Proceedings of the
International Conference on Mechanical Engineering 2005
(ICME2005) 28- 30 December 2005, Dhaka, Bangladesh

ICME05-TH-25

EMISSIONS OF MAJOR POLLUTANTS FROM LIGNITE-BASED POWER GENERATION IN THAILAND: PART 2. ANNUAL RATES OVER THE POST-CRISIS YEARS

Vicharn Tanetsakunvatana [1] and Vladimir I. Kuprianov [2]

[1]Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi,
91 Pracha-uthit Road, Tungkru, Bangkok, 10140, Thailand
[2]School of Manufacturing Systems and Mechanical Engineering
Sirindhorn International Institute of Technology, Thammasat University
P.O. Box 22, Thammasat Rangsit Post Office, Pathumthani, 12121, Thailand

ABSTRACT

In Thailand, the Mae Moh power plant fired with domestic lignite is one of the largest electric power producer in the country providing, however, about 15–20% to the national electricity production in different years. By the fiscal 1997, the power plant electricity production was gradually increased to 19,376 GWh per year. Because of the low fuel quality and absence of gas-cleaning facilities on some boiler units, the environmental impacts by the power plant in the years prior to 1998 were significant. Ultimate analysis of Thai lignite (averaged over a year) is provided for the years 1997–2003. Specific CO_2, NO_x, SO_2, PM emissions for the 75-, 150- and 300-MW boiler units, estimated with the use of the properties of "average fuel" as well as unit operating conditions, are quantified for each year in the period of study. Effects of the unit loading on the specific emissions are discussed. Assessment of the annual emission rate of the major pollutants discharged form the power plant was carried out taking into account the actual electricity production by the boiler units. During the post-crisis years, significant reductions in the annual emission rate were achieved for SO_2 and PM, mainly, due to the management efforts. Annual rates of the CO_2 and NO_x emissions were somewhat reduced through the years 1997–2003 remaining, however, at high levels. The computational results of this work can be used for the reliable environmental risk assessments for the areas in Northern Thailand surrounding the Mae Moh power plant.

Keywords: Power Plant, Boiler Units, Specific Emissions, Annual Emission Rates.

1. INTRODUCTION

For more than four decades, low-rank lignite has been one of the major fossil fuels used for power generation in Thailand. The Mae Moh power plant is the only lignite-based power producer in the country providing, however, about 15–20% of the national electricity production in different years. Significant expansion in the installed capacities at this power plant was achieved in the 90's. By 1996, the overall installed capacity of the power plant approached 2,625 MW, which allowed the power plant to supply 19,376 GWh in 1997, prior to the financial and economic crises [1].

Thai lignite characterized by significant contents of fuel-S, ash and moisture, as well as by elevated fuel-N, seems to be one of the worst world coals. The boiler units of the Mae Moh power plant are therefore strong contributors to the air pollution in the surroundings.

Major gaseous pollutants (CO_2, NO_x and SO_2) as well as particulate matter (PM) emitted from the power plant units are dispersed over the large territory in Northern Thailand and neighboring countries (Laos, southern provinces of China and Myanmar) Moreover, highly hazardous trace elements (TE), such as As, Cr, Ni and other heavy metals contained in fly ash of Thai lignite, penetrate into local ecosystems and atmospheric environment via PM [2,3]. Severe impacts done by the power plant to the environment and human health in the 90s have been documented in some References [1,4].

Despite the significant efforts undertaken by the Mae Moh power plant in reducing the emissions from the boiler units (especially, SO_2 and PM), the CO_2 and NO_x emissions from this power plant are still of great concern. To assess the progress in the power plant environmental performance and for providing accurate environmental risk assessment for the surrounding areas, the annual emission rates for the major pollutants discharged into the environments are required.

Modeling and quantifying the annual rate of CO_2, NO_x, SO_2 and PM emissions from the Mae Moh power plant for the post-crisis years of 1997–2003 were the main objectives of this work. Effects of load factor on power plant emission characteristics were the focus of study as well.

2. MATERIALS AND METHODS

2.1 Boiler Units of the Mae Moh Power Plant

In 1997–2003, three groups of the boiler units (classified by the capacity) were involved in power generation at the Mae Moh power plant: three 75-MW units, four 150-MW units and six 300-MW units.

The utilities of the "old generation", the 75-MW boiler units (Units No. 1–3), were erected and started in 1978–1981. By 1999, the power production by these units was significantly reduced, and since March 2000, they have been totally out of operation. For a full (100%) unit load, the boilers of this unit group were designed to produce 83 kg/s of superheated steam at 515^oC and 86 bar. The furnace of each boiler with the cross-sectional area of $9.1\times 9.1\ m^2$ ensured the heat release rate of about 2.4 MW/m^2. In the boiler furnace, 15 swirling-type burners were arranged on the front wall in five tiers. The boilers were designed to burn fuel at the specified excess air ratio of 1.29. The 75-MW boiler units were equipped with the electrostatic precipitators (ESPs) whose ash-collecting efficiency was about 98%. Neither de-SO_x nor de-NO_x facilities were used on the boiler units of the "old generation".

The 150-MW boiler units (Units No. 4–7) were constructed and started in 1984–1995. For the full load, the tangentially-fired boilers of these units were designed to produce some 120 kg/s of superheated steam at 535^oC and 140 bar at the full load. Reheated steam of about 110 kg/s was returned to the boiler with the aim of increasing the temperature to 535^oC at 34 bar. In the tangentially-fired furnace of a boiler unit, the fuel and air were injected into the furnace through the ports placed along the continuous vertical line in each corner of the furnace. The excess air ratio at the boiler furnace was specified to be 1.28. The units were equipped with the high-efficiency (99.5%) ESPs.

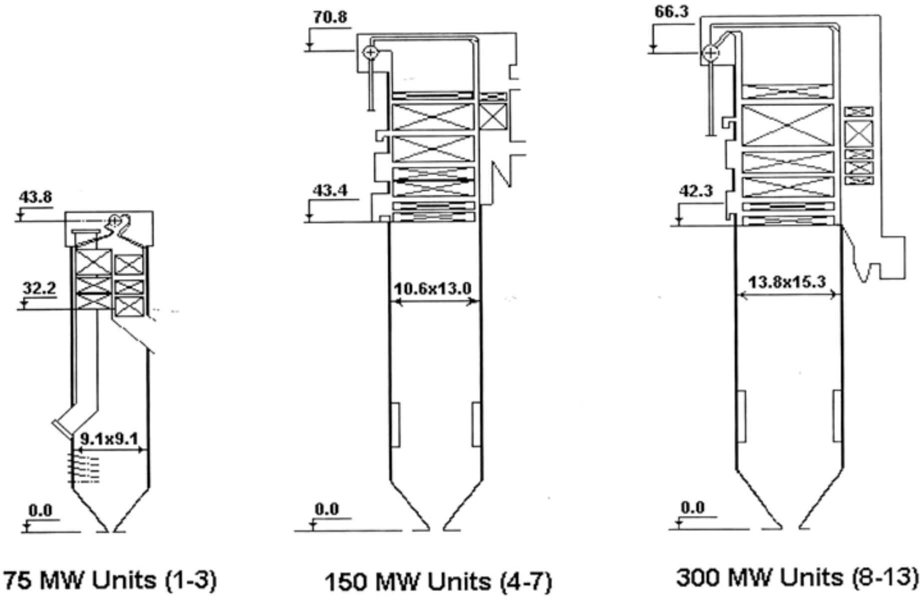
A few years later, in December 1999 – February 2000, flue-gas (FGD) systems were introduced on these boiler units.

The largest group is represented by the 300-MW units (Units No. 8–13) which started operation in 1989–1995. The steaming generating capacity of a fully-loaded boiler of the 300-MW unit was designed to be some 250 kg/s of superheated steam at 540^oC and 160 bar. About 220 kg/s of the steam was returned to the boiler for reheating to 540^oC at 38 bar. A tangentially-fired furnace ($15.3\times 13.8\ m^2$) of the boiler was equipped with five-tier corner burners ensuring the heat release rate of about 3.8 MW/m^2 at the full unit load. The excess air ratio was specified for these boilers to be 1.2 (referred to the furnace exit). All 310-MW units were equipped with the 99.5%-efficiency ESPs. However, installation of the FGD system on each boiler unit was complete with some delay (in 1995–1997).

Like in the 75-MW units, NO_x was not mitigated in the power plant boilers of the higher capacities (e.g. with the use of flue gas recirculation or selective non-catalytic reduction system) or removed with the use of the de-NOx systems. Hence, this pollutant formed in the furnace of the boiler units entirely penetrated into the atmospheric environment.

Meanwhile, as follows from the above power plant history, 75-MW units as well as the 150- and 300-MW boiler units (prior to installation of the FGD units) represented the sources of severe environmental impacts.

The schematics of the utility boilers of the 75-, 150- and 300-MW units are shown in Fig. 1. The furnace dimensions provided in these schematics are important data in the modeling of the NO_x emissions whose formation rate depends on the temperature in the burner zone (affected by the furnace geometry [5]).



75 MW Units (1-3) 150 MW Units (4-7) 300 MW Units (8-13)

Fig 1. Schematics of the boilers of the 75-, 150- and 300-MW units at the Mae Moh power plant.

Table 1: Ultimate analysis (wt.%) and *LHV* (MJ/kg) of "average" Thai lignite ("as-received" basis) used for predicting the annual emission rates of the major pollutants discharged from the Mae Moh power plant in 1997–2003.

Year	W	A	C	H	O	N	S	*LHV*
1997	27.56	29.90	30.45	1.08	7.44	1.07	2.50	10.21
1998	27.10	30.30	30.46	1.08	7.44	1.07	2.55	10.23
1999	29.00	27.50	30.04	1.07	9.01	1.01	2.37	9.83
2000	29.90	27.20	30.32	1.32	7.85	1.02	2.39	10.29
2001	29.90	27.30	29.67	1.34	8.22	1.05	2.52	10.07
2002	30.20	26.60	29.93	1.43	8.21	1.12	2.51	10.24
2003	30.60	26.80	29.54	1.48	7.58	1.12	2.88	10.26

2.2 The Fuel

As shown in Part 1 of this work, the quality of Thai lignite is subject to apparent seasonal fluctuations. At the beginning of the rainy season (usually, in May), the moisture content in the supplied fuel starts increasing affecting all the components of the fuel ultimate analysis. On the contrary, during the dry season, the fuel moisture is gradually changed to lower values. Because of both random and seasonal fluctuations, the fuel moisture may vary within 15% band, whereas the fluctuation ranges for fuel ash and fuel-S are even greater (25–30%) in different months of the particular year, causing corresponding changes in the fuel *LHV*.

However, in long-term observations, it is reasonable to deal with "average" fuel (e.g. averaged over a year), thus ignoring the seasonal fluctuations in the fuel quality [2]. Such an approach is applied in this work.

The ultimate analysis and *LHV* of "average" fuels (on "as-received" basis), obtained by statistical treatment of data accumulated at the power plant, are shown in Table 1 for the fiscal years 1997–2003. As seen in Table 1, the fluctuation ranges of the properties of the "average" fuels provided for this 7-yr period are much lower than those for the particular year.

2.3 Methodology and Essential Input

In accordance with the work objectives, the annual rates of the major pollutants (CO_2, NO_x, SO_2 and PM) were estimated for the time period of interest. During the first stage of this computational study, the corresponding specific emissions were calculated for the 75-, 150- and 300-MW boiler units with the use of the emission models provided in Part 1 of this work, for the particular fuel in Table 1. At the second stage, using the above specific emissions and actual values of the electricity production in the selected year by each group of the boiler units, the total amounts of CO_2, NO_x, SO_2 and PM discharged from the particular boiler group were estimated. Finally, by summing these effluents, the total amounts of CO_2, NO_x, SO_2 and PM discharged from the Mae Moh power plant were readily estimated for the particular fiscal year.

For the 150- and 300-MW boiler units equipped with both FGD system and ESPs, the overall ash-collecting efficiency was assumed to be 99.9%, whereas it was "only" 99.5% for the units with no de-SO_x system. Referring to the above discussion, the ash-collecting efficiency of the "old generation" 75-MW units was assumed to be at a relatively low level, 98%. Meanwhile, for the FGD systems of the 150- and 300-MW boiler units, the SO_2-removal efficiency was assumed in these computations to be 97%.

Following the above methodology, the characteristics of interest were calculated for the boiler units as operated at the 100% load. As follows from power plant statistics, because of quite low fuel properties, the boiler units have been generally operated at 85–100% loads and the above approach could be justified. However, prior to the emission computations, special experimental test were carried out on a selected 300-MW unit with the aim of studying the effects of the unit loading on the emission characteristics.

3. RESULTS AND DISCUSSION

3.1 Effects of Unit Loading on Major Emissions

A selected 300-MW boiler unit firing Thai lignite was tested at three reduced loads, 96%, 83% and 67%. For providing accurate thermal and emission assessments, the fuel was sampled in each test run. Table 2 shows the fuel properties for the tests at various unit loads. In the first and second test runs, (i.e. at typical unit loads), the fuel properties were found to be quite close to each other resulting in near the same meanings of the fuel lower heating value.

Table 2: Ultimate analysis (wt.%) and *LHV* (MJ/kg) of Thai lignite ("as-received" basis) fired in the 300-MW units during the experimental tests at different unit loads (MW).

Power Output	W	A	C	H	O	N	S	*LHV*
287	32.40	26.14	28.81	1.81	6.81	1.23	2.80	10.38
249	33.50	22.36	29.58	1.52	9.06	1.24	2.74	10.06
200	29.00	27.50	26.94	1.41	5.90	1.09	3.06	9.83

Table 3: Major thermal and emission characteristics measured in the experimental tests on the 300-MW boiler unit operated at different unit loads

Variable	Unit	Run No.		
		1	2	3
$\dot{W}_e$	MW	287	249	200
O_2[a]	%vol.	2.61	2.45	2.19
$\dot{m}_{sh}$	kg/s	241	211	174
t_{sh}	^{o}C	539	538	532
$\dot{m}_{rh}$	kg/s	210	184	152
$t_{rh,1}$	^{o}C	342	336	323
$t_{rh,2}$	^{o}C	537	536	512
t_{fw}	^{o}C	239	233	223
ϑ_{wg}	^{o}C	160	155	150
SO_2[b]	ppm	156	48	20
NO_x	ppm	361	418	265
CO	ppm	-	-	-
C_{fa}	wt.%	0.09	0.12	0.14

[a] At the economizer outlet

[b] Downstream from the FGD system.

Table 3 shows the major operating variables, SO_2, NO_x and CO emission concentrations (in the 6% O_2 flue gas) as well as unburned carbon in the fly ash measured in the experimental tests at different boiler loads.

Because of the constraints associated with operation of the FGD system, the excess oxygen was slightly diminished with lowering the boiler load, remaining, however, at fairly the same level. While the steam properties were maintained by the control system, the required thermal power of the unit was secured by the steam flow rates (of superheated and reheated steam). As seen in Table 3, the feed water temperature was reduced with lower unit loads affecting the specific (both thermal and emission) characteristics.

For the reduced boiler loads, the waste flue gas temperature was lowered leading to the improvement in the boiler thermal efficiency [6]. However, the reduction in the boiler feed water temperature indicates deterioration in the thermal efficiency of the power generation cycle.

The inverse relationship between C_{fa} and the unit load could be basically explained by the reduction in the flame temperature (i.e. in the burner zone) with lower unit loads, despite the increase in the residence time of fuel particles. No CO emission was found in these tests because of sufficient excess air.

The NO_x emission concentration was increased from 361 ppm to 418 ppm when the unit load was reduced from 96 to 83%; however, at the lowest load (67%), the NO_x emissions was as high as 265 ppm. These facts could be basically explained by the effects of the flame temperature and residence time, both being varied with changing the unit load.

Significant reduction in the SO_2 emissions from 156 ppm (at the 96% load) to 20 ppm (at 67% load) pointed at the increased efficiency of the FGD system with diminishing the unit load; as the result, the flow rate of the flue gas was lowered leading to an increase in the residence time of the flue gas in the FGD unit.

Based on the data in Table 3, the boiler heat losses, thermal efficiency (as *LHV* percent) as well as fuel consumption were determined for the test runs at different loads by Ref. [6]. Due to the significant effect of the waste gas temperature, the boiler efficiency was found to improve from 91.9 to 92.3% when the boiler unit reduced its power output from 96 to 67%. Taking into account boiler actual properties at the reduced loads and also the changes in the boiler thermal efficiency, the boiler fuel consumption was found to reduce from 69.7 to 55.9 kg/s for the above load variation. However, because of the deterioration in the power cycle efficiency, the specific fuel consumption by the 300-MW boiler unit was found to increase from 874 to 987 kg/MWh, affecting, accordingly, the specific emission characteristics of the unit.

Table 4 shows the specific emissions quantified for the 300-MW boiler unit, for the fuel properties in Table 2. Like in the Part 1 of this work, the specific NO_x and SO_2 emissions in Table 3 were determined based on the corresponding experimental emission concentrations, whereas the specific CO_2 and PM emissions were predicted by the emission models. Since the reduction in the unit load leads to some improvements in the ESP efficiency [7], the latter was assumed in the calculations to be 99.9%, 99.92% and 99.95% for the 287-, 249- and 200-MW power outputs, respectively.

Following the changes in the fuel consumption, the emission rates were generally reduced (except for NO_x at the 83% unit load). However, as follows from the data in Table 4, the specific gaseous emissions were in the correlations with the respective emission concentrations in Table 3 as well as with the specific fuel consumption.

Like in the previous test series, the specific CO_2 emissions were at an elevated level, of 923–975 kg/MWh, for this load range actually typical for coal-fired utilities. Meanwhile, the PM specific emission was strongly affected by the overall ash-collecting efficiency of the ESP and FGD systems leading to the reduction in the PM emissions at reduced loads despite an increase in the specific fuel consumption.

Table 4: Specific emission characteristics of the 300-MW boiler unit operated at different unit loads

Variable	Unit	Run No.		
		1	2	3
m_{CO2}	kg/MW h	923	994	975
m_{NOx}	kg/MW h	2.604	3.094	1.994
m_{SO2}	kg/MW h	1.608	0.508	0.215
m_{PM}	kg/MW h	0.233[a]	0.168[b]	0.172[c]

[a] For 99.9% overall ash-collecting efficiency.

[b] For 99.92% overall ash-collecting efficiency.

[c] For 99.95% overall ash-collecting efficiency.

Table 5: Specific emissions (kg/MWh) of the major pollutants discharged from distinct units of the Mae Moh power plant in the fiscal year 2000

Utility	NO_x	SO_2	CO_2	PM
75-MW boiler unit	2.165	36.39	1155	5.685[a]
150-MW boiler unit	1.715	0.904 [b]	957	0.236[c]
300-MW boiler unit	1.623	0.893 [b]	946	0.233[c]

[a] For 98% ash-collecting efficiency.

[b] Equipped with the FGD units.

[c] For 99.9% overall ash-collecting efficiency.

3.2 Annual Emission Rates of Major Pollutants

As an illustration, Table 5 shows the specific emissions of the major pollutants predicted for distinct boiler units the fiscal year of 2000 when the power generation from the 75-MW units was as low as 92 GWh. Note that in all months of this fiscal year, the flue-gas desulphurization was secured by the individual FGD systems on all of the 300-MW units. However, the 150-MW Units No. 6 and 7 were equipped with a FGD system (serving simultaneously for the two boiler units) only in December 1999; similar retrofitting was done on the 150-MW Units No. 4 and 5 in February 2000. So, Table 5 provides actually the data predicted for the months when the 150- and 300-MW boiler units were operated with the FGD systems.

Compared to the fiscal year 1997 (the year of the peak of power generation by the Mae Moh power plant), it was managed to reduce dramatically, 35 times, the specific SO_2 emissions from these units to about 0.9 kg/MWh (against 31.5 kg/MWh in the fiscal year 1997) by installation of the FGD systems. A certain progress was also achieved in the reduction of the PM emissions (about 0.23 kg/MWh against 1.3 kg/MWh, respectively) due to the contribution of the FGD systems to the improvement of the ash-collecting efficiency.

However, the CO_2 and NO_x emissions for the fiscal years of 1997 and 2000 were found to be of the same orders and corresponded some changes in the fuel properties. While the specific CO_2 emission was diminished with higher boiler unit capacity, basically, due to the improvement in the thermal efficiency of the power cycle, the reduction in the specific NO_x emissions could be explained by the diminishing of the specific fuel consumption as well as by different operating conditions in the burner zone of the boilers (temperature, excess air ratio).

Based on the specific emissions and power generation for distinct boiler units of the Mae Moh power plant, annual emission rates for the major pollutants were quantified for this power plant for the fiscal years 1997–2003. Table 5 shows the annual emission rates along with data on the annual power production. Because of the economic crisis, the power production by the Mae Moh power plant was somewhat reduced in 1998–2000 but stabilized at the value of about 17,000 GWh in the last three years.

The predicted results in Table 5 show that with the decommission of the 75-MW units (in 2000) and installation of the FGD systems on all of the 150-MW and 300-MW units, the environmental performance of the Mae Moh power plant was significantly improved, especially in terms of SO_2 and PM emissions. The SO_2 effluent decreased dramatically from 391.1 ktons in 1997 to 106.3 ktons in 1999 and then to 17.19 ktons in 2000. Meanwhile, the PM annual emission rate diminished from 25.1 ktons in 1997 to 8.85 ktons in 1999 and then to 4.13 ktons in 2000, as seen in Table 5.

However, the elevated CO_2 emission rates, of 14,767 to 18,949 ktons in different years of the period of interest, a well as elevated NO_x emission rate, of 25.61 to 35.39 ktons, are of great concern at this power plant.

For typical operating conditions of the boiler units (at the 85–100% units' load), the emission characteristics of a boiler unit equipped with both FGD and ESP systems should be corrected in accordance with the load factor. For instance, the NO_x and CO_2 emission characteristics in Table 5 and 6 can be increased by some 10% and 5%, respectively, in environmental risk assessments.

Table 6: Annual power production by the Mae Moh power plant (GWh) and emission rates of the major pollutants (ktons) predicted with the use of actual fuel properties (averaged over distinct years) for the period of 1997–2003

	1997	1998	1999	2000	2001	2002	2003
Power production	19,376	17,106	15,783	15,548	17,338	16,924	17,177
CO_2	18,949	16,682	15,606	14,767	16,469	15,940	15,939
NO_x	35.39	31.14	26.47	25.61	28.96	29.16	28.05
SO_2	391.1	164.3	106.3	17.19	16.91	16.22	19.28
PM	25.10	16.52	8.85	4.13	4.16	3.89	3.99

The power plant's environmental performance could be further improved through implementation of measures reducing the CO_2 and NO_x emissions. As an option, the boilers of the Mae Moh power plant could be retrofitted and switched to co-firing Thai lignite with natural gas (available in this country).

The boilers currently employed at the power plant should be replaced with the ones designed with the (circulating) fluidized-bed systems and those suitable for the co-firing of lignite with various biomass fuels.

4. CONCLUSIONS

The environmental performance of the lignite-fired Mae Moh power plant was successfully estimated with the use of the specific emissions of major pollutants (CO_2, NO_x, SO_2, PM) as well as the electrical power production by the power plant units for the fiscal years 1997–2003. The annual emission rates were quantified for the major pollutants discharged from the power plant in different years of this time period.

As may be concluded, with 900–1100 kg/MWh (for different years) CO_2 specific emissions, the power plant contributes significantly to the greenhouse gas emissions in this region. Elevated NO_x emissions (25.61 to 35.39 ktons, for different years) are of great concern as well.

Due to the efforts undertaken by the power plant, it was managed to reduce significantly the annual effluents of SO_2 and PM from this power plant. The annual SO_2 emission rate decreased dramatically from 391.1 ktons in 1997 to 17.19 ktons in 2000. Meanwhile, the PM effluents diminished from 25.1 ktons in 1997 to 4.13 ktons in 2000.

The computational results of this work can be used for reliable environmental risk assessments for the areas in Northern Thailand surrounding the power plant.

5. ACKNOWLEDGEMENT

The authors would like to thank the Mae Moh power plant (EGAT Public Company Ltd) for allowing the boiler unit tests. The authors wish to acknowledge the financial support provided by the Energy Policy and Planning Office, Ministry of Energy, Thailand.

6. REFERENCES

1. Kouprianov, V.I., Bashkin, V.N., Towprayoon, S., Milindalekha, J. and Wongyai, K., 2002, "Emission of Arsenic and Gaseous Pollutants from Power Generation in Northern Thailand: Impact on Ecosystems and Human Health", World Resource Review, 14: 98-115.
2. Kouprianov, V.I., 2002, "Influence of Lignite Quality on Airborne Emissions from Power Generation in the Russian Far East and in Northern Thailand", Fuel Processing Technology, 76: 187-199.
3. Hart, B.R., Powell, M.A., Fyfe, W.S., Ratanasthien, B., 1991, "Geochemistry and Mineralogy of Fly-ash from the Mae Moh Lignite Deposit, Thailand", Energy Sources, 17: 23-40.
4. Dopatka, J., Ford, N. and Jiajanpong, K., 2003, "Opportunities to achieved improved WFGD performance and economics", *Proc. Combined Power Plant Air Pollutant Control Mega Symposium*, Washington DC, pp. 7: 1-16.
5. Bezgreshnov A.N., Lipov Yu.M. and Shleipher B.M., 1991, *Computation of Steam Boilers*, Energoatomizdat, Moscow (in Russian).
6. Basu, P., Cen, K.F. and Jestin, L., 2000, *Boilers and Burners*, SPRINGER, New York, USA.
7. Chattopadhyay, P., 2000, *Boiler Operation Engineering* (2nd edition), TATA McGRAW-HILL, New Delhi.

7. NOMENCLATURE

Symbol	Meaning	Unit
A	Ash content in "as-received" fuel	%wt.
C	Carbon content in "a.-r." fuel	%wt.
C_{fa}	Carbon content in fly ash	%wt.
H	Hydrogen content in "a.-r." fuel	%wt.
LHV	Lower heating value of the fuel	MJ/kg
m	Specific mass flow rate	kg/MWh
$\dot{m}$	Mass flow rate	kg/s
N	Nitrogen content in "a.-r." fuel	%wt.
O	Oxygen content in "a.-r." fuel	%wt.
S	Sulphur content in "a.-r." fuel	%wt.
W	Moisture content in "a.-r." fuel	%wt.
$\dot{W}_e$	Electrical power output	MW
t	Steam (water) temperature	°C
ϑ_{wg}	Temperature of the waste flue gas	°C

Subscripts

fw	feed water
sh	superheated steam
rh,1	steam at the reheator inlet
rh,2	steam at the reheator outlet