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Assessment of gaseous, PM and trace element emissions from a 300-MW lignite-fired boiler unit for various fuel qualities

V.I. Kuprianov [a,*], V. Tanetsakunvatana [b]

[a] 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
[b] Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, 91 Pracha-uthit Road, Tungkru, Bangkok 10140, Thailand

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Abstract

Modeling of effects of fuel quality on the emissions of major pollutants (NO_x, SO_2, CO_2 and PM) and eight trace elements (As, Co, Cr, La, Mo, Ni, Sb and U) from a 300-MW boiler unit fired with Thai lignite was the main focus of this study. The NO_x and SO_2 emission models were validated with the use of experimental data. Emission rates and specific emissions (per MW h) of the major pollutants and trace elements were quantified by including efficiencies of the flue gas desulphurization system and electrostatic precipitators in the computations. As shown in this work, the contributions of 300-MW boiler units fired with Thai lignite to the "greenhouse" and "acid rain" gas emissions in the region are significant. Additionally, substantial amounts of hazardous As, Cr and Ni are emitted from the boiler units into the atmosphere via fly ash particles.

Keywords: Power plant; Heat losses; Boiler efficiency

1. Introduction

For more than four decades, low-rank lignite has been one of the major fossil fuels used for power generation in Thailand because of shortage in the high-quality energy sources. The Mae Moh power plant, currently consisting of four 150-MW and six 300-MW units, is the only lignite-based power producer in the country providing, however, about 15% of national electricity production [1]. Because of the low fuel quality, the boilers of this power plant are strong contributors to the air pollution in the surrounding areas of the Mae Moh valley in Northern Thailand. Major gaseous pollutants (NO_x, SO_x and CO_2) and particulate matter (PM) emitted from the power plant are dispersed over a large area in the region. Moreover, a large number of trace elements (TE) contained in fly ashes of Thai lignite, are carried into different ecosystems via PM [2]. Accumulations of As and other hazardous trace elements in soil, ground water, aquatic plants and tree leaves have been found in the vicinity of lignite-fired power plants in Northern Thailand and elsewhere [3,4].

During the last 10 years, the Mae Moh power plant has made significant efforts to reduce the SO_2 and PM emissions. Decommissioning of the 75-MW units with low-efficiency ash-collecting devices and installation of flue gas desulphurization (FGD) systems for all of the existing units resulted in the substantial reduction of the ground ambient SO_2 concentrations in the Mae Moh valley from about 1000 ppb, in mid-1990s, to below 300 ppb, at present [5].

However, significant CO_2 and NO_x emissions from this power plant are of great concern. The CO_2 effluents contribute substantially to the "greenhouse" emissions in the region, and the NO_x emissions continue to sustain the acidification loading on local ecosystems. Another serious

* Corresponding author. Tel.: +66 2 986 9009x2208; fax: +66 2 986 9112.
E-mail address: ivlaanov@siit.tu.ac.th (V.I. Kuprianov).

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environmental impact by the power plant is associated with elevated concentrations of As in water and sediments in the aquatic ecosystem near the power plant [6].

Due to random and seasonal fluctuations in the quality of Thai lignite, both thermal efficiency and emission performance of the boilers are quite variable, leading to fluctuation in the emission of major pollutants from the power plant [7]. In order to provide accurate environmental risk assessments for the surrounding area, it is necessary to quantify the emission characteristics of the power plant units in relation to fuel properties, boiler operating conditions, and the efficiencies of the pollution control systems.

Because of the predominant share of the 300-MW boiler units in the lignite-based electric power production in Thailand, this work focused on one of the 300-MW boiler units fired with Thai lignite. Modeling the effects of fuel quality on the emissions of major pollutants (NO_x, SO_2, CO_2 and PM) and hazardous trace elements (As, Co, Cr, La, Mo, Ni, Sb and U) discharged from the boiler unit was the main objective of this work.

2. Materials and methods

2.1. The boiler unit

Fig. 1 shows the schematic diagram of a 300-MW boiler unit of the Mae Moh power plant firing Thai lignite. At full load, the boiler supplies some 255 kg/s of the superheated steam at 540 °C and 160 bar to a high-pressure steam turbine. About 220 kg/s of steam at 38 bar is returned from the turbine into the boiler for reheating to 540 °C. A tangentially-fired boiler furnace of 13.8 × 15.3 m in size with straight-flow type burners arranged at four corners ensures a heat release rate (per unit cross-sectional area) of about 3.8 MW/m^2 at the full boiler load when firing Thai lignite with the design fuel properties [8].

In order to reduce SO_2 and PM emissions, the boiler unit is equipped with a wet flue gas desulphurization (FGD) system and a multi-stage electrostatic precipitator (ESP) system consisting of four units, ESP-1, ESP-2, ESP-3 and ESP-4, connected in series. In most performance tests previously carried out on some 150- and 300-MW power plant units, the FGD systems have demonstrated a very high, 97.5–98.5%, SO_2 removal efficiency [9,10]. The ash-collecting efficiency of the ESP system rated by the manufacturer is also very high, of about 99.5% [8]. Furthermore, the wet FGD system installed downstream from the ESPs contributes significantly to capturing fine ash particles, reducing the PM concentration in the flue gas by up to 90% [11] and, thus, increasing the overall ash removal efficiency to 99.95%.

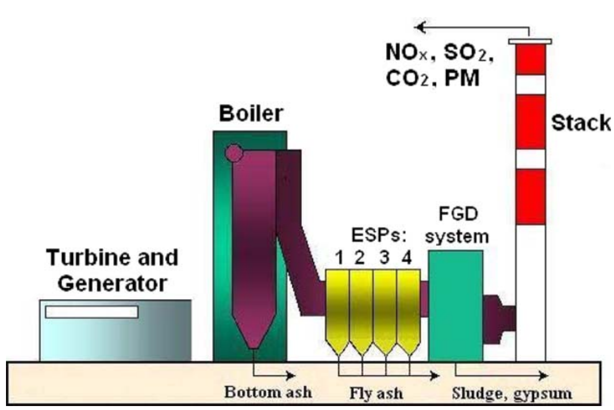

Fig. 1. Schematic diagram of a 300-MW boiler unit.

However, NO_x are not mitigated in the boiler or reduced in an external de-NO_x system. Hence, NO_x formed in the boiler are entirely emitted into the atmosphere.

The excess air ratio at the boiler furnace outlet (affecting the boiler thermal efficiency and NO_x emissions [12]) is specified at 1.20 [8]. However, because of operational constraints for the FGD system, this operating variable is actually maintained at slightly lower value (1.17).

2.2. Boiler heat losses, thermal efficiency and fuel consumption

It appears that the emission rate of the gaseous pollutants discharged from the boiler unit depends on the fuel consumption, $\dot{m}_f$ (kg/s), a measure of the fuel actually burned out in the boiler furnace, which is basically determined by taking into account the total heat input to a boiler, the rate of heat transfer to working fluid circulating in the boiler components and the boiler thermal efficiency, η_b (%) [12].

Analysis of the thermal efficiency was carried out in this work based on the heat-loss method. The boiler heat losses (as percentages of the fuel lower heating value, LHV), with waste gas (q_2), by incomplete combustion (q_3), owing to (external) surface radiation and convection (q_5) and with ash and slag (q_6) were calculated (or assumed) by Ref. [12], while the heat loss owing to unburned carbon (q_4) was estimated by a model including the effects of the fuel and ash properties and excess air ratio at the boiler furnace [13].

2.3. Emission models

2.3.1. NO_x emissions

A method for estimation of uncontrolled NO_x emissions from a fossil fuel-fired boiler is given in Ref. [14]. By the method, the mass concentration of "thermal" NO_x as NO_2 (g/m^3, standard conditions) in wet flue gas at the boiler furnace outlet is calculated to be:

$$C_{NO_2^{th}} = 7.03 \times 10^3 C_{O_2}^{0.5} \bar{t} \exp(-10860/T_m) \quad (1)$$

where C_{O_2} is (excess) oxygen concentration in the flue gas (kg/m^3, standard conditions) in the post-flame region; T_m is maximum (or effective) temperature in the burner zone (K); $\bar{t}$ = relative time factor accounting for the residence time. The computational models for C_{O_2}, T_m and $\bar{t}$ are provided in Refs. [14,15].