ESTABLISHMENT OF EMISSION CHARACTERISTICS, EMISSION FACTORS AND HEALTH RISK ASSESSMENT FROM A COAL-FIRED POWER PLANT

MUTAHHARAH BINTI MOHD MOKHTAR

UNIVERSITI TEKNOLOGI MALAYSIA

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MUTAHHARAH BINTI MOHD MOKHTAR

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ABSTRACT

The objectives of this research are to investigate the emission characteristics of a coal-fired power plant (CFPP) in Malaysia and the ability of the air pollution control devices (APCDs) currently in used to comply with the limits specified in the new Environmental Quality (Clean Air) Regulations 2014 (CAR 2014) as well as to establish emission factors for the studied CFPP. The emission data are further used to evaluate the health risks of the emissions from CFPP under CAR 2014 by air dispersion modelling and health risk assessment (HRA). The studied CFPP is a 2100 MW employing APCDs of electrostatic precipitator and flue gas desulphurisation (FGD). Emissions were determined using manual and continuous stack samplings. The emission characteristics were established from the modified CFPP configuration that took into account the effects of coal quality (combustion of only sub-bituminous or bituminous coal) with FGD being in on and off modes. Each pollutant demonstrates different characteristics which would further influence the control mechanism. The study also showed that the existing APCDs were able to comply with the CAR 2014. The emission factors were established for uncontrolled and controlled emissions which would allow the estimation of the impact of emission from CFPP prior to development of new plant or expansion of existing plant as well as selection of APCDs needed to comply with emission standard. For HRA, the predicted ground level concentrations from air dispersion modelling were used as input. The HRA demonstrated different health risks for scenario of emissions from the studied CFPP under normal operation and scenario in the event that pollutants are emitted at limits specified in CAR 2014, with further assessment been given to the latter.

ABSTRAK

Objektif-objektif kajian ini adalah untuk menyiasat ciri-ciri pelepasan loji janakuasa arang batu (CFPP) di Malaysia dan keupayaan alat-alat kawalan pencemaran udara (APCDs) yang sedang digunakan di CFPP di Malaysia untuk mematuhi had yang ditetapkan dalam Peraturan Kualiti Alam Sekitar (Peraturan Udara Bersih) 2014 (CAR 2014) yang baru serta untuk mewujudkan faktor pelepasan bagi loji yang dikaji. Data pelepasan kemudiannya digunakan untuk menilai risiko kesihatan daripada CFPP yang dikaji berdasarkan CAR 2014 dengan menggunakan pemodelan penyebaran udara dan penilaian risiko kesihatan (HRA). Loji yang dikaji berkapasiti 2100 MW dan menggunakan APCDs iaitu pemendak elektrostatik dan penyahsulfuran gas flu (FGD). Pelepasan gas flu telah ditentukan menggunakan persampelan serombong secara manual dan berterusan. Ciri-ciri pelepasan telah diwujudkan dari konfigurasi CFPP yang telah diubahsuai yang mengambil kira pengaruh kualiti arang batu (pembakaran arang batu sub-berbitumen atau berbitumen) dengan FGD dalam mod beroperasi dan tidak beroperasi. Setiap pencemar menunjukkan ciri-ciri yang berbeza yang akan mempengaruhi mekanisma kawalan. Kajian ini juga menunjukkan bahawa APCDs sedia ada dapat mematuhi CAR 2014. Faktor pelepasan telah diwujudkan untuk pelepasan yang tidak dikawal dan dikawal yang membolehkan anggaran impak pelepasan dari CFPP dilakukan sebelum pembangunan loji baru atau penambahbesaran loji sedia ada dan juga pemilihan APCDs untuk mematuhi piawai pelepasan. Untuk HRA, kepekatan paras tanah yang diramalkan oleh permodelan penyebaran udara telah digunakan sebagai input. HRA tersebut menunjukkan risiko kesihatan yang berbeza untuk senario pelepasan dari loji yang dikaji di bawah operasi normal dan senario sekiranya bahan pencemar dilepaskan pada had yang ditetapkan dalam CAR 2014, dengan penilaian lanjut telah diberikan kepada senario kedua.

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LIST OF ABBREVIATIONS

ACI	-	Activated carbon injection
APC	-	Air pollution control
CAR	-	Clean Air Regulations
CEMS	-	Continuous emission monitoring system
CFPP	-	Coal-Fired Power Plant
DEIA	-	Detailed Environmental Impact Assessment
EF	-	Emission factor
EPA	-	Environmental Protection Agency
ESP	-	Electrostatic precipitator
FGD	-	Flue gas desulphurisation
FF	-	Fabric filter
GLC	-	Ground level concentration
HAP	-	Hazardous air pollutants
HCl	-	Hydrochloric acid
HF	-	Hydrogen fluoride
Hg	-	Mercury
HRA	-	Health risk assessment
IPP	-	Independent Power Producer
MAAQG	-	Malaysia Ambient Air Quality Guidelines
NO_x	-	Nitrogen oxide
TNB	-	Tenaga Nasional Berhad
PAH	-	Polyaromatic hydrocarbon
PCDD	-	Polychlorinated dibenzo dioxin
PCDF	-	Polychlorinated dibenzo furan
PM	-	Particulate matter
PC	-	Pulverised coal

PPA	-	Power Purchase Agreement
SCR	-	Selective catalytic reduction
SNCR	-	Selective non-catalytic reduction
SO_2	-	Sulphur dioxide
TE	-	Trace element
VOC	-	Volatile organic compounds

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CHAPTER 1

INTRODUCTION

1.1 Background of Coal-fired Power Plants in Malaysia

Prior to 1980s, energy sector in Malaysia was dominated by oil. However, world oil crisis in 1970s has changed the scenario and prompted formulation of policies such as National Energy Policy 1979, National Depletion Policy 1980 and Fuel Diversification Strategy (1981 & 1999) to reduce major dependence on oil and for sustainable economic development (Rahman Mohamed and Lee, 2006). The Four Fuel Diversification Strategy implemented in 1981 aimed to achieve balanced utilization of natural gas, coal, oil and hydro. The strategy was then substituted by the Five Fuel Diversification Strategy in 1999 which include renewable energy as the fifth fuel. Implementation of Fuel Diversification Strategy has resulted in drastic drop of oil and has led to new development of coal-fired power plant (CFPP) (Oh, 2010).

To date, the operating CFPPs in Malaysia are as listed in Table 1.1. Sultan Salahuddin Abdul Aziz Shah Power Station (Kapar Power Plant) in Kapar, Selangor which was opened in 1987 is the major power plant in Klang Valley region and the first CFPP in Malaysia. It is also the only power plant in the country with triple fuel firing capability (coal, natural gas and oil). Based on air quality management study for Klang Valley region conducted by Japan International Corporation Agency (JICA) in 1993, it was reported that the studied power plants (Kapar and another gas-fired power plant in Klang Valley region) contributed to the highest sulphur oxide (SO_x), nitrogen oxide (NO_x) and dust emission in that region. Of these two plants, Kapar Power Plant that fired oil and coal was the most polluting. At that time, coal consumption in Kapar Power Plant alone reached up to 806,400 ton/year. Till date, there are another three coal-fired power plants operating in Peninsular Malaysia (i.e. in Manjung, Tanjung Bin and Jimah) with total capacity of 7600 MW as shown in Table 1.1. Compared to CFPPs in Peninsular Malaysia, CFPPs in Sarawak have much lower generation capacity from coal at 320 MW only. This is because total installed capacity in Sarawak is only at 1315 MW (Wikipedia, 2016b) compared to Peninsular Malaysia at 21,817 MW (Wikipedia, 2016a). Energy mix in Sarawak also includes hydro turbines, diesel engine, gas turbine and combine cycle.

Coal supply in Malaysia is handled by TNB Fuel Services (TNBFS) Sdn Bhd. TNBFS is a fuel supplier to TNB Generation and Independent Power Producers (IPP) having Power Purchase Agreement (PPA) with TNB. Its functions to ensure that fuel is procured and delivered at optimal cost taking into account the quality and reliability of supply. In 2010, TNBFS reported that coal consumption for Kapar Power Plant increased up to 4,000,000 ton/year and the total coal consumption of the four plants was about 16,000,000 ton/year (Figure 1.1).

Coal is attractive due to its abundance availability and the price is low and stable. Although Malaysia owns coal reserves at Kapit and Mukah in Sarawak and Maliau in Sabah (Ong *et al.*, 2011), coals for power generation are mainly imported from countries such as Indonesia, Australia, China and South Africa due to the high extraction cost as the coal deposits are located in the interior areas where infrastructure are poor (Rahman Mohamed and Lee, 2006).

Table 1.1: Coal-fired Power Plant (CFPP) in Malaysia (Oh, 2010)

Power plant	**Location**	**Operator**	**Capacity (MW)**	**Operation year**
Sultan Salahuddin Abdul Aziz Shah Power Station	Kapar, Selangor	Kapar Energy Ventures Sdn Bhd	600 (Phase 1)	1987
			1000 (Phase 2)	2001
Sejingkat Power Corporation Plant	Kuching, Sarawak	Sejingkat Power Corporation Sdn Bhd, a subsidiary of Sarawak Energy Berhad	210	1993
Manjung Power Station	Manjung, Perak	Tenaga Nasional Berhad (TNB) Janamanjung Sdn Bhd	2100	2003
			1000	2016
PPLS Power Generation Plant	Kuching, Sarawak	PPLS Power Generation, a subsidiary of Sarawak Energy Berhad	110	2002
Tanjung Bin Power Station	Pontian, Johor	Tanjong Bin Power Sdn Bhd, a subsidiary of Malakoff	2100	2007
			1000	2016
Jimah Power Station	Lukut, Negeri Sembilan	Jimah Energy Ventures Sdn Bhd	1400	2008

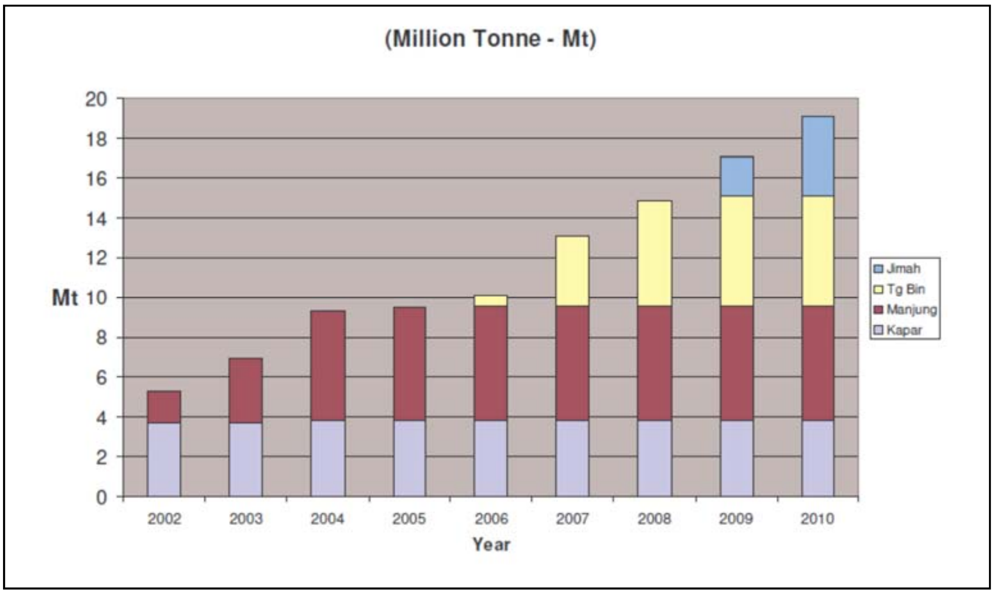

Figure 1.1: Coal Demand (million tonne per year) in Peninsular Malaysia (TNBF, 2010)

Coal-fired power plant (CFPP) is always perceived as dirty and polluting. In Malaysia, a bitter experience had occurred during 2008 until 2010 on the development of a CFPP in Sabah (a state located in the east of Malaysia). A plan to build CFPP in Sabah has been initiated since 2006 to avoid frequent blackout and brownout. Location for the CFPP was first proposed at Silam, Lahad Datu in 2008, but then the project proponent was instructed to find another location at Palm Oil Industrial Cluster (POIC) Sandakan in 2009 and again another location at Felda Sahabat in 2010. The proposed CFPP received strong opposition from the locals and non-governmental organizations (NGO). They claimed that exposure to coal burning could lead to both air and water pollutions besides threatening marine life. These cause adverse effects on human health such as birth defects and gene mutations; deadly diseases such as cancer and heart attacks; as well as destroying the wildlife and natural environment. Due to the strong objection, the project was later terminated (New Straits Times, 2011).

Nevertheless, it should be noted that coal demand for power plants in Peninsular Malaysia demonstrates a steady increment as shown in Figure 1.1. Current electricity generation mix in Malaysia is 58% gas, 33% coal and 9% hydro. Based on the approved generation development plan as reported by Energy Commission (2013), the power generation sector will have more coal plants as the gas price increases, where by 2019, the generation mix is projected to be 64% coal, 32% gas and 4% hydro (this varies from the previous reported fuel mix shown in Table 1.2). Such planning is made in order to control the cost of electricity as coal prices are less prone to market variations. Two existing coal-fired power plants at Manjung and Tanjung Bin have recently completed plant expansion to increase a total of 2000 MW to national capacity by year 2016 (Table 1.1), and this consequently will result in increased coal consumption of around 25 million tonne/year. More consumption of coal will definitely increase the emissions of air pollutants to atmosphere. This situation is a challenge to energy sector because while meeting energy demand, the environmental aspect should not be neglected.

Coal is an abundant fuel resource in the worlds' developing regions and forecasts show that it is likely to remain a dominant fuel for electricity in many countries for some years to come (Paul, 1999). This may be the reason of quite a number of studies have been conducted on emissions from CFPP in other countries such as Japan (Yokoyama *et al.*, 2000), China (Kunli *et al.*, 2002; Zhang *et al.*, 2008; Zhao *et al.*, 2008; Zhao *et al.*, 2010), Poland (Glodek and Pacyna, 2009), Korea (Pudasainee *et al.*, 2009), Spain (Fernández-Martínez *et al.*, 2004), Netherlands (Meij and te Winkel, 2006, 2007) and Taiwan (Lin *et al.*, 2007). Among the subject matters discussed in the published papers are the development of emission factors, emission trend, effectiveness of air pollution control technologies, regulatory impacts on the emission, and health risk assessment.

1.2 Emissions from Coal-fired Power Plant

Evaluation of the environmental impact of the fuel mix change in Malaysia as shown in Table 1.2 by Jafar *et al.* (2008) shows that the strategy will somehow generate higher CO_2, SO_2 and NO_x emissions by 2020 due to increase in coal consumption for power generation. Shekarchian *et al.* (2011) reported that 56% of the total emission (i.e. CO, CO_2, SO_2 and NO_x) from electricity generation in Malaysia for year 2008 was due to high coal usage.

Table 1.2: Change in Fuel Use as Aimed in Fuel Diversification Strategy (EPU, 2006)

Fuel	**Percentage (%) of fuel use**	
	Year 2000	**Year 2020**
Gas	74.9	40
Coal	9.7	29
Hydro	10.4	30
Petroleum	5	1

Apart from SO_2, NO_x, carbon dioxide (CO_2) and CO emission, CFPP also generates hydrogen fluoride (HF), hydrogen chloride (HCl), heavy metals and dioxins (Nescaum, 2011) which are toxic and hazardous. In Malaysia, due to environmental concern, development of CFPP is listed as Prescribed Activity under Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) Order 1987 which requires a Detailed Environmental Impact Assessment (DEIA) study to be conducted prior to development. Further, emissions from CFPP have to comply with the stipulated limits in the Environmental Quality (Clean Air) Regulations. Emission limits for CFPP in Malaysia was initially based on Environmental Quality (Clean Air) Regulations 1978 for fuel burning equipment which specifies limit only for particulate matter (PM) of 400 mg/Nm^3. This is the reason of Kapar Power Plant (the first CFPP in Malaysia) installed electrostatic precipitator (ESP) only as the air pollution control system to meet the PM limit.

In 2005, DOE Malaysia drafted a new Environmental Quality (Clean Air) Regulations to replace Environmental Quality (Clean Air) Regulations 1978, and since then, new CFPPs in Malaysia are required to comply with the stipulated limits as shown in Table 1.3. This new regulation is more stringent and specifies limits for additional pollutants such as SO_2, NO_2, HCl, HF, Hg, CO and dioxins/furans. The new regulation has been gazetted in year 2014 as Environmental Quality (Clean Air) Regulations 2014 (CAR 2014).

Table 1.3: Emission Limits for Coal-fired Power Plant (CFPP) as Stipulated in the New Environmental Quality (Clean Air) Regulations 2014

Fuel type	**Pollutant**	**Capacity**	**Limit value**
Solid and liquid fuels	Sum of SO_2 and SO_3 expressed as SO2	> 10 MW_e	500 mg/Nm^3
	Sum of NO and NO_2 expressed as NO_2	> 10 MW_e	500 mg/Nm^3
	Hydrogen chloride (HCl)	> 10 - < 100 MW_e	200 mg/Nm^3
	Hydrogen chloride (HCl)	≥ 100 MW_e	100 mg/Nm^3
	Hydrogen fluoride (HF)	> 10 - < 100 MW_e	30 mg/Nm^3
	Hydrogen fluoride (HF)	≥ 100 MW_e	15 mg/Nm^3
	Carbon monoxide (CO)	> 10 MW_e	200 mg/Nm^3
	Total particulate matter (PM)	> 10 MW_e	50 mg/Nm^3
	Mercury (Hg)	> 10 MW_e	0.03 mg/Nm^3
	Dioxin/furan (PCDD/PCDF)	> 10 MW_e	0.1 ng TEQ/Nm^3

Note: Emission limit at standard conditions for temperature and pressure for dry gas (volume at 273K, 101.3 kPa), O_2 reference content at 6%.

Comparison of the Malaysia new emission limits with emission limits from other countries (Table 1.4) shows that the new emission limits are less stringent. New limits for SO_2 and NO_2 of 500 mg/Nm^3 are still way too high compared to other countries. Other countries such as European Union (EU), United States, China and Japan impose stringent limits due to them heavily relying on coal as a source of energy reaching up to 78% in China (Ancora *et al.*, 2015), thus resulting in the existence of many CFPPs in their countries. Malaysia, on the other hand, has diversified sources of energy which include natural gas, coal and hydro.

Table 1.4: Emission Limits and Emissions from Best Performing Coal-fired Power Plants from Other Countries

Pollutant	**European Union (EU)**	**United States**	**China**	**Japan**
Sulphur dioxide (SO_2) mg/Nm^3	[a]Existing plants 130 (annual average) 205 (daily average) New plant 75 (annual average) 110 (daily average)	[a]50 – 60 (new units) 22 (new plants)	[a]Existing plants 50 (hourly average) New plant 35 (hourly average)	[a]30 – 35 (annual average)
Nitrogen oxides (NO_x) mg/Nm^3	[a]150	45 – 70[a]*	[a]Existing plants 100 (hourly average) New plant 50 (hourly average)	[a]60 – 70 (annual average) 40 (new plants)
Particulate matter (PM) mg/Nm^3	[a]16 (large existing plants) 10 (new plants)	N.A	5[a]*	4 – 5[a]*
Mercury (Hg) mg/Nm^3	[a]0.004 (existing plants) 0.002 (new plants)	[a]0.0015 (existing plants) 0.0005 (new plants)	[b]0.03	N.A

Note:
[a]Myllyvirta (2015)
[b]Ancora et al. (2015)
**Emissions data from best performing coal-fired power plants*
N.A – not available

It should be noted that a number of CFPPs in Malaysia were constructed before year 2005, which means that the plants were designed to comply with the emission limit in Environmental Quality (Clean Air) Regulation 1978. Therefore, the ability of the CFPPs to comply with the new emission limits is unknown, which is the main aim of this study.

1.3 Overview of Thesis

This study aims to assess the emissions from coal-fired power plant, establishment of emission factor and assessment of health risk. This thesis consists of seven chapters. The outlines of each chapter are described as below.

Chapter 1 provides the introduction of the study covering the background of coal-fired power plant in Malaysia, emissions from the plant and emission limits. In addition, an overview of this thesis is also presented.

Chapter 2 provides the background of the study such as plant location and study area, characteristics of the coal supplied and burned, the process flow of coal combustion, air pollution system and emission limits of the studied CFPP. The problem statement, objectives and scope of the study are also presented.

Chapter 3 presents the methodology adopted to carry out this study covering the sampling of coal, ash and stack emission as well as analysis of the samples. In addition, the chapter provides the methodology to estimate emission using mass balance and establishment of emission factor. Finally, the estimation of ground level concentration (GLC) by air dispersion modelling and health risk assessment (HRA) are presented.

Chapter 4 presents the emission characteristics of the studied CFPP covering emission into atmosphere (i.e. point source emission) and contaminants (i.e. trace elements) that shift into fly ash and bottom ash due to coal combustion. For air emission, the focus was on the parameters specified in the new Environmental Quality (Clean Air) Regulations 2014 and some heavy metals while trace elements were the interest in the generated fly ash and bottom ash. Finally, the environmental assessment of the studied CFPP is presented.

Chapter 5 presents the establishment of emission factors for the studied CFPP based on the emission data obtained in Chapter 4. The established emission factors were then applied in a case study to develop alternative emission control strategy for compliance with the new Environmental Quality (Clean Air) Regulations 2014.

Chapter 6 presents the dispersion of air pollutants from the studied plant using air dispersion model (AERMOD). Four emission scenarios were discussed; 1) measured emission data as discussed in Chapter 4; 2) emission limits as per CAR 2014; 3) emission under the alternative control strategy as discussed in Chapter 5; and 4) worst case scenario in the event of failure of APC system. Further, a health risk assessment (HRA) of emissions from the studied plant was carried out based on the predicted maximum ground level concentrations (GLCs).

Chapter 7 presents the overall conclusion of this study and provides recommendations for future study. Finally, the list of publications from this thesis is provided in Appendix A.

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