Development of Ultra-low NOx Coal Firing M-PM Burner and Successfully Operational Results

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There is hope for coal as an important future energy source because of its abundant and evenly distributed reserves. On the other hand, much lower NOx is desired to reduce environmental load and MHPS has, in response to this desire, developed and commercialized an ultra-low NOx burner (M-PM burner) to be used for coal-fired boilers. Verification tests for power generation (with an output of 350-700MW, coal with an intermediate fuel ratio, about 10% ash) using 4 actual boilers in which the burners alone or combustion burners and AA (Additional Air) nozzles were modified demonstrated the achievement of the world's best ultra-low NOx level of 50-110ppm, also finding measures applicable to reducing operating costs.

1. Introduction

There are abundant reserves of coal and it is an evenly distributed source of energy that is not confined to specific regions, and it is expected that coal-fired boilers for power generation will be in important role in the future. On the other hand, CO_2 emissions from coal per unit amount burned are larger than those from oil or gas, and moreover, the significant N content of the fuel generates a large amount of NOx, thus requiring high-efficiency and low-environmental load operation.

Furthermore, the reduction of operating costs by making both CO_2 mitigation and low-NOx combustion compatible, decreased repair costs through measures such as extending the burner life and lower consumption of ammonia for use in the denitrification system are required by all users.

Mitsubishi Hitachi Power Systems, Ltd. (MHPS), for the establishment of innovative low-NOx combustion technology satisfying the above factors, combined high-precision CFD technology with large-scale combustion tests and developed and commercialized a new M-PM (multiple pollution minimum) burner, thereby achieving the world's best level of NOx/unburned combustibles scarcity. This paper establishes a new concept of coal firing low-NOx combustion and exemplifies the results from several actual operations of new burners developed based on this concept.

2. M-PM burner concept

2.1 M-PM burner concept draft

In recent years, MHPS has expanded the application range of simulation analysis technology improved significantly in its calculation capability to a variety of combustion state simulations and burner development. Previous developments include a volatile matter emission model into which the coal molecular structure is incorporated for the higher computational accuracy, an ignition model to calculate the reaction rate of volatile matter in detail, and a NOx model with some radical models introduced into the reaction pathway. Using the above simulation technology, we identified the location of NOx generation in a conventional low-NOx burner for the M-PM burner concept draft.

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Figure 1 shows the analytical results of combustion tests of an existing low-NOx A-PM burner[1, 2] conducted in a 4-t/h single-burner furnace.

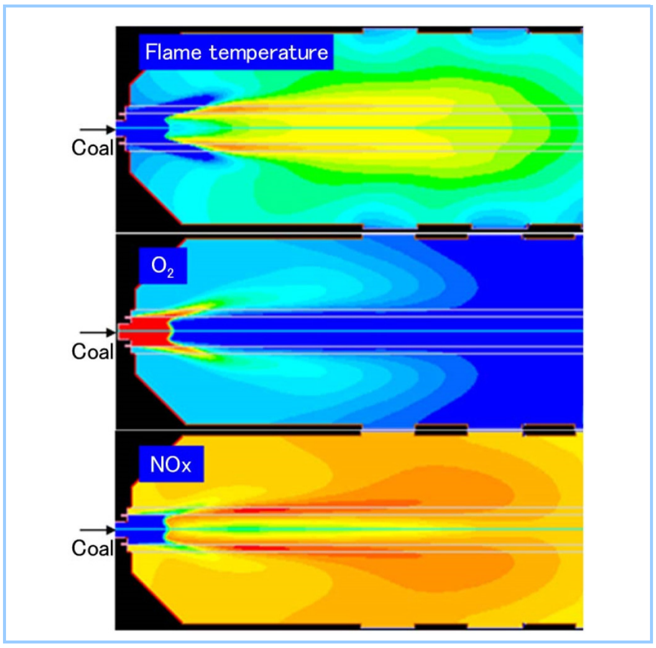

Figure 1 Analytical results of conventional low-NOx A-PM burner

Conventional low-NOx A-PM burners realized low-NOx combustion by feeding pulverized coal separately according to its concentration in the air (rich and lean) between the outer and inner nozzle circumferences, as well as stable ignition by installing a flame holder (stabilizer) at the secondary air nozzle to efficiently use in-furnace radiation. Figure 1 shows that the burner is placed on the left side and the flames are formed to the right. Downstream from the flame, an AA (additional air) nozzle is installed. This analysis found ignition to be stable even at a burner air ratio of less than 1. On the other hand, it was found that NOx is generated in a high temperature and high-oxygen zone that is formed as a result of the secondary air being sent into the high temperature zone around the periphery of the flame, and we considered that if a burner suppressing such a condition was developed, it would enable the further curtailment of NOx.

2.2 Low-NOx combustion concept

Based on analytical results of an existing low-NOx A-PM burner, the further lower-NOx combustion concept was drafted and verified (**Figure 2**). Air supply in the circular-firing system is completed by feeding secondary air and auxiliary air (corresponding to tertiary air) in that order to primary-air and pulverized coal flames. In 2-stage combustion, AA is further injected from the downstream and the whole process is roughly divided into an ignition zone, a reductive combustion zone, and a combustion completion zone.

(1) Internal flame stabilized combustion

Previous burner developments emphasized stable ignition on the outside periphery of a pulverized coal flow, resulting in a major cause for the local formation of a high-temperature and high-oxygen zone. Hence it was decided to place these flame stabilizers within the pulverized coal flow (inside the nozzle’s front section), as well as to bring an ignition delay to the outside periphery by sending surrounding secondary air straight ahead. The exclusive supply of primary air to the ignition section and the commencement of combustion in the low-oxygen zone allow the NOx to be reduced effectively inside the flame. In addition, as the flames develop from inside the pulverized coal stream to the outside periphery of the stream, secondary air around the coal burner and auxiliary air are mixed gradually, preventing from narrow high temperature and high-oxygen zone on the outside periphery of the flames, thereby also making the reduction of NOx around the burner possible. Furthermore, since spacious inside ignition area allows the combustion temperature to be kept high even inside the flame free from concern over incomplete burning, faster in-flame char combustion than ever before reduce unburned carbon.

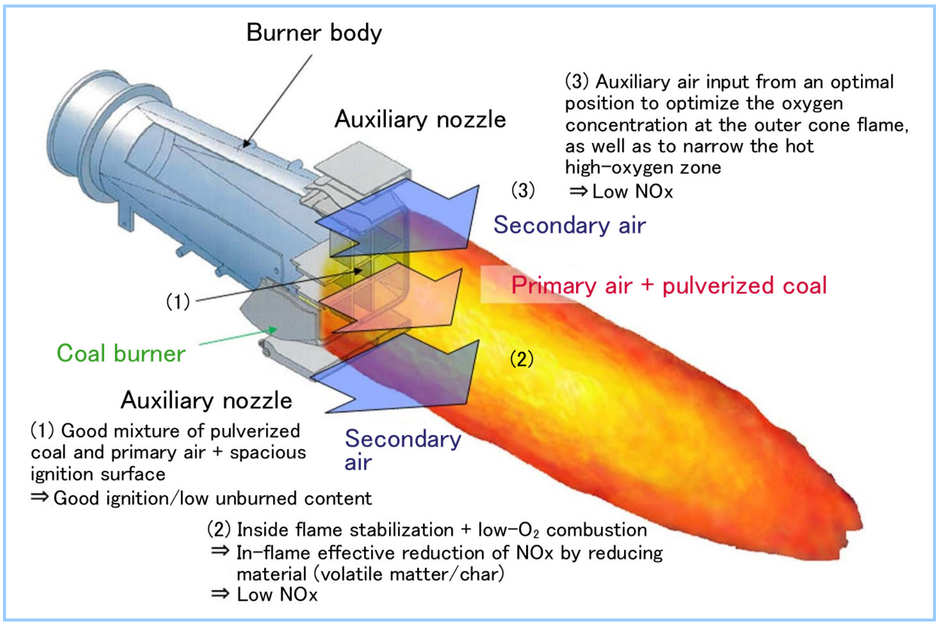

Figure 2 M-PM burner concept

(2) Secondary air injection from an optimal position

Secondary air is roughly classified into that input from the nozzle's outside periphery as in Figure 2 (coal secondary air) and that input from the neighboring air nozzle (auxiliary air: supplementary air). Here, in coal combustion, the volatile matter quickly completes its combusting, while char requires some time to burn. In consideration of the time required for mixing, relatively low-flow rate coal secondary air closer to the primary air contributes to volatile matter combustion, while relatively high-flow rate auxiliary air somewhat distant from the primary air contributes to char burning. If secondary air is insufficient, volatile matter is incomplete combusted to prevent char from burning. On the other hand, if excessive oxygen remains, it hampers NOx reduction. For this reason, the distribution adjustment of coal secondary air and auxiliary air is much important for low NOx and unburned carbon.

(3) NOx reduction at AA section

Since the atmosphere becomes oxidative after AA injection, the N remaining in char, as well as the gas phase N content, become NOx at a high conversion rate. When the stoichiometric ratio in burner zone decreases, the N content released before AA injection decreases, while the char N oxidized by AA increases. Meanwhile, an increase in AA ratio promotes combustion at the AA section and the amount of thermal NOx generated also increases. If the burner air ratio is higher under same boiler total excess air, therefore, the amount of NOx generated at the AA section decreases.

In general, an increase in AA ratio intensifies the reducing atmosphere at the burner section, thereby achieving a reduction in NOx, but if the aforementioned alleviation of and high temperature and high-oxygen zones are realized by inside flame stabilization, the reducing atmosphere within the flames can be maintained even though the stoichiometric ratio in the burner zone is raised, thereby permitting NOx occurrence at the AA section to slow for the assumed possibility of maintaining an equivalent NOx level even if the AA ratio is reduced (stoichiometric ratio in the burner zone is raised)..

3. Results of tests using a 4-t/h single burner test furnace

A burner based on the aforementioned low-NOx combustion concept was test-designed and, after screening with a single-burner test furnace for combustion of 100kg/h or 500kg/h in terms of pulverized coal supply amount, the final verification was conducted by means of a 4-t/h single-burner test furnace, using the selected burner. The selected flame stabilizer, installed at the primary air nozzle, was shaped/arranged as to constantly and forcefully stabilize the flames, while rectifying the streams to facilitate effective ignition from inside. The 4t/h furnace can be tested with an almost same actual-scale burner, and data assuming actual equipment, including the state of ignition, NOx, unburned carbon and flame temperature, can be obtained..

(1) State of combustion

Figure 3 shows the state of combustion in the 4t/h furnace. M-PM burner tests found that a spacious uniform surface for ignition was formed in front of the nozzle and ignition equal to or better than that of a conventional low-NOx A-PM burner could be obtained.

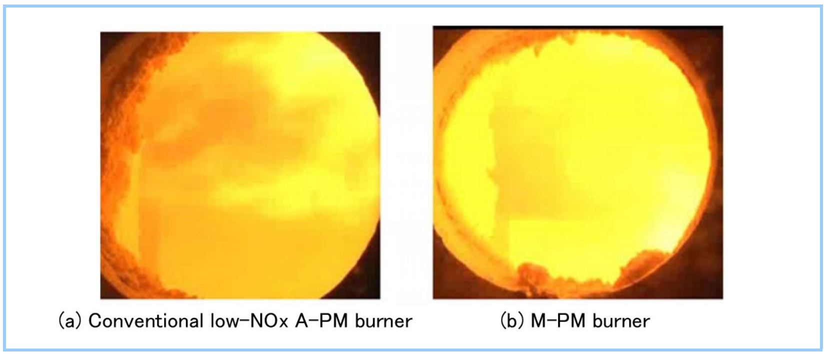

Figure 3 State of combustion in 4-t/h single-burner test furnace

(2) Characteristics of NOx/unburned combustibles

Regarding the developed M-PM burner, **Figure 4** compares NOx and Figure 4 (b) compares unburned carbon in ash when tested, using coal with an intermediate fuel ratio. In coal with an intermediate fuel ratio, NOx was found to have been reduced by 20-40% for the same unburned combustibles. The unburned combustibles were also found to have decreased by 25-50% if NOx was the same. Although these rates of reduction depend on operating conditions and physical boiler sizes, it was found that NOx and unburned carbon could be reduced with a roughly actual-scale burner.

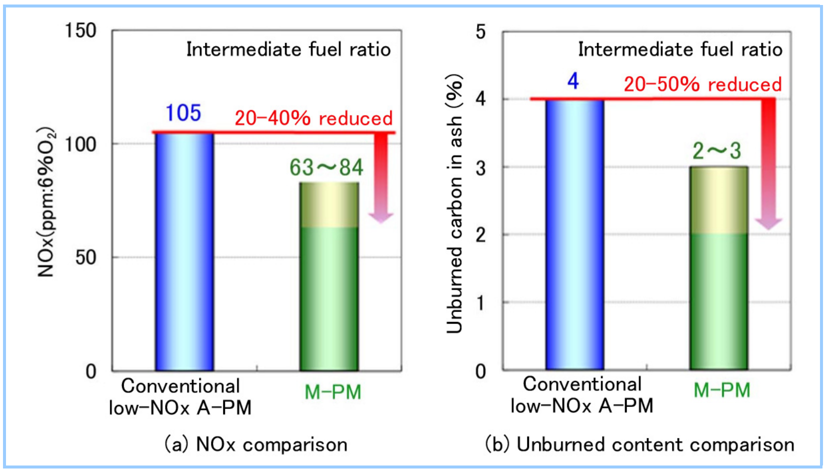

Figure 4 NOx/unburned content comparison for 4-t/h single-burner test furnace

4. Operational results of actual burner

M-PM burners verified in the test furnace located in Mitsubishi Heavy Industries Research & Development Center started in November, 2012 to be operated one by one at 8 domestic or overseas units for the present steady performance-guaranteed operation in effect in all units without clinker adhesion, burnout of nozzles and other defects. This paper cites the results of operation in an overseas Z2 unit (700MW) and a domestic H5 unit (600MW) as typical examples of actual operation. The coal used in both is intermediate fuel ratio bituminous coal containing roughly 10-15% ash and Chinese coal operated in the overseas unit contains roughly 1% N, while the N content of Australian coal used in the domestic unit is about 1.8%.

4.1 State of operation (overseas Z2 unit)

Table 1 summarizes the specifications for modification, and the photo showing the state of combustion (**Figure 5**) was taken at the time of 50%-load 3-stage coal firing burner operation, where combustion was found to be quite stable. The metal temperature of the coal firing burner was kept sufficiently low. **Figure 6** compares the characteristics of NOx and unburned carbon in fly ash before and after modification. M-PM burner modification and additional AA installation enable a conventional burner's NOx to be reduced from 170ppm to about one third-worth 53ppm, while keeping unburned carbon in fly ash equal to or less than those before modification, justifying quite favorable results.

Table 1 Content of Z2 unit modification

Item	Spec.
Boiler output	700MW
Number of burner stages	6 stages
Type of boiler	Forced circulation boiler
Combustion system	4-corner/turning combustion
Content of modification	(1) Replacement of burner nozzle Conventional burner⇒M-PM burner (2) Additional AA installation

Figure 5 State of combustion in Z2 unit

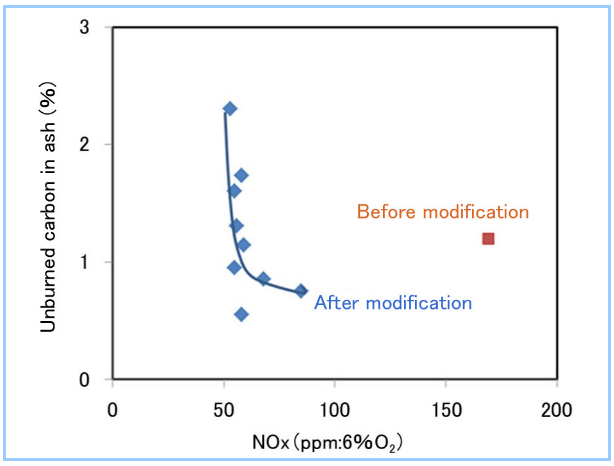

Figure 6 Comparison of Z2 unit performance before/after modification

4.2 State of operation (domestic H5 unit)

Table 2 summarizes the specifications of the modification. Quite stable combustion was also found, the same as in the overseas unit. **Figure 7** compares performances (NOx and unburned carbon emission characteristics) before and after modification. It was found that NOx decreased by 30% (158→110ppm) for equivalent unburned combustibles

Table 2 Content of H5 unit modification

Item	Spec.
Boiler output	600MW
Number of burner stages	6 stages
Type of boiler	Variable pressure operating once-through boiler
Combustion system	4 corner/turning combustion
Content of modification	Replacement of burner nozzle A-PM burner => M-PM burner

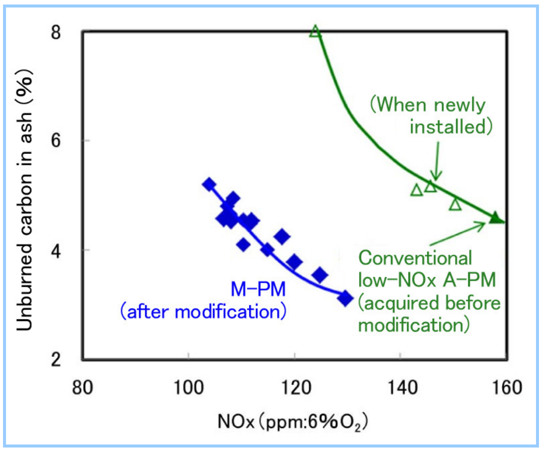

Figure 7 Comparison of H5 unit performance before/after modification

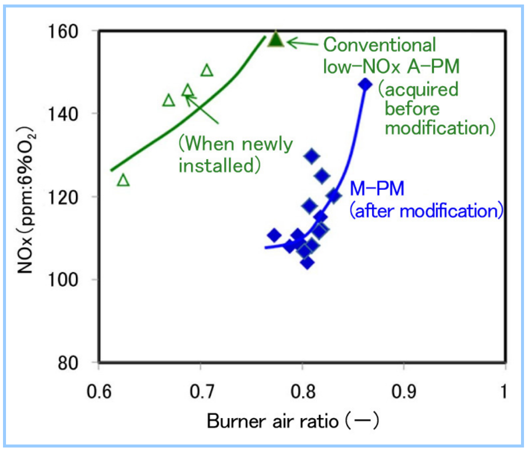

Figure 8 Comparison of H5 unit characteristics for NOx generation

This unit only modified MHPS's existing low-NOx A-PM burner to an M-PM burner, demonstrating the effectiveness of the latter in NOx reduction. Next, **Figure 8** compares NOx emission characteristics (NOx by stoichiometric ratio in burner zone). The stoichiometric ratio in burner zone indicates the ratio of air contained in the boiler in total, from which the amount of AA is deducted. It was found that NOx can be reduced by 30% for the burner air ratio, equal to that of an unmodified conventional low-NOx A-PM burner.

In addition, even if the ratio is raised to 0.87, it resulted in the amount of NOx equivalent to the unmodified ratio of 0.77. This proved that the mitigated high-temperature and high-oxygen zone around the outside periphery permits a NOx reduction zone to be formed even if the stoichiometric ratio in burner zone is raised. As for unburned carbon, it was found to have decreased from 4.6 to 3.0% under certain conditions, proving that the modification of an M-PM burner improves the characteristics of NOx and unburned carbon emission.

5. Conclusion

Based on the new concept of a next-generation coal firing combustion system, MHPS has developed and commercialized an M-PM burner. The operation (using coal with an intermediate fuel ratio of 10-15% ash content) in a utility boiler that has undergone the modification into an M-PM burner witnessed a 30% reduction of NOx from that of an existing low-NOx A-PM burner, not only achieving the world's best level of low-NOx/low-unburned carbon emission, but also proving the usefulness of such a reduction in curtailing future running costs. Moreover, low-NOx operation can be assured even if the burner air ratio is high, and the basic concept of an M-PM burner could also be verified on an actual basis. MHPS intends to make continuous R&D efforts toward the future, aiming at the further improvement of performance.

Reference

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2. Takashima, R. et al., Application of The A-PM Burner for Low-combustibility Petroleum Coke, International Conference on Power Engineering-03 (ICOPE-03) November 9, 2003, Japan