Latest Low-NO*x* Combustion Technology for Pulverized-coal-fired Boilers

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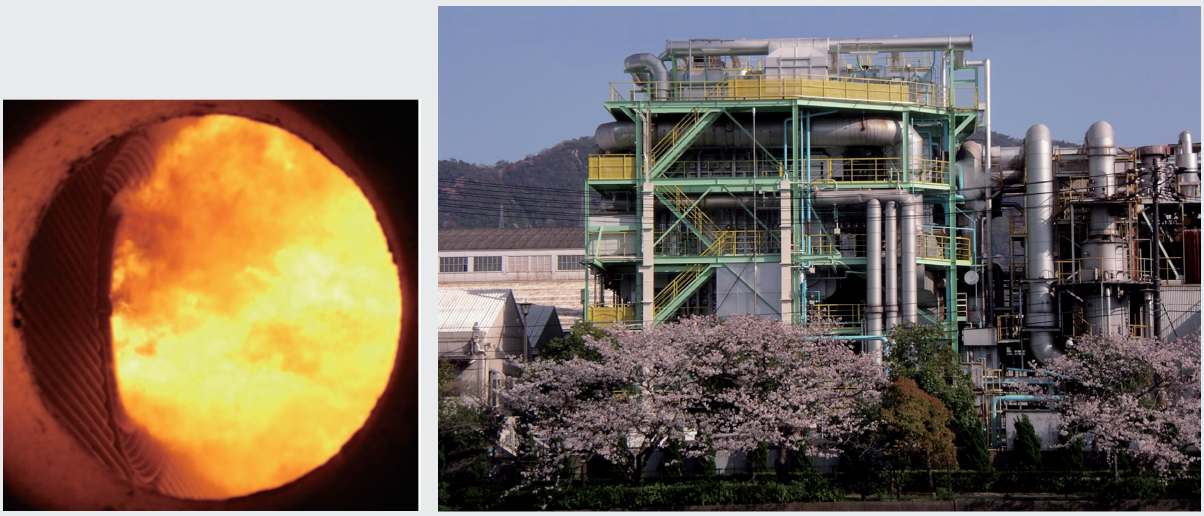
OVERVIEW: Hitachi has long been working on the development of low NOx combustion technologies to satisfy the worldwide need for environmental conservation and has devised the world-first concept of "in-flame NOx reduction" which has been applied in the field of pulverized coal combustion technology in the HT-NR burner series. Hitachi has developed new technology to lower NOx levels even further by improving the structural design and operation of a two-stage air port system which is used in combination with in-flame NOx reduction. This work has been progressed using a large-scale combustion test facility that simulates actual furnace conditions and through the use of a numerical analysis technique developed in-house. The new technology can lower boiler outlet NOx by 40% for the same level of CO.

INTRODUCTION

COAL-FIRED power plants are still a major energy source worldwide because they provide a stable supply of energy. The environmental burden from coal-fired power plants such as NO*x* (nitrogen oxide), SO*x* (sulfur oxide), and CO_2 (carbon dioxide) is higher relative to the calorific output than in oil-fired or gas-fired plants and therefore the industry needs to reduce emissions and prevent their harmful effects. Hitachi has been working on improving technologies for reducing this environmental burden.

NO*x* is a major environmental burden but can be minimized by better combustion methods (low-NO*x* combustion technologies). In practice, this



(a) (b)

Fig. 1—Burner Flame (a) and Upgraded Large-scale Combustion Test Facility (b).
Babcock-Hitachi K.K. (BHK) has developed a test furnace in which actual boiler furnace conditions can be simulated by operating the burner flame under the same conditions as an actual boiler. This upgraded large-scale combustion test facility played a large role in refining the company's low NOx (nitrogen oxide) combustion techniques. A new two-stage after-air-port system that handles the trade-off between NOx and CO (carbon monoxide) has been developed and its performance verified at a 600-MWe-class power station in Europe.

improvement has been achieved by developing better burner combustion methods for use in furnaces. This paper summarizes the latest low-NO*x* combustion technologies.

DEVELOPMENT OF LOW-NO*x* COMBUSTION TECHNOLOGIES

Fig. 2 shows the sequence of steps in the development of low-NO*x* combustion technologies. The two basic principles used to reduce NO*x* are in-flame NO*x* reduction[1] and TSC (two-stage combustion). Significant developments have been achieved through fundamental research, screening of performance, burner structure and TSC port studies, verification in large-scale combustion test facilities, and demonstrations in actual boilers.

The fundamental research consisted of an investigation into the basic NO*x* reduction reaction and fluid dynamics utilizing measurement devices and numerical analysis. The purpose of our research in this field was to achieve greater accuracy in numerical analysis, clarify ignition mechanisms[2], and firmly establish the reaction models[3] for chemical species such as of NO*x* and CO (carbon monoxide).

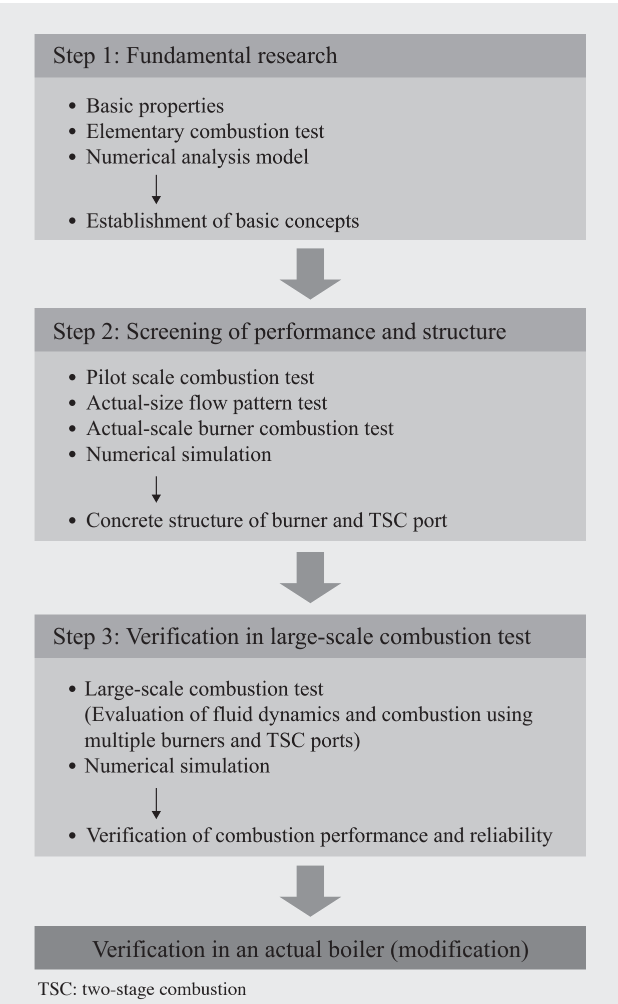


Fig. 2—Development of Low-NOx Combustion Technologies.
A comprehensive development process from fundamental research through to verification on actual boilers ensures high reliability.

For burner development, the optimum burner structure was determined through screening combustion tests in a 500-kg/h test rig. After that, the fluid dynamics were verified using actual-size burner models. Burner performance was verified in combustion tests using a large single burner (3 t/h coal flow).

After determining the combustion methods to use in the burner and TSC port, the combustion performance was verified in a large-scale test furnace equipped with multiple burners and multiple TSC ports. The test furnace simulates conditions in a real boiler. The combustion performance and fluid dynamics of the furnace and the interaction between jets from burners and TSC ports were studied under conditions similar to those of an actual boiler furnace.

The reliability of scaling up the design to an actual boiler based on the results from the large test furnace was verified by a numerical analysis that considered the differences in size and heat input.

OUTLINE OF LARGE-SCALE COMBUSTION TEST FACILITY

The large-scale combustion test facility burns approximately 3 t/h of coal. This is one of the largest combustion test facilities in the world. An outline of the test facility is shown in Table 1 and Fig. 3.

The test facility was extensively modified with close attention paid to the following items to ensure that conditions in actual boilers could be simulated accurately.

(1) Accurate pulverized coal flow measurement

Coal for the combustion test was supplied to the furnace through the burner after grinding to the

TABLE 1. Outline of Large-scale Combustion Rig

Item	Details
Heat input	About 20 MW
Coal flow	About 3.0 t/h
Main equipment	Pulverizer, furnace, pulverized coal burners, TSC ports, heat exchangers, AQCS (flue gas treatment system)

AQCS: air quality control system

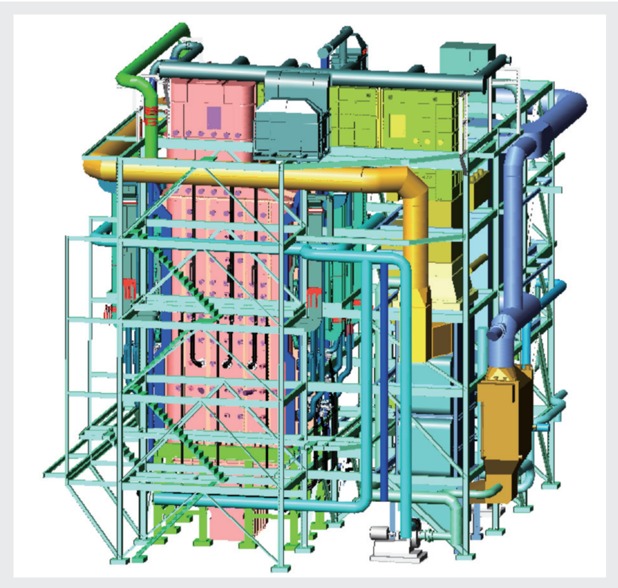


Fig. 3—Outline of Large-scale Combustion Test Rig.
The test furnace simulates conditions in actual boilers.

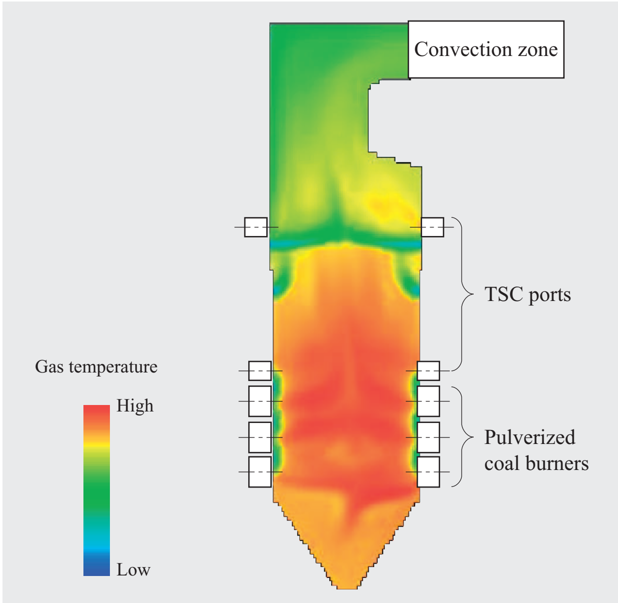


Fig. 4—Distribution of Furnace Gas Temperature (Numerical Analysis).
Testing confirmed that the furnace gas temperature of an actual boiler can be simulated.

required fineness by a pulverizer. The distribution of pulverized coal to the burners in the actual boiler setup is determined by accurately measuring the pulverized coal flow to each burner.

(2) Higher furnace gas temperature

The combustion test furnace is smaller than an actual furnace and this causes a problem with lower temperature due to the relatively higher heat release through the furnace walls. For this reason, the test furnace was modified to optimize the location of refractory material based on an evaluation of the furnace gas temperature profile using a numerical simulation (see Fig. 4). This resulted in a peak furnace gas temperature of 1,850°C similar to that in an actual boiler. Achieving a similar temperature profile to an actual boiler allows NO*x* formation and the combustion speed of pulverized coal to be simulated under the same conditions as in an actual boiler.

(3) Rearrangement of burners and TSC ports to match actual boilers

The following physical relationships were made adjustable so that the arrangement of burners and TSC ports could be set up in the same way as in the actual boiler.

- The distance between burners and TSC ports located above the burners
- The distance between furnace side walls and wing burners/TSC ports

This allows the residence time for the combustion reaction to be tailored to match actual boiler requirements and allows the distribution of reaction products to be evaluated accurately.

METHODS FOR LOWERING NO*x* AND CO LEVELS

NO*x* Reduction Reaction in Burner

The HT-NR (Hitachi NO*x* reduction) burner series has a unique combustion mechanism called “in-flame NO*x* reduction” whereby NO*x* is subject to a reduction reaction in the flame of the burner. The in-flame NO*x* reduction technology causes the NO*x* to undergo a reduction reaction under the high-temperature and fuel-rich conditions immediately after the ignition of the pulverized coal. Fig. 5 shows an outline of the in-flame NO*x* reduction concept.

Fig. 6 shows the structure of the HT-NR3 burner. The following sections describe the features that allow the burner to achieve extremely low NO*x* emissions.

(1) Expansion of recirculation zone after flame stabilizing ring

A rapid ignition of pulverized coal just after the fuel nozzle exit is important for maintaining the stable flame that enhances the operation of in-flame NO*x* reduction. Establishing a flame at the early stages of combustion promotes consumption of oxygen and enlarges the reduction zone where the oxygen concentration is low.

In the HT-NR3 burner, the recirculation zone

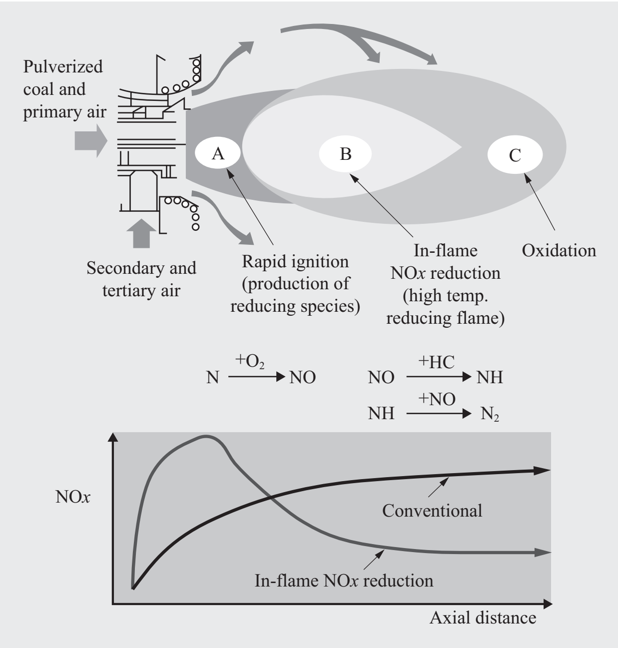


Fig. 5—Concept of In-flame NOx Reduction.
NOx is reduced under high temperatures and fuel-rich conditions just after the ignition point.

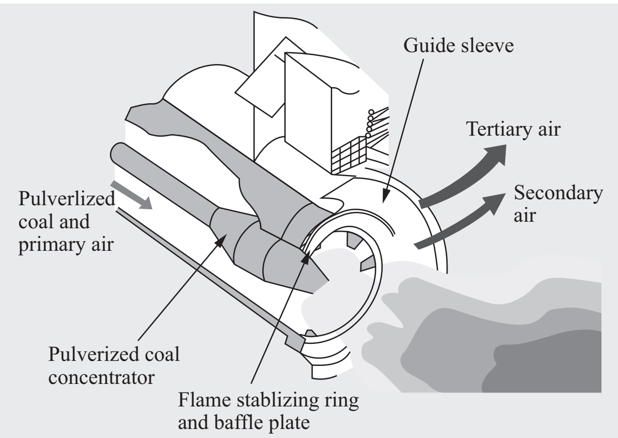


Fig. 6—The Structure of HT-NR3 Burner.
The new burner design takes maximum advantage of in-flame reactions that reduce NOx.

formed at the exit of fuel nozzle is enlarged by attaching a baffle plate to the flame stabilizing ring fitted at the exit of the fuel nozzle to redirect the secondary air jets that blow air from around the circumference of the fuel so that they blow in a more outward direction. The rapid heating of the pulverized coal in the region of hot gas that is retained in the recirculation zone enhances ignition.

(2) Concentration of pulverized coal

The concentration of the pulverized coal is a critical factor in enhancing ignition. The denser the pulverized coal, the shorter the distance between coal particles. This promotes rapid ignition and flame stability through better flame propagation. The PC (pulverized coal) concentrator has the shape of an artillery shell and is installed in the fuel nozzle of the HT-NR3 burner. The pulverized coal and primary air both tend to move closer to the inner wall of the fuel nozzle in the parallel part of the PC concentrator but the difference in momentum between the pulverized coal and air at the exit of the fuel nozzle means that only the air returns to the central zone. As a result, pulverized coal is concentrated around the flame stabilizing ring located at the exit of the fuel nozzle.

(3) Optimum flow pattern of outer air

Tertiary air expands to the outside at the burner exit and this forms a reducing zone with fuel-rich conditions in the flame. The tertiary air then returns to the center of the flame after the NO*x* reduction reaction has completed and mixes with the flame to promote further combustion. In the HT-NR3 burner, a simple guide sleeve effectively separates this reaction from the outer air.

The development of HT-NR burner series succeeded in lowering NO*x* emissions as shown in Fig. 7.

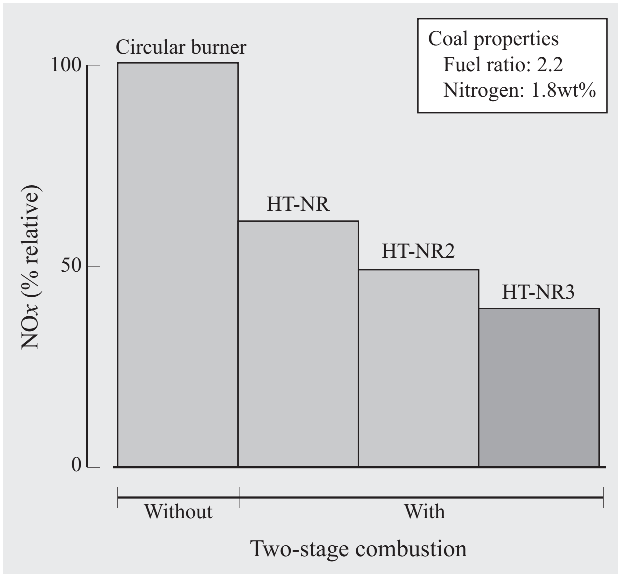


Fig. 7—NOx Performance of HT-NR Series.
Development of low NOx burners has drastically lowered NOx levels.

Lower NO*x* Through Improved TSC Ports

Use of TSC in the burners further reduces NO*x*. In this method, a combustion reaction under air-poor conditions is promoted between the burners and the TSC ports with the reaction being completed between the TSC ports and the furnace exit.

It is well known that increasing the distance (H_R) between the burners and TSC ports helps lower NO*x* levels. However, assuming the same furnace height, making HR longer shortens the distance between the TSC ports and the furnace exit, resulting in lower combustion efficiency due to higher CO and UBC (unburned carbon). This trade-off relationship between NO*x* and CO/UBC is a problem to be resolved.

To overcome this trade-off, Hitachi has developed new multi-stage TSC ports and succeeded in promoting a combining of the TSC air and unburned gas.

This new technology allows the same level of CO reduction to be achieved within a shorter distance. This can even prevent an increase in CO when the reducing zone is enlarged to lower NO*x* levels. That is, the development of this new combustion method simultaneously lowers levels of both NO*x* and CO. Fig. 8 shows the difference between the concepts used in the conventional and new combustion methods.

The new multi-stage TSC port system requires at least two TSC port stages. Each TSC port tier corresponds to a particular region of the furnace and supplies air based on the distribution of unburned gas so as to promote mixing of unburned gas and air.

Enlarging the distance between the burners and TSC ports also helps lower the level of thermal NO*x* produced in the high-temperature combustion region and this complements the lower levels of fuel NO*x* achieved by enlarging the reducing zone. "Thermal NO*x*" is the generic term for nitrogen oxides produced from nitrogen in the air at high temperature. The temperature of the furnace gas gradually decreases with the height of the furnace due to cooling through radiation to the furnace walls. By optimizing the distance between burners and TSC ports, the furnace gas temperature at the TSC port locations can be controlled so that thermal NO*x* does not increase.

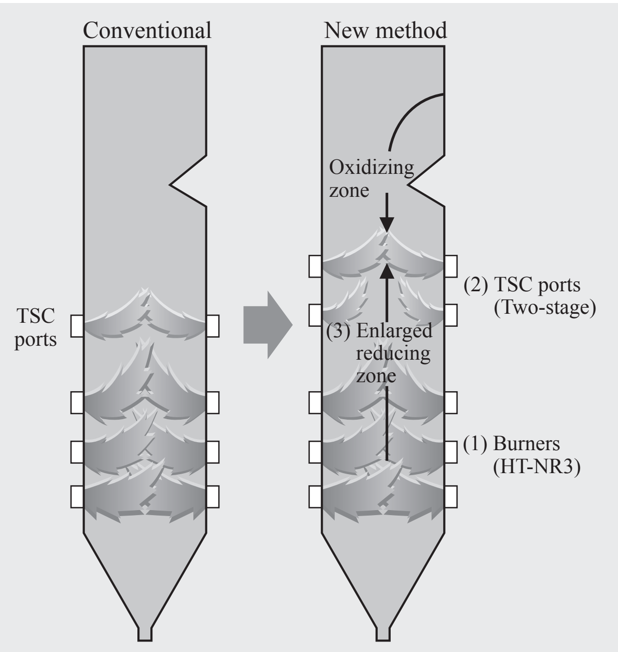


Fig. 8—Concept of New TSC System.
The new TSC system can simultaneously lower NOx and CO levels.

COMBUSTION TEST RESULTS IN LARGE-SCALE TEST RIG

Fig. 9 shows the results of combustion testing in a large-scale test rig. The test rig was fitted with HT-NR3 burners and the new TSC ports. Standard PRB (powder river basin) sub-bituminous coal was used as the test fuel.

The level of NO*x* was lowered by 40% compared to the conventional TSC method while maintaining the same CO level. Detailed measurements of chemical species and temperature in the furnace proved that the results matched the performance of the new TSC system predicted by numerical analysis.

The new TSC system was installed in an existing 600-MWe-class utility boiler with the aim of lowering CO levels. A numerical analysis was carried out prior to the installation to predict the effects of

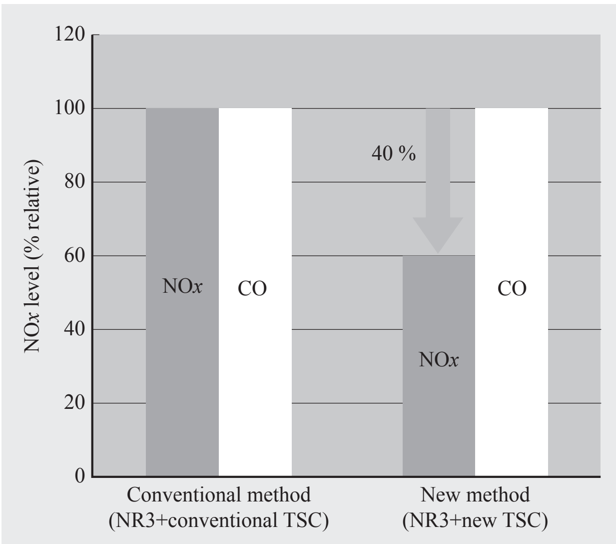


Fig. 9—Results of Combustion Testing on Large Test Rig.
The new combustion method lowers NOx levels without increasing CO.

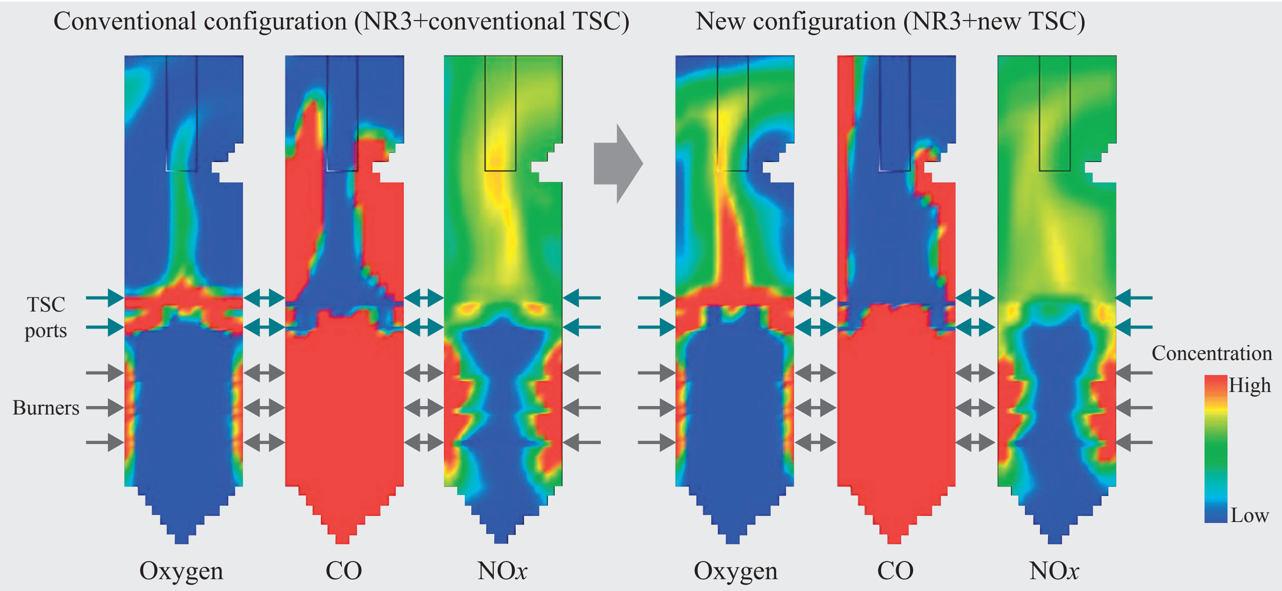


Fig. 10—Example Numerical Analysis Results.
The results show that the new multi-stage TSC ports drastically lower CO levels without changing the level of NOx.

changing from a conventional two-stage TSC system to the new TSC system. Fig. 10 shows the results of the analysis as represented by the distributions of gas compositions (oxygen, CO and NO*x*) along a vertical cross section of the furnace, and Fig. 11 shows the overall results in terms of the reduction in NO*x* level.

The locations of the existing two-stage TSC ports on the boiler were left unchanged and therefore the size of the NO*x* reducing zone between the burners and the TSC ports remained as it was. The numerical analysis predicted that the CO level would be lowered by more than 50% without any change in the NO*x* level. This result depends on lowering the concentration of CO around the front and rear walls in the upper part of the furnace (red colored region in the figure). In the new TSC system, each tier of TSC ports corresponds to a particular region of the furnace and supplies air based on the distribution of unburned gas to promote the mixing of unburned gas and air. In this way, the new TSC system drastically lowers the level of CO.

After the numerical analysis was completed, the new TSC system was installed on the actual boiler. Fig. 12 shows the results of demonstration testing.

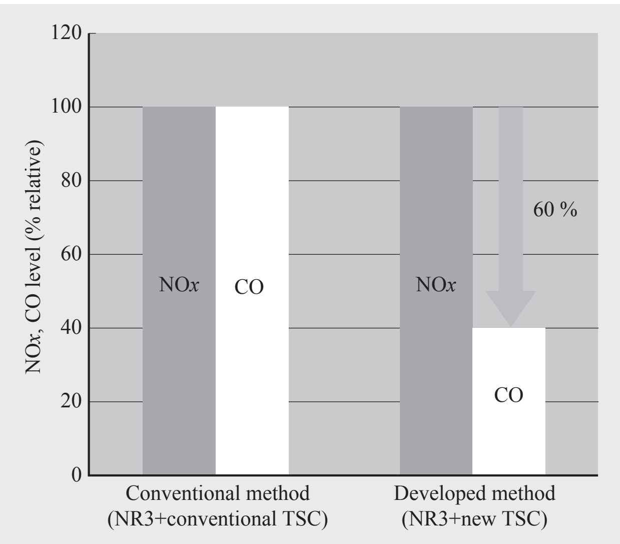


Fig. 11—Results of Numerical Analysis.
The analysis indicates that the new combustion method can lower CO by more than 50% without changing NOx levels.

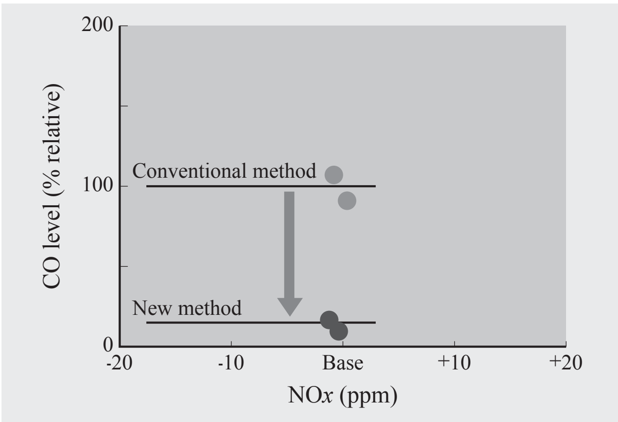


Fig. 12—Results of Testing on 600-MWe-class Boiler.
Tests on an actual boiler demonstrated that the reduction in CO predicted by numerical analysis is also obtained in practical operation.

These show that the reduction in CO levels is even greater than predicted by the numerical analysis.

CONCLUSIONS

The requirement to protect the environment while still supplying cost-effective equipment is placing even greater demands on the development of low-NO_x combustion technology. At the same time, the types of coal used for power generation are becoming more diverse in order to ensure a reliable supply of energy.

Our testing and numerical analysis work has established reliable evaluation parameters capable of dealing with the current standard of coal used in the power generation industry.

Our combustion technologies have also been tested in practical applications where they have delivered excellent results.

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