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Comparison of Pollutant Ambient Concentration from Two Air Pollution Control (APC) Strategies in Coal-fired Power Plant

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In this paper, ambient concentrations of Hg and dioxins/furans from two air pollution control (APC) strategies are compared. The strategies include the existing APC strategy at the studied coal-fired power plant (CFPP) and the proposed APC strategy for compliance with parameters in the Environmental Quality (Clean Air) Regulations (CAR) 2014. The former system consists of electrostatic precipitator (ESP) and flue gas desulphurisation (FGD) which are commonly employed in CFPP in Malaysia, whereas the latter consists of activated carbon injection (ACI), fabric filter (FF) and FGD. It was found that the emissions under the proposed APC strategy of ACI + FF+ FGD have higher margin of limits compared to the existing APC strategy of ESP + FGD. The emissions values were then used as input in AERMOD to predict the ambient concentrations of pollutants. The findings show that the ambient concentrations of Hg and dioxins/furans from both strategies are well below the ambient guideline values, with those emitted from the proposed APC strategy are so low to the point that they are negligible.

1. Introduction

The inorganic and organic content of coal results in emission of various air pollutants during coal combustion. In 1980's and 1990's, the main focus of worldwide emission standard for coal-fired power plant (CFPP) was to control particulate matter (PM), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2). In Malaysia, such emission standard is known as Environmental Quality (Clean Air) Regulations 1978 under Environmental Quality Act, 1974 (EQA, 1974). Early CFPPs in Malaysia are equipped with electrostatic precipitator (ESP) and flue gas desulphurisation (FGD) using seawater which are deemed sufficient to comply with the CAR 1978. Evolving studies on air pollutants from CFPP have shown the need to control other pollutants such as acid gases (hydrogen chloride (HCl) and hydrogen fluoride (HF)), heavy metals and dioxins/furans. Therefore, after 36 y, Malaysia has gazetted a new regulation of the Environmental Quality (Clean Air) Regulations 2014, which specifies additional pollutants (HCl, HF, mercury (Hg), carbon monoxide (CO), dioxins/furans) and establishes more stringent emission limits for CFPP. The new and stringent emission standard has prompted the shift in air pollution control (APC) system for CFPP in Malaysia.

1.1 Air pollution control (APC) system for compliance with the CAR 2014

The CAR 2014 specifies emission limit for PM, NO_2, SO_2, HCl, HF, Hg, CO and dioxins/furans. These pollutants can be controlled as follows:

a) Front-end changes
   This includes controlling coal quality and increasing the efficiency of coal combustion. The front end changes would mainly control the emission of CO and NO_2.
b) End-of-pipe control
   The end-of-pipe controls include the available air pollution control technologies such as selective catalytic reduction (SCR), activated carbon injection (ACI), sodium bicarbonate/lime injection fabric

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filter (FF), ESP, wet and dry FGD. The end-of-pipe controls would influence the emission of particulate, acid gases (SO_2, HCl, HF) and hazardous air pollutants (HAPs) (Hg and dioxins/furans).

Generally, the control of CO and NO_2 should not be a major concern because supposedly, power plant is commonly operating at high efficiency. In order to achieve high efficiency, complete combustion of coal must take place in boiler and this would avoid formation of CO and NO_2. Most of the CFPPs in Malaysia are equipped with ESP and FGD which can control the emission of particulates and acid gases. Nevertheless, for compliance with the CAR 2014, there is a need to control the emission of Hg and dioxins/furans as well.

Various technologies are available to control Hg and dioxins/furans separately. Mercury (Hg) can be controlled through the coal quality itself i.e. coal bleaching to reduce Hg content in coal. Injection of ACI into flue gas is the most reliable technology to remove Hg. Nevertheless, particulate control is necessary to re-capture the carbon that has been used once it adsorbs Hg from the flue gas. Derenne et al. (2009) reported 90 % of Hg removal from a combination of activated carbon and fabric filter. In addition, NO_x controls such as SCR have a co-benefit for Hg reduction through oxidation of Hg. As for dioxins/furans, a report by Nescaum (2011) shows that ACI could reduce PCDD/Fs emission in a coal–fired power plant while technologies such as SCR, particulate controls and dry sorbent injection have a co–benefit in reducing dioxins/furans emissions. A study by Chi et al. (2005) demonstrated that ACI and bag filter could effectively remove vapour phase and particle phase dioxins/furans up to 98 %.

It is of interest to employ a system that can effectively remove both Hg and dioxins/furans simultaneously. Derenne et al. (2009) suggested that a combination of ACI and FF could achieve up to 90 % removal of Hg while Chi et al. (2005) reported that dioxins/furans could be removed up to 95 %. For overall compliance with the CAR 2014 for pollutants of PM, NO_2, SO_2, HCl, HF, Hg, CO and dioxins/furans, the APC strategies must be able to treat PM, HAPs and acid gases. As such, ACI is proposed for HAPs, FF for PM removal, and seawater FGD for treatment of acid gases.

This paper aims to compare the ambient concentrations of Hg and dioxins/furans from the existing APC strategy of the studied CFPP of ESP and seawater FGD and from the proposed APC strategy of ACI, FF and seawater FGD. The objectives of this paper are 1) To establish the CFPP emission data of Hg and dioxins/furans from the existing and proposed APC strategies; and 2) To obtain ambient concentrations of Hg and dioxins/furans from the two APC strategies.

2. Methodology

2.1 Descriptions of the studied coal-fired power plant (CFPP)

The studied CFPP is a 3 x 700 MW power plant that employs pulverised coal technology. The three units burn a total of 20,000 t/d coal. The plant practices coal blending before firing. The studied plant receives three types of coal qualities e.g. poor (0.8 weight % sulphur content), medium and good grade (about 0.1 weight % sulphur). The coals are stockpiled in the coal yard according to the different grades. Prior to feeding into furnace, stacker reclaimer will grab and mix the coals before dumping the mixture into conveyor to the feeder of the furnace.

The plant is equipped with air pollution control system of electrostatic precipitator (ESP) and flue gas desulphurisation (FGD) using seawater to treat particulate and acid gases as shown in Figure 1. The treated flue gas is emitted to the atmosphere through three chimneys of 200 m tall.

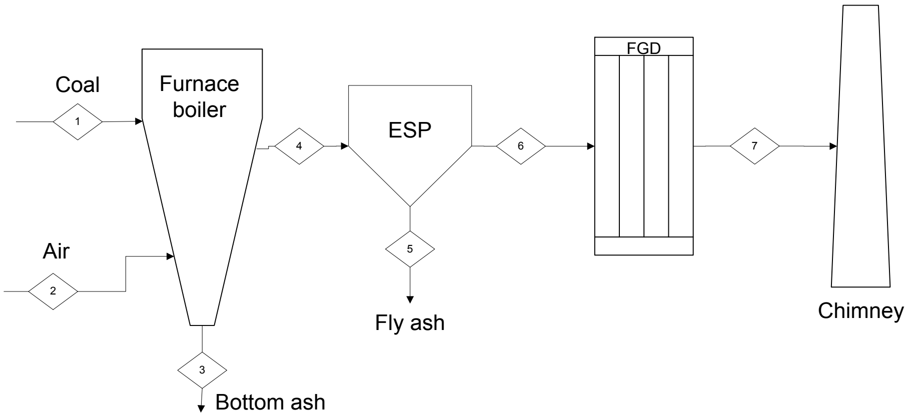

Figure 1: Schematic diagram of one generating unit (1 x 700 MW) of the studied coal-fired power plant

2.2 Establishment of emission data

The existing and the proposed APC strategies for CFPP are as follows:

a) Existing : ESP + FGD
b) Proposed : ACI + FF + FGD

Emission data were established for the emission of Hg and dioxins/furans from the existing and the proposed APC strategies. The typical expression to relate the emission level and control systems is represented by the following equation (US EPA, 1997):

$$E = AR \bullet EF \bullet (1-ER) \tag{1}$$

Where;
E = emission concentration (mg/Nm^3)
AR = activity rate [coal feeding rate (kg/h) / volume of flue gas (Nm^3/h)]
EF = uncontrolled emission factor (mass rate)
ER = overall emission reduction factor

The uncontrolled EF refers to the EF developed from emission data without any control of Hg and dioxins/furans. The uncontrolled EF for dioxins/furans from the studied CFPP had been developed by Mokhtar et al. (2014a) whereas for Hg, the EF was developed based on the data published by Mokhtar et al. (2014b). The emission reduction factor was conservatively estimated at 90 % based on published data for Hg (Derenne et al., 2009) and dioxins/furans (Chi et al., 2005). The values for parameters in Eq(1) to calculate emission data for the existing and the proposed APC strategies are shown in Table 1.

Table 1:Values for emission calculation

Parameter	Pollutant	
	Hg	Dioxins/furans
Coal feeding rate (kg/h)	2.8×10^5	
Volume of flue gas (Nm^3/h)	2.4×10^6	
EF	0.086 mg/kg	0.1 ng I-TEQ/kg
ER (existing)	0	0
ER (proposed)	0.9	0.9

2.3 Air dispersion modelling

Air dispersion model was used to predict ambient concentration of pollutants. Models such as Safe-Air II and ADMS 5 were used in previous study by Vairo et al. (2014) to predict ambient concentration of pollutant from power plant. In this study, AERMOD model was used for the purpose. The AERMOD modelling system was run with a commercial interface, AERMOD View (Lakes Environmental Software, 1995). The steps involved in AERMOD modelling are shown in Figure 2.

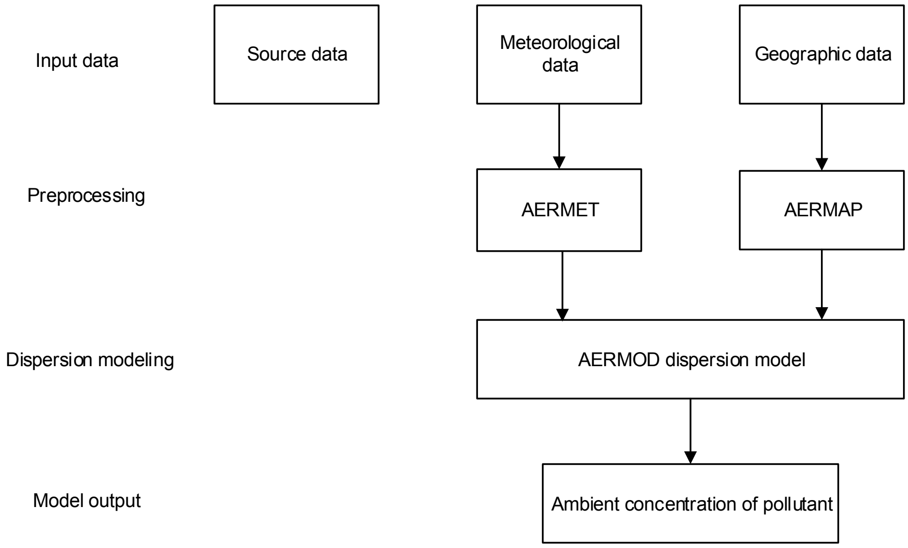

Figure 2: Flow in AERMOD modelling system

According to the Guideline on Air Quality Models by the EPA (2005), five years of representative meteorology data should be used when estimating pollutant concentrations using an air quality model. Consecutive years from the most recent, readily available 5-years period are preferred. The 5-years (1st January 2008 to 31st December 2012) meteorological data used in this study were generated by Mesoscale Meteorological Model (MM5) and purchased from Lakes Environmental in Samson and TD-6201 format files. The data were then pre-processed using AERMET (Lakes Environmental Software, 1995). AERMET organised the meteorological data into a format which is compatible with the AERMOD dispersion model.

The topographical effects of the site were addressed by employing the elevated terrain option in the software whereby contours lines with resolution of ~90 m are obtained from the Shuttle Radar Topography Mission (SRTM3) database maintained by the U.S. National Geospatial-Intelligence Agency (NGA) and the U.S. National Aeronautics and Space Administration (NASA). The terrain data were pre-processed with AERMAP (Lakes Environmental Software, 1995) prior to modelling in AERMOD.

3. Results and Discussion

3.1 Emission data of the existing and the proposed APC strategies

The emission concentrations of Hg and dioxins/furans obtained from Eq(1) for the two APC strategies are shown in Table 2. The emissions are well below the limits specified in the CAR 2014. Nevertheless, the emissions under the proposed APC strategy have higher margin of limit compared to the existing APC strategy.

Table 2: Emission concentrations of Hg and dioxins/furans from the existing and the proposed air pollution control (APC) strategies

Pollutant	Existing APC strategy	Proposed APC strategy	Limits as per CAR 2014
Mercury (Hg) (mg/Nm^3)	0.01	0.001	0.03
Dioxins/furans (ng I-TEQ/Nm^3)	0.01	0.001	0.1

CAR 2014 – Environmental Quality (Clean Air) Regulations 2014

3.2 Ambient concentrations of pollutants from the existing and the proposed APC strategies

The predicted maximum ambient concentrations of Hg and dioxins/furans obtained from AERMOD modelling for the two APC strategies are shown in Table 3 and 4. The ambient concentrations were obtained for 1 h, 24 h and annual average. It was found that the ambient concentrations under the proposed APC strategy are much lower than the existing APC configuration to the extent it could be considered negligible. Since the standards for Hg and dioxins/furans are not specified in Malaysia Ambient Air Quality Guidelines (MAAQG), ambient air guidelines from other countries are used as comparison. Table 3 and 4 show that the predicted ambient concentrations are well below the guidelines values.

Table 3: Predicted maximum ambient concentration of Hg and dioxins/furans compared with ambient air quality limit for the existing APC strategy

Pollutant	One (1) hour average concentration	One (1) hour ambient air guideline	Twenty-four (24) hour average concentration	Twenty-four (24) hour ambient air guideline	Annual average concentration	Annual ambient air guideline
Mercury (Hg) (µg/m^3)	0.008	1.5[a]	0.001	2[b]	0.00032	0.33[c]
Dioxins/ furans (pg/ TEQ/m^3)	0.00915	N.A	0.00134	0.1[b]	0.00034	N.A

[a] Arizona Ambient Air Quality Guidelines
[b] Ontario's Ambient Air Quality Criteria (AAQC)
[c] New Zealand Ambient Air Quality Guidelines (guideline for inorganic mercury)
N.A – not available

Table 4: Predicted maximum ambient concentration of Hg and dioxins/furans compared with ambient air quality limit for the proposed APC strategy

Pollutants	One (1) hour average concentration	One (1) hour ambient air guideline	Twenty-four (24) hour average concentration	Twenty-four (24) hour ambient air guideline	Annual average concentration	Annual ambient air guideline
Mercury (Hg) (µg/m^3)	0.0038×10^{-6}	1.5[a]	0.00055×10^{-6}	2[b]	0.00014×10^{-6}	0.33[c]
Dioxins/ furans (pg TEQ/m^3)	0.00375×10^{-9}	N.A	0.00054×10^{-9}	0.1[b]	0.00014×10^{-9}	N.A

[a] Arizona Ambient Air Quality Guidelines
[b] Ontario's Ambient Air Quality Criteria (AAQC)
[c] New Zealand Ambient Air Quality Guidelines (guideline for inorganic mercury)
N.A – not available

The results show that pollutants from CFPP must be treated for compliance with emission limits of the CAR 2014. In order to achieve this, CFPP must be incorporated with reliable APC technologies and strategies. Even though the existing APC strategy already results in concentration of pollutants that comply with the stipulated stack emission limits and ambient air guideline values, investment in better APC strategy could compensate in the event of increasing coal consumption and changes in coal quality that will influence pollutant emission level.

It should be noted that residual pollutants may exist after treatment with APC. Thus, by ensuring that the pollutants comply with stack emission limits, it could be guaranteed that the ambient concentrations will be at safe level. The residual pollutants could be managed by sufficient stack height to disperse the pollutants into the environment. In addition, conducive meteorological factors could further dilute the concentration of residual pollutants before they reach ground level.

3.3 Economic aspects of APC strategies

Qualitative economic evaluation of both APC strategies indicates that the proposed APC strategy costs higher than the existing APC strategy. The major cost is contributed from the installation and operation of FF. Hanseni and Rensburg (2006) reported that the operational cost of FF in coal-fired power plant was higher than ESP. Nevertheless, the net benefits of the proposed APC strategy should be the primary target regardless of the cost. (Zhang et al. (2015)) concluded that even though the average control costs for multi-pollutant control strategy are higher than gradual control strategy, the average health benefits are higher for the former than the latter.

4. Conclusion

The Environmental Quality (Clean Air) Regulations 2014 impose limits to additional parameters including hazardous air pollutants (HAPs) of Hg and dioxins/furans for coal-fired power plants. To the author knowledge, there is no coal-fired power plants in Malaysia equipped with air pollution control (APC) for treatment of the HAPs. The comparison of ambient concentrations from the existing and proposed APC strategies shows that the ambient concentrations of Hg and dioxins/furans from the latter are negligible. Therefore, the proposed APC strategy will give better assurance for safe ambient concentrations and protection to human health.

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