that the **NR-LE** burner and OFA system enables to achieve NOx level lower than 200 mg/Nm^3 if the burners are operated with lower stoichiometric condition around 0.9.

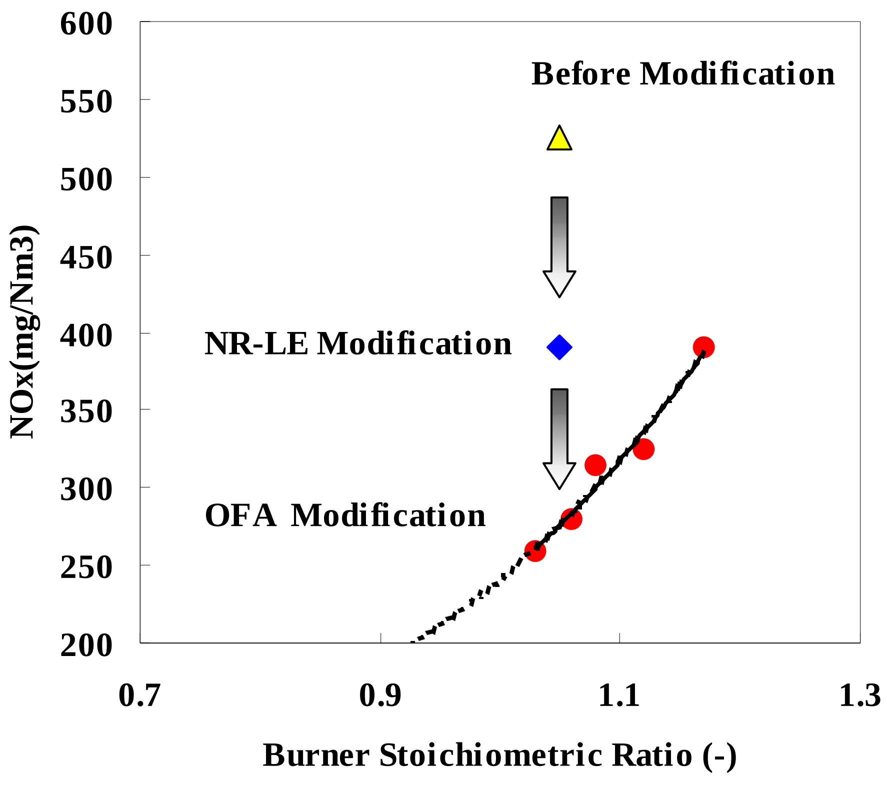


Figure 12. NOx emission results

Conclusion

For the purpose of improving the load range and emission level of lignite fired power plants, the new combustion system has been developed. This new combustion technology includes the improved arrangement and the new type of low NOx burners called **NR-LE** burners (NOx Reduction - Load Extension) which apply high temperature philosophy which is same as NR burner concept. A single burner combustion test was performed in Babcock-Hitachi's test rig with the **NR-LE** type low NOx burner by using Czech lignite which was supplied by Enprima. Furthermore, in an actual power station of Vresová in Czech, scale-up size of this burner was equipped, as well as the modified OFA system. The results contribute to the boiler minimum load improvement and a stable operation with the remarkable low NOx emission level.

Reference

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