Development of Ultra-low NOx Coal-firing Burner

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Mitsubishi Heavy Industries, Ltd. (MHI) has developed an ultra-low NOx burner (the M-PM burner) for coal-fired boilers, the demand for which is expected to remain firm. In addition to our prominent experience in this field, the burner was developed based on the concepts of low-NOx combustion conceived from the results of computational fluid dynamics (CFD) analysis, a field in which the recent improvement of calculation capacity has been remarkable. The scale-up test was conducted using a combustion test furnace with a single burner. Compared with latest low NOx burners before the development of the M-PM burner (A-PM burners), NOx emissions were cut by 40% under the condition in which the unburned carbon content was the same. The M-PM burner was then installed in an actual unit, simultaneously achieving a 42% decrease in NOx emissions (NOx level: approximately 50 ppm and the unburned carbon in the fly ash is 1% for coal with a fuel ratio of 1.7) and a 50% decrease in unburned carbon content. The use of our new burner can be effective not only for lower NOx emissions, but also for the improvement of efficiency and the prevention of sulfidation corrosion.

1. Introduction

Coal is an energy source with abundant reserves and the demand for coal-fired boilers is expected to continue in the coming years. Compared with gas or oil, on the other hand, coal produces higher CO_2 emissions per unit of combustion energy and contains larger amounts of nitrogen, making environmental measures more important. In addition to CO_2 reduction owing to improved combustion efficiency, the consumption of ammonia used in the denitrification system needs to be reduced by achieving lower NOx combustion. It is also necessary to reduce maintenance by extending the nozzle life or reducing the corrosive atmosphere to protect the furnace walls. As a viable, innovative low-NOx combustion system satisfying these demands, we have successfully developed a new burner (multiple pollution minimum burner; M-PM burner) by conducting large-scale combustion tests with the application of advanced CFD technology. This report presents the major test results regarding this new burner.

2. Concepts of M-PM burner

2.1 MHI low-NOx combustion technologies

(1) Pollution minimum (PM) burner

Generally, the amount of NOx produced during the combustion of pulverized coal is shown by a convex-shaped distribution with the peak being at 3–4 of the weight ratio of primary air to coal (A/C). The peak approximately corresponds to the stoichiometric ratio for volatile matter. In the operation of the pulverized coal fired system, the A/C ratio at the outlet of the coal pulverizer is approximately 2 and thus relatively large amounts of NOx are emitted.

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However, our PM burner has a pair of two coal burner nozzles, feeding pulverized coal separately according to its concentration in the air (rich and lean) to form a coal rich flame and a coal lean flame, respectively. The A/C ratio of each flame is sufficiently deviated from 3–4 and the combined use of these flames has made low NOx combustion possible.

(2) In-furnace NOx reduction technology (Mitsubishi advanced combustion technology; MACT)

In MACT, combustion air is separately supplied to the main burner combustion zone and the combustion completion zone (the air provided in the combustion completion zone is called additional air or AA). The NOx-reducing atmosphere created in the furnace enables low NOx combustion. Ahead of other countries, MACT was applied to oil-fired boilers in 1981 and coal-fired boilers in 1985.

(3) Advanced pollution minimum (A-PM) burner

The A-PM burner was developed based on the same principle as that of the PM burner for fewer NOx emissions, but it requires only a single nozzle. In the nozzle, different pulverized-coal concentrations in the air (coal-lean and coal-rich) are achieved in the inner circular area and its surrounding outer area, thereby realizing low NOx combustion. Furthermore, the flame holder is equipped with the primary nozzle, and radiation in the furnace is effectively utilized to stabilize the ignition. The combined use with MACT can achieve better NOx characteristics, allowing unburned carbon content to be decreased and the range of applicable types of coal to be extended.

2.2 Concept of low NOx combustion

Calculation capacity in CFD analytical technology has improved significantly in recent years and it was used in the development of our burners. To achieve better computational accuracy, we are constructing various models such as the volatile matter emission model that takes coal molecular structure into consideration, the ignition model used for the detailed calculation of volatile matter reaction rate, and the NOx model to which various radicals are introduced in the reaction pathways. **Figure 1** shows the CFD analysis results of combustion testing using a 4 t/h test furnace with a single conventional A-PM burner.

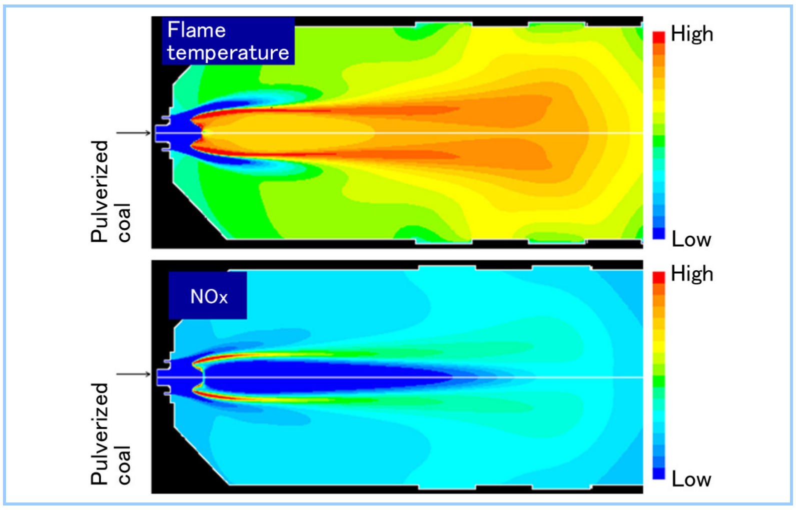

Figure 1 CFD analysis results of conventional A-PM burner

The burner is located on the left side of the figure, forming a flame toward the right. Although there is no indication in the figure, AA nozzles are installed in the downstream region of the flame. The air ratio in the burner is below 1. Considering the obtained flame temperature and NOx concentration distribution results, together with our expertise and experience, we have developed the M-PM burner based on the concepts shown in **Figure 2**.

(1) A large, uniform ignition area is created over the entire surface of the burner nozzle to achieve better ignition performance than a conventional A-PM burner.

(2) According to the coal combustion characteristics, the optimum amount of secondary air is supplied at the optimized timing in order to optimize the oxygen concentration in the outer flame. As a result, the high temperature and high oxygen level area in the outer flame, which causes the formation of NOx, is diminished.

(3) By maintaining the reducing atmosphere in the inner flame, NOx is effectively reduced by the existing reducing substances in the inner flame (volatile matter and char) and simultaneously, the combustion of unburned carbon is facilitated.

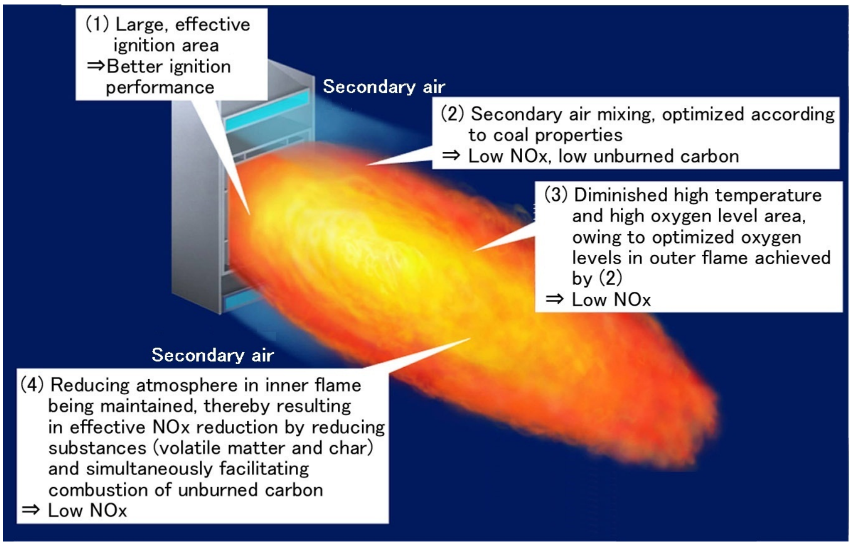

Figure 2 Basic concepts for our new low-NOx burner (M-PM burner)

3. Test results of 4 t/h test furnace with single burner

Several kinds of trial burners were designed based on the aforementioned concept of low NOx combustion and were screened using a 100 kg/h or 500 kg/h combustion test furnace with a single burner. The selected burner was then tested on a 4 t/h test furnace with a single burner, to perform the final verification. With the 4 t/h furnace, the test burner can be almost the same scale as the actual equipment, making it possible to obtain data such as flame temperature, unburned carbon in fly ash, NOx emissions and the ignition performance of the coal burner, which are applicable to the actual operating conditions.

3.1 Combustion condition

Photographs of the combustion in the 4 t/h furnace are shown in **Figure 3**. With the M-PM burner, a large, uniform ignition area is formed over the front surface of the nozzle. Ignition performance that is better than the A-PM burner has been demonstrated.

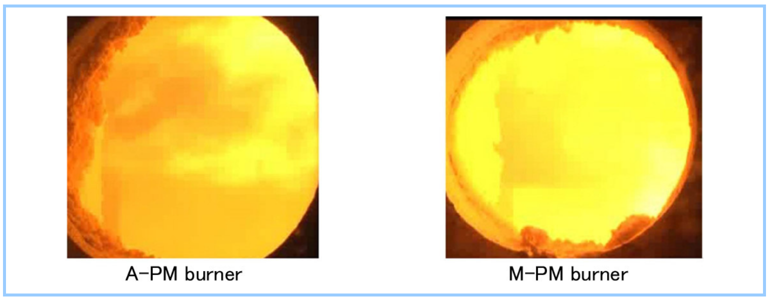

Figure 3 Combustion comparison in a 4 t/h furnace

3.2 NOx/unburned carbon characteristics

Three types of coal with different fuel ratios (the fuel ratio is defined as the ratio of fixed carbon to volatile matter) were tested using the M-PM burner. The NOx emission results are given in **Figure 4**, while the unburned carbon content results are shown in **Figure 5**.

Under the same unburned carbon content condition, NOx emissions from coal with an intermediate fuel ratio were decreased by 40%. Because with a lower fuel ratio, more volatile matter is contained in coal and consequently, the amount of reducing substances produced during combustion increases, the decrease rate of NOx emissions was greater in coal with a low fuel ratio than in coal with a high fuel ratio. In the M-PM burner, the mechanism of low NOx combustion is conceived from the concept of the effective utilization of such reducing substances. Therefore, the decrease rate increases as the fuel ratio becomes smaller. Under the same NOx conditions, on the other hand, the unburned carbon content of coal with an intermediate fuel ratio was halved.

Regarding coal with a high fuel ratio, the decrease rate was slightly increased. In the case of coal with a low fuel ratio, the unburned carbon content was already low and therefore remained the same. In the M-PM burner, carbon with low combustibility can also be burned effectively, which accounts for the effect shown more evidently by less combustible coal types.

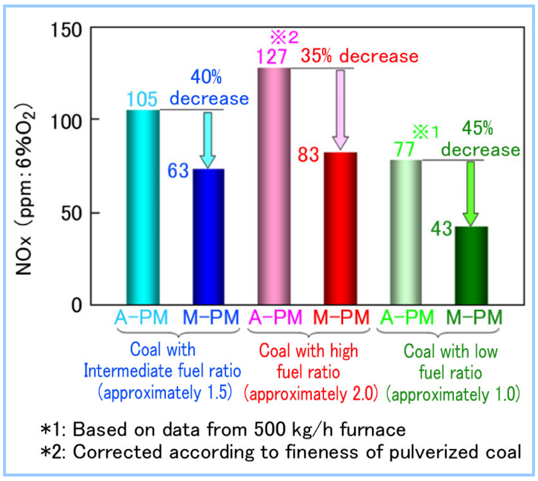

Figure 4 Comparison of NOx emission results obtained by combustion test using 4 t/h furnace with single burner

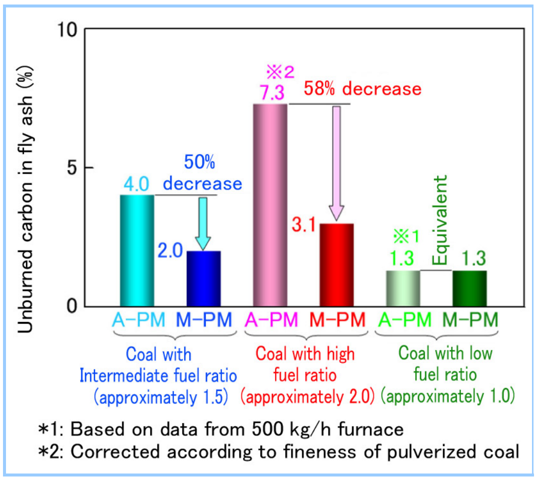

Figure 5 Comparison of results of unburned carbon content in fly ash, obtained by combustion test using 4 t/h furnace with single burner

4. Results of test operation by actual unit

The M-PM burner, for which the final verification was conducted using a 4 t/h test furnace, was introduced to an overseas unit. **Table 1** gives the description of the modifications for retrofitting. The retrofitted unit was a large circular-firing, four-corner-fired boiler of 700 MW output class. The existing burner was replaced with the M-PM burner and MACT was adopted (additional installment of AA nozzles). From November 2012, three domestic/overseas units in total subsequently commenced operations with M-PM burners. In all the units, the performance guaranteed values were satisfied and operations have continued smoothly without problems such as burning damage or clinker deposition on the nozzles

Table 1 Description of modification for retrofitting of the overseas unit

Item	Specifications
Boiler output	700 MW
Number of stages of burner	6 stages
Boiler type	Forced circulation boiler
Firing system	4 corners, circular firing
Modification for retrofitting	(1) Replacement of burner nozzle (2) Additional installment of AA wind box

4.1 Operational status

Figure 6 shows a photograph of combustion condition, which was taken during the operation of the three-stage coal burners at 50% load. The combustion was very stable. **Figure 7** shows the metal temperature of the coal-firing burner. Under normal operation conditions, the metal temperature of the coal burner nozzle is maintained around 500 to 600°C and thus a longer operating life can be expected. According to our visual observations, although only over a short period of time, none of the problems such as deformation, burning damage or slag deposition on the nozzles occurred.

4.2 NOx/unburned carbon characteristics

Figure 8 compares the results of NOx emissions before and after modification of the aforementioned overseas unit. The combustion performance was adjusted using coal with an intermediate fuel ratio (fuel ratio: 1.7). The modifications to the M-PM burner and the installation of additional AA nozzles allowed NOx emissions to be decreased to nearly one-third (from 170 ppm to 53 ppm), while the unburned carbon content in fly ash was lower than before, thereby obtaining excellent results.

Figure 6 Diagram of combustion with M-PM burner installed in actual unit

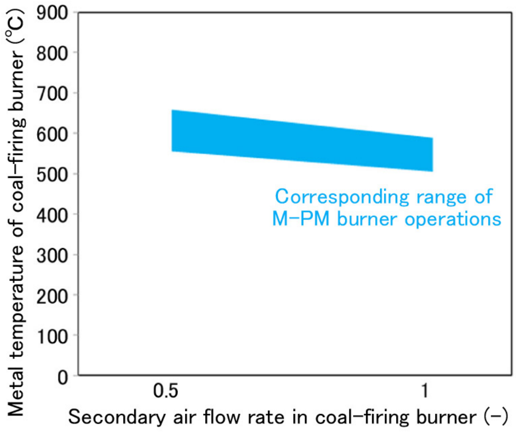

Figure 7 Relationship between secondary air velocity and metal temperature of coal-firing burner

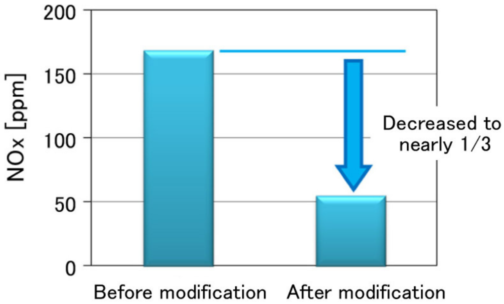

Figure 8 NOx emission comparison before and after modification of overseas unit

In **Figure 9**, the characteristics of the NOx level/unburned carbon content are compared between the M-PM burner and an A-PM burner (because the data was obtained from different units, correction was performed to make the operational conditions the same), indicating a 42% decrease in NOx emissions and 50% reduction in unburned carbon content in fly ash. In the M-PM burner, in addition to the creation of a large, uniform ignition area over the entire surface of the nozzle enabling effective NOx reduction to occur in the inner flame, carbon with low combustibility can also be burned effectively. These advantages made a clear difference in the results, even on an actual operational scale.

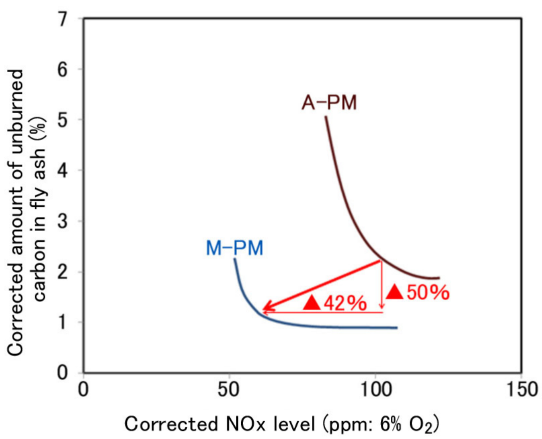

Figure 9 Comparison of M-PM burner with conventional A-PM burner

Figure 10 shows the relationship between the NOx level and the air ratio in the burner (i.e., the ratio of the air excluding AA in the main combustion zone). A prominent advantage of the M-PM burner is the optimization of the oxygen concentration in the outer flame, which in turn diminishes the high temperature and high oxygen level area that causes the formation of thermal NOx. Therefore, less NOx can be emitted even in a range of relatively-high burner air ratios. The operational results have confirmed that NOx emissions can be suppressed as low as an A-PM burner, even in the range of a burner air ratio between 0.85 and 0.9.

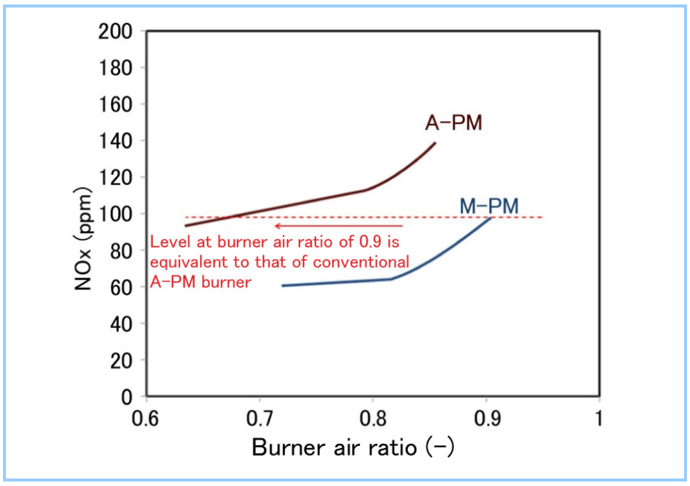

Figure 10 Relationship between NOx level and air ratio in burner

4.3 H_2S measurement results

The method of low NOx emissions achieved by supplying air separately from the burner and AA nozzles is commonly used today.

As a result of the reducing atmosphere created due to the low excess air ratio in the burner, the sulfur the in coal is converted to hydrogen sulfide (H_2S), and the problem of sulfidation corrosion of the furnace walls is becoming more conspicuous.

Figure 11 shows the results of H_2S measurement in the overseas unit with the M-PM burner and the unit equipped with an A-PM burner. Measurements were conducted vertically and horizontally in the furnace, mainly covering "the zone between the first burner nozzle from the top and the AA nozzle," in which there is a tendency for H_2S levels to increase. The lines in the figure are the result of connecting the highest value points of the zone under each measurement condition.

It is already known that there is a tendency for H_2S levels to decrease with any increase in the air ratio in the burner. It has been demonstrated that with the use of the M-PM burner, the H_2S level at the same burner air ratio is decreased by approximately 30% compared with a conventional A-PM burner. This effect is considered to result from the optimization of the oxygen concentration in the outer flame. With the M-PM burner, as described in section 4.2, NOx emissions can be lowered even in the range of high burner air ratios. Therefore, it has also been demonstrated that H_2S levels can be remarkably decreased through the use of the M-PM burner.

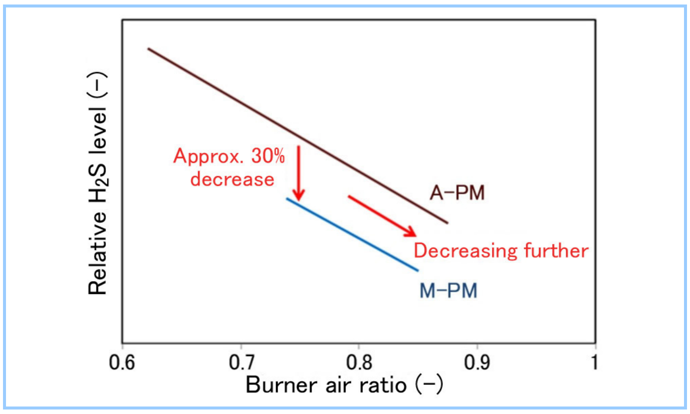

Figure 11 Relationship between H_2S level and air ratio in burner

5. Conclusion

Based on new concepts, we developed an ultra-low NOx coal-firing burner (the M-PM burner). Compared with MHI's latest low NOx burners before the development of the M-PM burner (A-PM burners), the M-PM burner has enabled NOx emissions to be decreased by 42% and the unburned carbon content in fly ash to be decreased by 50%. With the M-PM burner, less NOx can be emitted, even at high burner air ratio ranges. When only the effect of the M-PM burner is taken into account, H_2S levels can be 30% lower than the A-PM burner. The occurrence of sulfidation corrosion is expected to become considerably less frequent as a result of operation with a high air ratio in the burner.

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