Development of Mill-burner System for Low-rank Coal with Super-high Moisture

RYUHEI TAKASHIMA*1 SHINJI MATSUMOTO*1

KENICHI ARIMA*1 TAKUICHIRO DAIMARU*2

YASUHIRO TAKEI*3 KAZUSHI FUKUI*3

Low grade coal accounts for half of all coal resources in the world, and super-high-moisture coal with a moisture content exceeding 50% is one such kind. When such super-high-moisture coal is applied to conventional USC boilers, the shortage of mill drying capacity and the decline of ignitability and combustibility caused by the decrease of oxygen concentration in burner zones and the increase of the moisture content of coal particles are the main concerns. In this research, grinding tests and combustion tests using super-high-moisture coal were carried out by Mitsubishi Hitachi Power Systems, Ltd. (MHPS), and the stable grinding conditions for preventing particle adhesion in mills under high humid atmosphere, as well as stable combustion under low oxygen concentration in primary gas, were verified. These results enabled the utilization of low grade and super-high-moisture coal in conventional USC boilers.

1. Introduction

Since coal is an energy source with abundant and ubiquitous reserves, the increasing demand for power generation by coal-fired units is expected to continue in the coming years.

Of all the recoverable coal reserves, approximately 50% are low-rank coals such as lignite and sub-bituminous coal. These coals are abundantly found in countries including Australia, Indonesia, the U.S. and in Europe, and are characterized mainly by low calorific value and a moisture content of nearly half of the mass. In Australian brown coal, for example, about 60% of the mass is made up of water[1].

As a fuel, low-rank coals have a low energy density. Therefore, compared with high-rank coals, international trade of low-rank coals is rare and they are mainly consumed locally in the mining areas. However, as the production of high-rank coals is expected to decline in the future, there is potential for an increase in the export of low-rank coals to countries such as Japan.

In response to the potential for the expanded utilization of low-rank coals, a mill-burner system for low-rank coal with a high moisture content was developed and a demonstration test was carried out as part of the 2013 national project for the promotion of coal production technologies “Technological optimization and demonstration for the utilization of overseas low-rank coals,” subsidized by the Ministry of Economy, Trade and Industry. This report presents its summary..

2. Technological challenges of combustion system for super-high-moisture coal

As shown in **Figure 1** (left), in existing lignite-fired mine-mouth power plants in Europe and Australia, high-temperature combustion gas (approx. 1,000°C) is extracted from the furnace to beater wheel mills wherein high-moisture coal is dried and pulverized. This conventional system,

*1 Chief Staff Manager, Combustion Research Department, Research & Innovation Center, Technology & Innovation Headquarters, Mitsubishi Heavy Industries, Ltd.
*2 Combustion Research Department, Research & Innovation Center, Technology & Innovation Headquarters, Mitsubishi Heavy Industries, Ltd.
*3 Chief Staff Manager, Boiler Business Strategy Planning Department, Boiler Products Headquarters, Mitsubishi Hitachi Power Systems, Ltd.

including the fireproof high-temperature gas system and beater wheel mills, requires frequent maintenance. More frequent maintenance work is needed in the case of low-rank coal in Southeast Asia, which generally has low grindability.

We made minimum modifications to the system of existing USC boilers for the utilization of super-high-moisture coal with a moisture content exceeding 50%. In our planned new system, low-temperature flue gas after the heat exchange is led to the vertical roller mill, the performance of which has been proven in the utilization of bituminous coal (Figure 1, right). Therefore, in this system, the temperature of flue gas for drying in the mill is lower than that in the case of a lignite-fired conventional system, thus the cost and maintenance frequency can be reduced, and the broadening of the grindability range of applicable coal can be simultaneously realized.

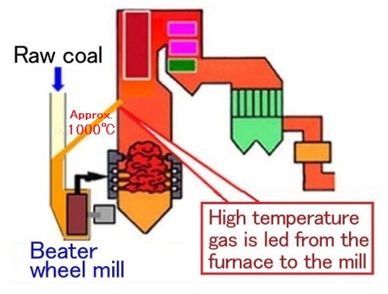
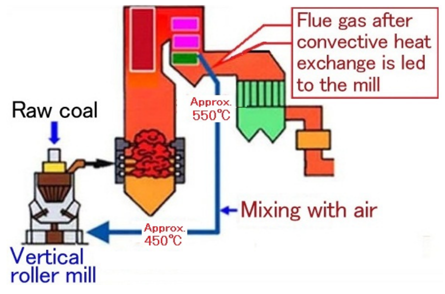
System	Existing system	MHPS low-temperature flue gas recirculation system
Outlined diagram		
Recirculated gas temperature	1,000℃	550℃
Mill type	Beater wheel mill	Vertical roller mill
Fineness of pulverized coal	40-50% of a 200 mesh pass (estimation)	70-80% of a 200 mesh pass
Features	・Frequent maintenance of the high temperature gas system ・Poor applicability to low-rank coals with low grindability, while there are many examples of coals with high grindability such as European lignite	・Reduction in cost and maintenance frequency by using a flue gas with a temperature cooler than the conventional system as a heat source for drying in the mill

Figure 1 Comparison of super-high-moisture coal-fired boiler systems

As a system similar to this new system, we have experience in the operation of vertical roller mills with a flue gas recirculation system for Mongolian brown coal (total moisture content: 44%)[2]. However, the following issues must be solved in order to use super-high-moisture coal (moisture content exceeding 50%.). The humidity in the mill is higher than that in our operation experience and we have to address the instability in operation due to pulverized coal accumulation or insufficient drying capacity. The drying medium is flue gas from the boiler which is low in O_2 and high in water content, and the humidity in the mill increases as a result of the drying process. The mill outlet condition (low O_2 and high humidity) is a more severe condition for combustion than that of a conventional system with bituminous or sub-bituminous coal, and these issues raise another concern about the instability of ignition or combustion in the burner.

To deal with these technical challenges, demonstration tests to examine the mill grinding and drying characteristics of high-moisture coal and the ignition and combustion stability in the burner under low- O_2 with high humidity were carried out.

Table 1 shows the test conditions of the new system for the utilization of super-high-moisture coal. As drying for high-moisture coal requires more heat at a mill, the high-temperature gas at the mill inlet must be applied. Supposing that the moisture content in pulverized coal at the mill outlet is 30%, the gas temperature required at the mill inlet is considered to be approximately 450°C.

The evaporation of water in raw coal increases the vapor concentration in the gas at the mill outlet and consequently the O_2 level of the primary gas in the burner is expected to be decreased to approximately 9%. The new system therefore involves operation under conditions deviating from the conventional system with bituminous or sub-bituminous coal. It was important to conduct grinding and combustion testing under such conditions, so we demonstrated the system validity for achieving stable grindability and combustibility.

Table 1 Planned system conditions for the use of super-high-moisture coal

Item		Existing MHPS systems		New system (plan)
Coal		Subbituminous coal	Mongolian brown coal	Very high-moisture coal
Mill	Total moisture in raw coal	27%	44%	55%
	Flue gas recirculation	No	Yes	Yes
	Inlet gas temperature	280°C	400°C	450°C
	Outlet gas temperature	60°C	70°C	75°C
	Outlet relative humidity	60%	60%	85%
Burner	Moisture content in pulverized coal	16%	22%	30%
	O_2 level in primary gas	20 vol.%	10 vol.%	9 vol.%

3. Grinding and drying test with vertical roller mill

For the study of the grindability and drying characteristics of high-moisture coal with the vertical roller mills, grinding and drying tests were carried out using a reduced-scale model of a vertical roller mill to verify the continuous and stable operation and drying characteristics.

Figure 2 is a system diagram of the grinding test facility. With regard to the grinding test facility, the standard grinding capacity is 2.6 t/h for bituminous coal. An auxiliary LPG burner was installed in order to obtain high-temperature flue gas as a drying medium. In addition, some insulation was provided for the pulverized coal fuel pipe system and the dust collector, and heaters were installed in order to maintain the temperature and prevent dew condensation.

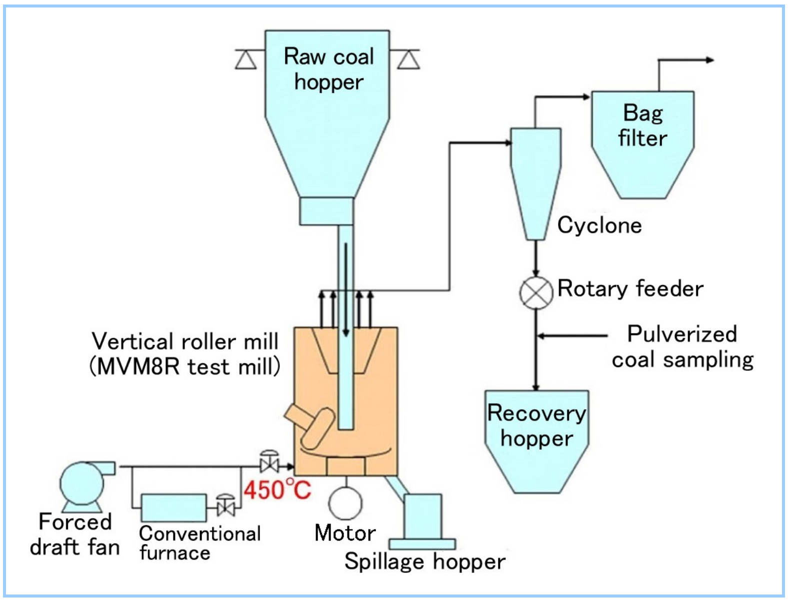


Figure 2 System diagram for test mill

Table 2 gives the properties of the sample coal. Upon the receipt of the Australian brown coal (which was used as a sample in this test), the moisture content in the raw coal was 61.4%, which is considerably higher than conventional bituminous or sub-bituminous coal, and there were some agglomerated particles that formed masses. The purpose of the test was to examine how these factors can affect the grindability and drying in the mill.

The grinding test conditions are shown in **Table 3**. For the evaluation of mill operation performance with high-moisture coal, three different coals with moisture contents of 45%, 50% and 55% were applied, and drying capacity and mill operation stability were verified in the test.

For the evaluation of mill operating conditions resulting from varying humidity at the mill outlet, humidity increased progressively in the range from 47% to 94% with (a) changes in the ratio of the pulverized coal flow rate to primary gas flow rate (i.e., solid/gas ratio) and (b) changes in the gas temperature at the mill outlet. Thus, the operatable upper limit was verified by monitoring the operating state and the presence or lack of agglomeration on the grinding table.

In the case of an outlet relative humidity of 85%, the pulverized coal on the grinding table after 2 hours of continuous operation was dry, which is nearly the same state as typical bituminous coal.

When the relative humidity at the mill outlet was increased by increasing the solid/gas ratio and reached 94%, there was a gradual increase in the amount of the roller lift in operation and wet agglomerated particles were found on the grinding table after operation. Based on the results, the upper limit of the relative humidity at the mill outlet to realize stable pulverization and drying of super-high-moisture coal were determined (applicable to a total moisture content of up to 55%)..

Table 2 Sample coal properties

Item		Unit	Very high-moisture coal sample (Australian)
Appearance		-	
Total moisture (upon receipt)		wt%	61.4
Proximate analysis	Moisture	wt%	23.6
	Fixed carbon	wt%	34.7
	Volatile matter	wt%	41.0
	Ash	wt%	0.78
	Higher calorific value	kcal/kg	4953

Table 3 Grinding test conditions

Item		New system (plan)	Demonstration test
Coal		Very high-moisture coal	Very high-moisture coal
Mill	Total moisture in raw coal	55%	45, 50, 55%
	Inlet gas temperature	450°C	up to 450°C
	Outlet gas temperature	75°C	67 to 75°C
	Outlet relative humidity	85%	47 to 94%

Figure 3 shows the relationship between relative humidity and the drying ratio fraction of pulverized coal.

As shown in the equation below, the drying ratio was calculated as a proportion of the evaporated water amount to the total moisture in the raw coal.

$$\text{Drying ratio (\%)} = \frac{\text{Evaporated water amount (kg/h)}}{\text{Total moisture in raw coal (kg/h)}} \times 100$$

According to the previous test results with bituminous and/or sub-bituminous coal, when the coal moisture content is 40% or less, the relationship between the relative humidity and the drying ratio can be expressed as the dotted line in the figure.

In this test in which the coal moisture content exceeds 45%, there was a tendency toward a higher drying ratio at the mill outlet than bituminous and/or sub-bituminous coal with a moisture content of 40% or less. This difference in drying characteristics is considered to be caused not only by the different levels of total moisture content in the raw coal, but also by the difference in coal properties and the form of the water in the coal.

Therefore, attention is required when designing the primary draft system, because there is a need for larger heat quantities for drying than the estimated values based on the conventional system with bituminous or subbituminous coal. To improve the prediction accuracy of the heat balance in the mill according to the coal properties, it is essential to continue to gather more relevant data.

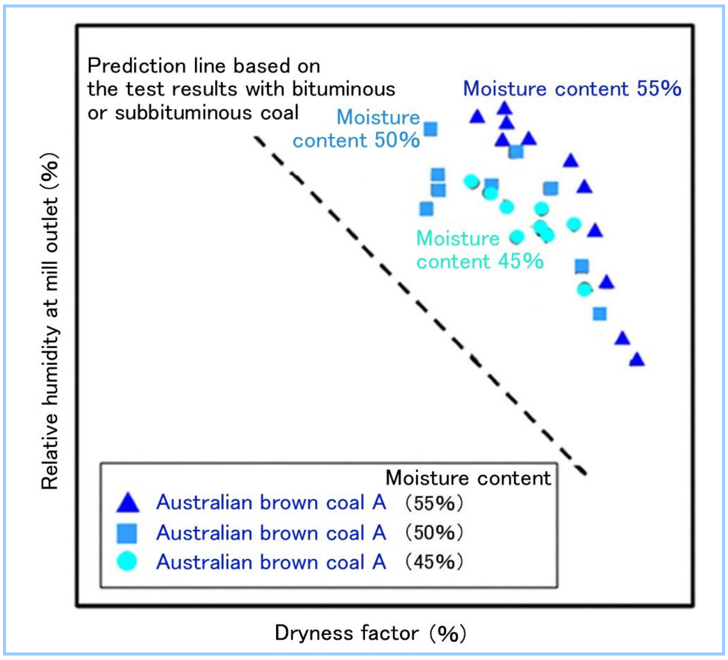


Figure 3 Relationship between relative humidity and dryness factor of pulverized coal

4. Demonstration of pulverized coal-fired burner in low-O_2 atmosphere

From the results of the grinding and drying test in the previous section, under the planned conditions in which super-high-moisture coal is dried/pulverized until the total moisture is reduced from 55% to approximately 30%, the ratio of solid coal to steam-containing primary gas in the burner (i.e., solid/gas ratio) is estimated to be approximately 0.2, and the O_2 concentration in the primary gas is decreased to nearly 9%. Based on these factors, combustion testing was carried out using a single burner test furnace under steam-induced low-O_2 conditions with a combination of flue gas recirculation.

Figure 4 gives the exterior view and system diagram of the single burner test furnace. In this test, flue gas drying and pulverization were designed to take place inside the mill. As in the actual units, the O_2 concentration in the primary gas was decreased through mixing flue gas recirculation. Humidity increased progressively in the range from 47% to 94%

In this test, grinding by the mill and combustion in the burner were carried out separately. Therefore, as a substitute for the moisture evaporated in the mill, an auxiliary boiler was used to produce steam, which was then added to augment the gas conditions at the mill outlet. In addition to combustion air provided to the main burner zone, as in the actual units, additional air (for two-stage combustion) was supplied to the combustion completion zone that is in the downstream area of the furnace. A NOx reducing atmosphere was thus created in the furnace, enabling low-NOx combustion.

The test burner was an MHPS low-NOx advanced pollution minimum (A-PM) burner. The A-PM burner realizes low NOx combustion by achieving different pulverized-coal concentrations (coal-lean and coal-rich) in the inner circular area and its surrounding outer area. Simultaneously, stable ignition is also enabled by effectively utilizing in-furnace radiation by means of the flame holder in the coal burner nozzle. Combined with the technology of two-stage combustion, the A-PM burner exhibits excellent low-NOx performance, reducing the unburned carbon content and extending the applicable range of coal[3].

Because of its excellent ignitability and combustibility, the A-PM burner has been installed in the direct mill system for the combustion of petroleum coke[4], which is a fuel with low flammability and low volatility. As a low-O_2 concentration around the burner nozzles was expected in the new system, the superior ignition and combustion performance of the A-PM burner, which is advantageous for the realization of stable ignition, was considered. The A-PM burner was thus selected for this test.

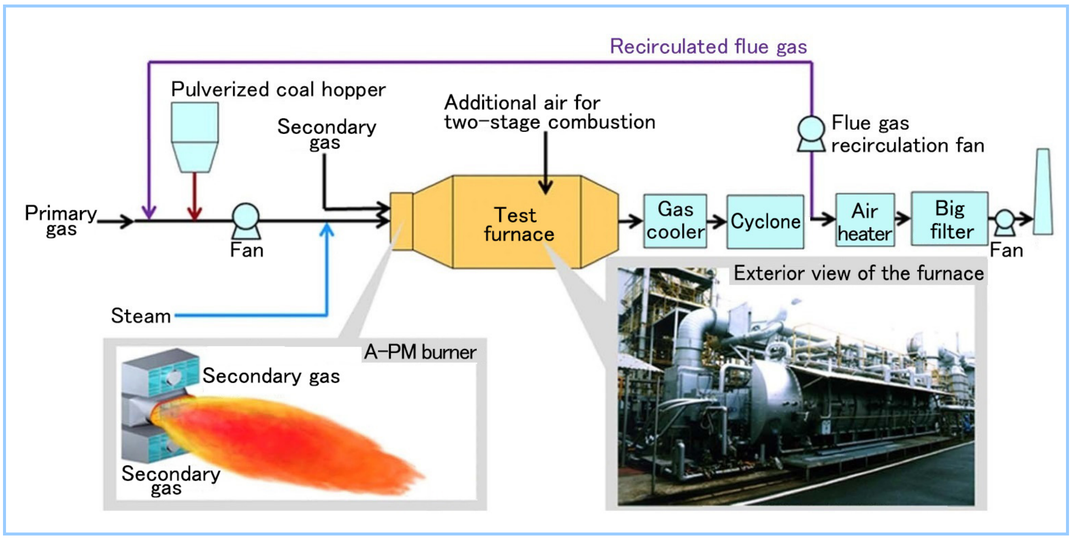


Figure 4 Exterior view and system diagram of the single burner test facility

Table 4 shows the properties of the tested coals. Australian lignite (moisture content: 62.8%) was fired for the test. The production conditions of the pulverized coal are shown in the results of the mill grinding and drying test. In low-rank coals such as lignite, the grade of coalification is low and the volatile matter is high, the combustibility of dried pulverized coal seems to be high. Therefore, compared with typical bituminous coal, the particle size of the pulverized coal used was set at 72% of a 200 mesh pass. The total moisture of the pulverized coal used in the test was 28.8%. The surfaces of the pulverized coal seemed to be dry and no agglomerated particles were found.

Table 4 Coal properties for the combustion test

Item		Unit	Row coal	Pulverized coal
Particle size		-		
Particle size		-	Several tens of millimeters (containing aggregated masses)	72% of a 200 mesh pass
Total moisture		wt%	62.8	28.8
Proximate analysis	Fixed carbon	wt%	16.4	31.4
	Volatile matter	wt%	19.9	38.1
	Ash	wt%	0.84	1.6
	Fuel ratio	-	0.82	0.82
	Higher calorific value	kcal/kg	2247	4300

The combustion test conditions are given in **Table 5**. The fuel flow into the test facility was constant (618 kg/h). The solid/gas ratio of the primary gas was 0.2 with flue gas recirculation flow control. The ignitability was verified in the O_2 concentration between 5.0% and 11.2%. The flue gas data, such as NOx or unburned carbon content, were also measured in the table 5 conditions, which are the planned mill operation conditions, with varying O_2 concentration at the outlet of the furnace..

Figure 5 shows the combustion conditions with a lower O_2 concentration in the primary gas.

When the O_2 concentration in the primary gas was progressively decreased from 11.2%, ignition was stable above 6.6%. As the O_2 concentration in the planned mill operation of actual units is 9%, there will be no combustibility problems caused under these planned conditions. As the results of testing to determine the minimum O_2 concentration for stable combustion, O_2 concentrations below 5% resulted in flame luminance becoming weak and heat flux also decreasing around the burner, making it difficult to maintain stable combustion.

Figure 6 gives the flue gas data with varying O_2 concentration at the furnace outlet.

Under stable ignition conditions, the NOx and unburned carbon are lower than bituminous coal and excellent combustibility can be realized.

Table 5 Combustion test conditions

Items	Unit	Change of O_2 level in primary gas	Change of O_2 level at furnace outlet
Moisture	%	28.8	
Fineness of pulverized coal	200 mesh pass	72%	
Coal consumption	kg/h	618	
Burner load	%	100	
O_2 level in primary gas	vol%-wet	5.0 to 11.2	8.8
Primary gas temperature	°C	75	
O_2 level at furnace outlet	vol%-dry	2.7	2.0 to 3.5
AA* ratio	%	30	
Aim	-	Examination of ignition stability with flue gas recirculation	Estimation of NOx and unburned under planned mill operations conditions

*AA: additional air (two-stage combustion air)

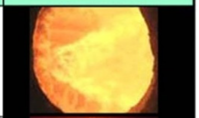
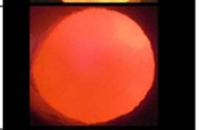
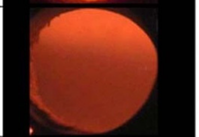
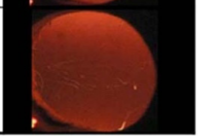
Coal	Moisture content in pulverized coal (wt%)	O_2 level in primary gas (% vol., wet)	Combustion in the vicinity of burner nozzle
Bituminous coal (for reference)	2.0	21.0	
Very high-moisture coal	28.8	11.2	
		6.6	
		5.0	

Figure 5 Combustion in an atmosphere with reduced O_2 levels in primary gas
(Burner load: 100%, O_2 level at furnace outlet: 2.7 % vol., dry)

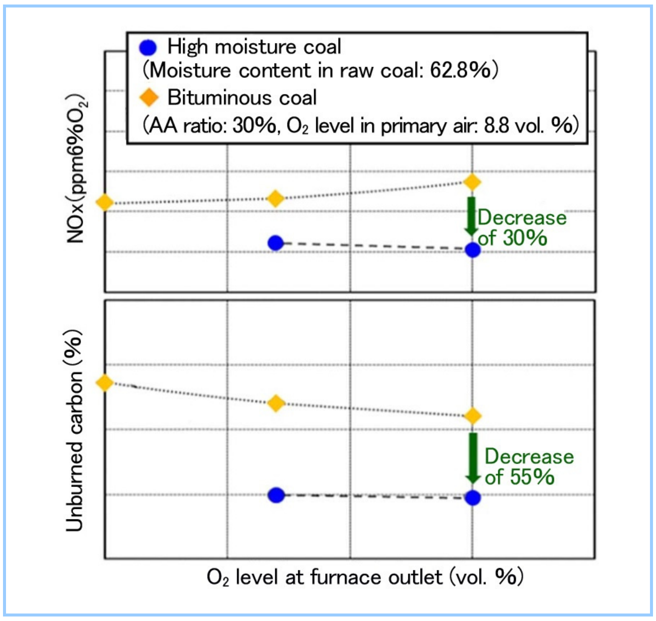


Figure 6 Flue gas characteristics with varying O_2 levels at furnace outlet

5. Conclusion

Super-high-moisture coal with a moisture content exceeding 50% is expected to play an important role in power generation in the future. To apply the advanced technical items in highly-efficient pulverized coal-fired power generation, a new mill-burner system was developed and a demonstration test to obtain the following results was carried out::

- To prevent pulverized coal agglomeration and accumulation in the mill, the upper limit of the relative humidity at the outlet was determined. When using super-high-moisture coal, there was a tendency toward a higher drying ratio than bituminous or subbituminous coal. It is necessary to analyze more operational data on drying characteristics based on the coal properties and improve the accuracy of the heat calculation method based on the drying characteristics according to the kind of coal.
- With the use of the A-PM burner, stable ignitability was maintained even under the conditions in which the solid/gas ratio of the primary gas in the burner was 0.2 and the O_2 concentration was as low as 6%. The NOx or unburned carbon could be lower than bituminous coal. Based on these results, we will develop a more detailed design of an actual combustion system and satisfy the needs of our customers for the utilization of super-high-moisture coal.

Acknowledgements

This research was carried out as part of the 2013 project for the promotion of coal production technologies, supported by a grant from the Agency for National Resources and Energy of the Ministry of Economy, Trade and Industry. We thank all the members who took part in this project.

Reference

1. Clarke et al., 2010 Survey of Energy Resources, World Energy Council, United Kingdom, (2010).
2. Kinoshita, M. et al., Rehabilitation Project for Lignite Coal Firing System in Mongolia, The Thermal and nuclear power, Vol.61 No.8, (2010) pp. 694-702
3. Sato, S. et al., RETROFIT APPLICATION OF MITSUBISHI LOW NOx SYSTEM, POWER-GEN 2000 International, (2000).
4. Arakawa, Y. et al., Development and Operation Results of Petroleum Coke Firing Boiler, Mitsubishi Heavy Industries Technical Review, Vol.42 No.3,(2005) pp. 112-115