eProceedings Chemistry 1 (2016) 53-57

eISSN 2550-1453 http://eproceedings.chemistry.utm.my/

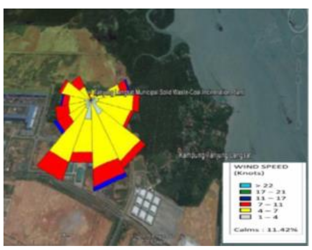
# Prediction of pollutants using aermod dispersion model for a 10MW Coal-MSW incineration power plant Tanjung Langsat, Johor

Nur Fatihah Adam and Anthony Nyangson Anak Steven @ Mohd Daniel*

*Department of Chemistry, Faculty of Science, Universiti Teknologi Malaysia, 81310 Johor Bahru.*
*Corresponding Author: tony@kimia.fs.utm.my*

***Article history :***
*Received September 2016*
*Accepted November 2016*

**GRAPHICAL ABSTRACT**



The wind rose for Tanjung Langsat coal-municipal solid waste incineration plant.

**ABSTRACT**

Eventhough Malaysia generates electricity from natural resources such as coal and natural gas, these non-renewable resources become depleted from year to year. An alternative to this problem is to generate electricity by municipal solid waste incineration. Despite being an attractive option for waste management, the combustion releases pollutants into the air which may influence human health and environment and led to strict enforcement of air quality regulation. Towards attaining the air quality targets, it is essential to evaluate the emission of the pollutants produced from the smoke stack in the plant. AERMOD dispersion model was used in this study to evaluate the ground level concentration of pollutants against stack height in Tanjung Langsat coal-municipal solid waste (MSW) incineration power plant. In this plant, coal was burned together with the municipal solid waste at different ratio. The findings showed the highest ground level concentration of NOx : 0.1316 $\mu g/Nm^3$, SOx : 0.0344 $\mu g/Nm^3$, particulate matter : 0.0206 $\mu g/Nm^3$, dioxin : $7.57\times10^{-12}$ $\mu g/Nm^3$, mercury : $2.86\times10^{-7}$ $\mu g/Nm^3$ and cadmium : $4.56\times10^{-5}$ $\mu g/Nm^{3}$ at 100 m stack height. For 50 m stack height, the highest ground level concentration of NOx : 0.2684 $\mu g/Nm^3$, SOx : 0.0700 $\mu g/Nm^3$, particulate matter : 0.0423 $\mu g/Nm^3$, dioxin : $7.74\times10^{-12}$ $\mu g/Nm^3$, mercury : $5.85\times10^{-7}$ $\mu g/Nm^3$ and cadmium : $9.29\times10^{-5}$ $\mu g/Nm^3$. The reported values still lower than the current emission limit stated in the Air Quality Regulation but in the future, this regulation will become more stringent. An improvement should be done to further reduce pollutant concentrations in order to make sure that the power plant meet the stringent future environmental law.

*Keywords: AERMOD dispersion model, coal-municipal solid waste, incineration*

© 2016 Dept. of Chemistry, UTM. All rights reserved

## 1. INTRODUCTION

The development of human civilizations runs in parallel to increasing pollutions in Malaysia. The most concern problem is air pollution, which are contributed by industries, transportation and open burning. In addition, combustion/management of municipal solid waste (MSW) also contributes to this pollution. However, MSW can be reduced by using 3R (reuse, reduce, recycle) approach, and nowadays, MSW has been utilized for energy production to decrease the amount of waste generated[1,2]. The use of the MSW for energy production, which is also known as recovery of the waste, has been implemented by other countries for many decades[3]. The energy can be generated by the incineration process of the wastes[3]. In addition, there are some countries such as Taiwan, Japan and China use this system to generate electricity[4,5]. In Malaysia, there are several MSW incineration power plants[6]. At the moment, a mini power plant is being constructed in Tanjung Langsat, Johor, which will be installed with with a new coal-MSW incineration system. This is to improve previous MSW incineration system applied in other MSW incineration plants[6] which are reported to have poor performance due to the inability to utilize high moisture MSW as fuel.

MSW is domestic disposed material produced in human daily life, such as product packaging, grass clipping, bottles, food scraps, papers and clothing[6]. These disposed materials come from homes, schools, hospitals and industries. In Peninsular Malaysia, the quantity of MSW has increased from 16,200 tonnes per day in 2001 to 19,100 tonnes per day in 2005, which is in average of 0.8 kg per day[7]. The increasing quantity of MSW is related with the population growth. According to the annual report in 2002 by the Ministry of Housing and Local Government, there is an increase of the population from 15,146,236 inhabitants in 1996 to 17,136,575 inhabitants in 2001[6]. From this information, it is proposed that, as the population increases, the amount of the MSW produced is increased[6]. The Malaysian government has made it mandatory to separate solid waste at source beginning 1st of Septembr 2015. This ruling will be implemented in stages. The implementation is pursuant to the regulations under Solid Waste and Public Cleansing Management Act 2007 (Act 672) enforced in the following states and Federal Territories: Kuala Lumpur, Putrajaya, Johor, Melaka, Negeri Sembilan, Pahang, Kedah and Perlis.

The current incineration process of MSW faced a few problems due to the organic and moisture content of the solid waste. The high content of moisture directly influences the incineration process by reducing the calorific value due to the heat of vaporization of water. Calorific value is refered as the amount of heat produced from the combustion product of combustion of MSW. The operational cost increases since the energy required to remove the moisture is high[9]. This will directly increases the operational cost of an incinerator, and in most cases, the incineration plant ceases to operate.

The main problem of combustion of coal is the release of harmful pollutants to the atmosphere. However, the combination of coal and MSW can reduce the concentration of the emitted pollutants such as nitrogen oxide (NOx), sulfur dioxide (SOx), particulate matter ($PM_{10}$) and carbon monoxide (CO)[3]. The efficiency of the combustion process depends on the characteristics of both sources, MSW and coal. Different types of coal have different carbon content, moisture and calorific value. The carbon content in coal supplies most of its heating value. The higher the carbon content, the lesser the moisture and the higher energy produced[11]. The other way to reduce the amount of the pollutants in the atmosphere is by using an air pollution control system (APCS) which include electrostatic precipitator (ESP), flue gas desulfurization (FGD) and bag filter[11]. Besides that, modelling technique can also be applied to forecast-the dispersion of pollutants emmited from the incineration plant[12]. There are several modelling softwares that have been approved by United State Environmental Protection Agency (USEPA) such as AERMOD, CALPUFF and CALINE3[13].

This study propose a predictive model of the dispersion of pollutants from the combustion of MSW and coal by using AERMOD modelling system. AERMOD is a system developed by Exponents scientist that relays to the air quality[13]. Findings from this study suggest the distance and the dispersionconcentration of the pollutants from the power plant. In addition, the type of pollutants and factors affectting the dispersion distance are also presented in this paper.

## 2. EXPERIMENTAL

### 2.1 Materials

This study focused on Tanjung Langsat MSW -coal incineration power plant near Tanjung Langsat Sanitary Landfill in Pasir Gudang, Johor. This power plant was expected to utilize 800 t/d of MSW co-combusted with coal. The emission of six types of pollutants; nitrogen oxide (NOx), sulphur oxide (SOx), particulate matter ($PM_{10}$), mercury (Hg), dioxin and cadmium (Cd) were measured using the AERMOD dispersion model. Three types of data; meteorological, geographic and emission data were obtained as input into the AERMOD dispersion model. The conceptual framework of the model is as shown in Figure 1.

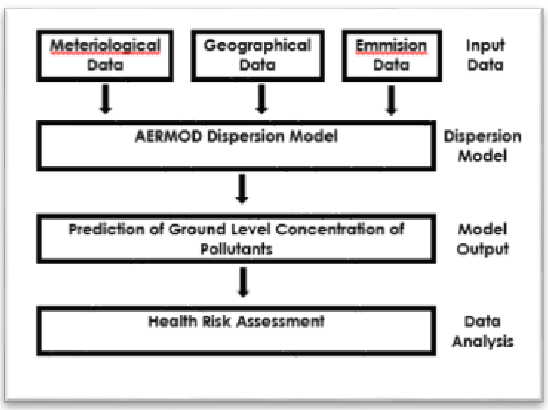



Fig. 1 The conceptual framework for the model.

The ratio of coal and MSW used as fuels in the incineration process was varied and different stack heights from which the pollutants were released to the air were tested to determined the ground level concentration of each pollutant (NOx, Sox, $PM_{10}$, Hg, dioxin and Cd). The models were constructed based on combustion of 100% coal, 50% coal:MSW and 100% MSW. The incineration stacks with height of 100m and 50m were also manipulated in the models. The maximum ground level concentration of each pollutants were compared with the air quality regulation guideline for Malaysia, Japan, European Union (EU) and Environmental Protection Agency (EPA) in order to determine the safety level of pollutant emission.

## 3. RESULTS AND DISCUSSION

The emission of pollutants from incineration stack depends on the wind speed and direction[14]. The wind rose of Tanjung Langsat coal-MSW incineration power plant is shown in Figure 2. Each of the wind rose consists of 16 cardinals showing the direction of the wind. Each of the cardinal consists of several spokes with different colors indicating the frequency and the wind speed. The data of wind speed from January to December 2015 demonstrated that wind blows most frequently from south-east with the maximum speed of 11-17 knots.

The combustion of different ratio of coal and MSW and the height of incineration stacks determined the maximum ground level concentration of pollutants released from the power plant. The emission of NOx from 100m stack due to the combustion of 100% waste, 50% coal and waste and 100% coal resulted in the maximum ground level concentration of 0.1316 µg/Nm$^3$, 0.0757 µg/Nm$^3$ and 0.0201 µg/Nm$^3$, respectively (Figure 3a). In addition to NOx, SOx was also emitted with the maximum ground level concentration of 0.0193 µg/Nm$^3$, 0.0268 µg/Nm$^3$, and 0.0344 µg/Nm$^3$ when 100% waste, 50% coal and waste and 100% coal were used as the fuels, respectively (Figure 3b).

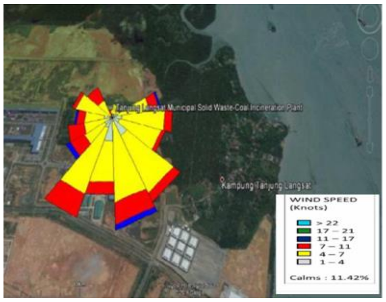



Fig. 2 The wind rose for Tanjung Langsat coal- municipal solid waste incineration plant.

The combustion of waste and coal also release $PM_{10}$ as the product of reaction[14,15,16]. However, the emission is lower compared to NOx and SOx. As showns in Figure 3c, the combustion of 100% waste produced 0.0071 µg/Nm$^3$ maximum ground level concentration of $PM_{10}$ while combustion of 50% coal and waste emitted 0.0139 µg/Nm$^3$ of the same pollutant. The highest maximum ground level of particulate matter resulted from the combustion of 100% coal is 0.0206 µg/Nm$^3$.

Relatively, Hg and dioxin were also emitted during the incineration process but in lower concentration (Figure 3d & 3e). The emission of Hg from the combustion recorded as $2.86 \times 10^{-7}$ µg/Nm$^3$ and the combustion for 100% coal and $.44 \times 10^{-7}$ µg/Nm$^3$ for 50% coal and waste (Figure 3d) while the emission value of Hg in combustion of 100% waste was considered negligible. The emission of dioxins due to the combustion of 100% waste resulted in $7.57 \times 10^{-12}$ µg/m$^3$ of the maximum ground level concentration while the combustion of 50% coal and waste produced $3.79 \times 10^{-12}$ µg/Nm$^3$ Figure 3e). Although the emission of Hg and dioxins were low, these pollutants have high toxicity and detrimental for environment and human health[17,18,19].

The combustion of coal and waste also emits heavy metals[20]. The findings showed that the ground level concentration of Cd resulted from the combustion of 100% waste was higher ($4.65 \times 10^{-5}$ µg/Nm$^3$) compared to the combustion of 50% coal and waste ($2.25 \times 10^{-5}$ µg/Nm$^3$) (Figure 3f). The emission value of both dioxins and Cd in combustion of 100% coal was considered negligible.

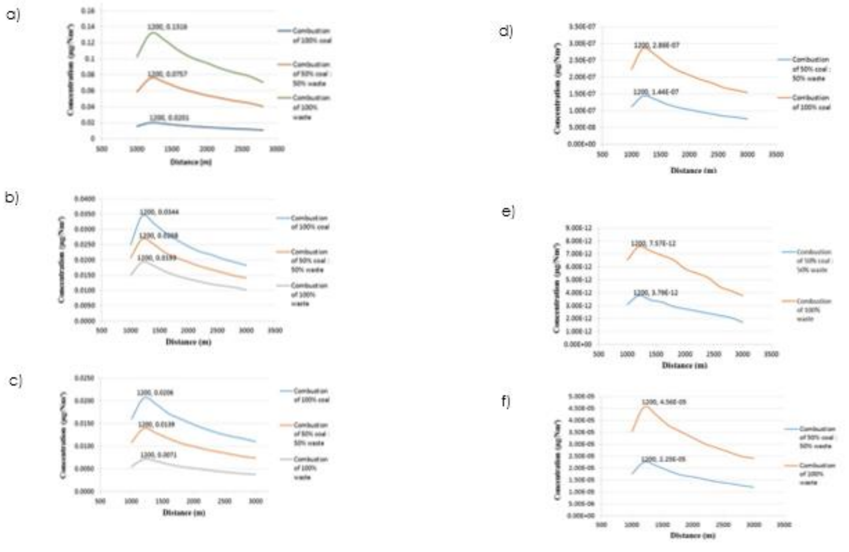


Fig. 3 Maximum ground level concentration of a) nitrogen oxide (NOx), b) Sulphur oxide (SOx), c) particulate matter ($PM_{10}$), d) Mercury (Hg), e) dioxins and f) cadmium (Cd) emitted through 100m of incineration stack.

Interestingly, but not alarming, the emission of the pollutants from 50m stack height were higher than 100m stack height as indicated by the ground level concentration of each pollutant in Figure 4. The combustion of different ratio of fuels, 100% coal, 50% coal and waste and 100% waste resulted in the emission of different concentration of NOx, 0.2684 µg/Nm$^3$, 0.1549 µg/Nm$^3$ and 0.0410 µg/Nm$^3$, respectively (Figure 4a). The combustion also emitted SOx which released the maximum ground level concentration of 0.0700 µg/Nm$^3$, 0.0392 µg/Nm$^3$, and 0.0545 µg/Nm$^3$ following the combustion of 100% coal, 100% waste and 50% coal and waste, respectively (Figure 4b).

During the incineration process, $PM_{10}$ were also emitted at lower concentration compared to NOx and SOx[14,15,16]. As shown in Figure 4c, the highest maximum ground level concentration of particulate matters was 0.0423 µg/Nm$^3$, which emitted from the combustion of 100% coal. The combustion of 50% coal and waste produced 0.0284 µg/Nm$^3$ maximum ground level concentration of $PM_{10}$ . Whereas the least maximum ground level concentration of $PM_{10}$ was 0.0146 µg/Nm$^3$ resulted from the combustion of 100% waste.

The emission of toxic chemicals, dioxins and Hg, during the incineration process from 50m height stack were also detected to be the lowest among the other pollutants. As shown in Figure 4d, the higher maximum ground level concentration of dioxins was observed at 100% waste ($7.74\times10^{-12}$ µg/Nm$^3$) compared to when 50% coal and waste ($3.87\times10^{-12}$ µg/Nm$^3$). The combustion of 100% coal resulted in higher maximum ground level concentration of Hg ($5.85\times10^{-7}$ µg/Nm$^3$) compared to the combustion of 50% coal and waste ($2.93\times10^{-7}$ µg/Nm$^3$) (Figure 4e). The emission value of dioxins and Hg from combustion of 100% coal and 100% waste was considered negligible.

Additionally, the maximum ground level concentration of Cd release $9.29\times10^{-5}$ µg/Nm$^3$ from 100% waste combustion and $4.65\times10^{-5}$ µg/Nm$^3$ from 50% coal and waste combustion(Figure 4f). The emission value of Cd in the combustion of 100% coal was considered negligible.

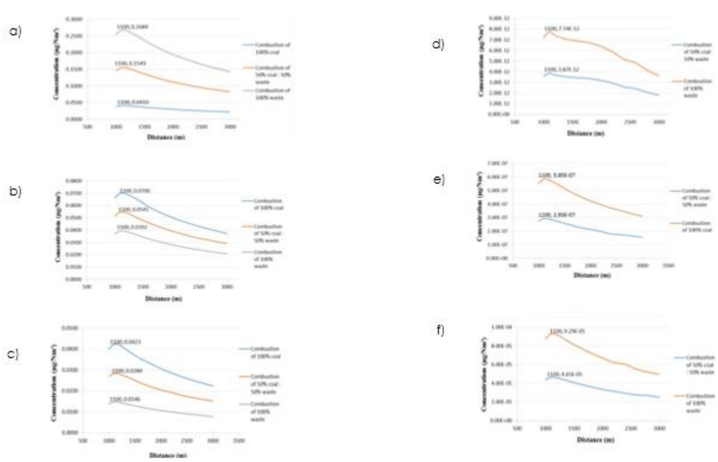


Fig. 4 Maximum ground level concentration of a) nitrogen oxide (NOx), b) sulphur oxide (SOx), c) particulate matter (PM10), d) dioxin, e) mercury (Hg) and f) cadmium (Cd) emitted through 50m incineration stack.

Overall, our reported values are still lower than the current emission limit stated in the air quality guideline of Malaysia, Japan and EU. The emission limit that stated in air quality regulation. The emission limit for nitrogen oxide is 200 mg/m$^3$, sulphur oxide (50 mg/m$^3$), particulate matter (100 mg/m$^3$), mercury (0.05 mg/m$^3$), dioxin (1ng/m$^3$) and cadmium (0.05 mg/m$^{3)}$ (Table 1) [21,22].

Table 1 The air quality guideline for Malaysia, Japan and EU

| Pollutants (mg/m³) | Malaysia | Japan | European Union (EU) | Enviromental Protection Agency(EPA) |
|---|---|---|---|---|
| PM10 | 100 mg/m³ | 100 µg/m³ | 50 µg/m³ | 50 µg/m³ |
| SOx | 50 mg/m³ | 104 µg/m³ | 125 µg/m³ | 125 µg/m³ |
| NOx | 200 mg/m³ | 75-113 µg/m³ | - | 40 µg/m³ |
| Mercury | 0.05 mg/m³ | - | - | - |
| Dioxin | 0.05 mg/m³ | - | - | - |
| Cadmium | 0.05 mg/m³ | - | - | 0.005 µg/m³ |

## 4. CONCLUSION

The combustion of coal and waste with different ratio will emit pollutants at different concentration, depends on the plant stack height. The ground level concentration of pollutants from 50m stack height is slightly higher than 100m stack height. The emission of the pollutants from both stack height are still below the current limit outlined by air quality regulation of Malaysia. Although the emission of pollutants is lower than the restricted values, the plant should consider undergo appropriate modifications or technology because it is expected that future air quality regulation will become more strict.

## ACKNOWLEDGMENT

This project was financially supported by Ministry of Education Malaysia and Universiti Teknologi Malaysia.

## REFERENCES

Abarca, L., Maas, G., and Hogland, W. (2013). Solid waste management challenges for cities in developing countries. *Waste Management*. 33(1), 220–232.

Abd Kadir, S. A. S., Yin, C. Y., Rosli Sulaiman, M., Chen, X., El-Harbawi, M. (2013). "Incineration of municipal solid waste in Malaysia: Salient issues, policies and waste-to-energy initiatives." *Renewable and Sustainable Energy Reviews.* 24, 181-186. Breeze, P. (2014). Power generation technologies. (2nd ed.). Elsevier Ltd.

Cabral, M., Toure, A., Garcon, G., Diop, C., Bouhsina, S., Dewaele, D., Cazier, F., Courcot, D., Dia, A. T., Shirali, P., Diouf, A., Fall, M., and Verdin, A. (2015). Effects of environmental cadmium and lead exposure on adults neighboring a discharge: Evidences of adverse health effects. Environmental Pollution. 206, 247-255

Feng, S., Gao, D., Liao, F., Zhou, F., and Wang, X. (2016). The health effects of ambient PM2.5 and potential mechanisms. *Ecotoxicology and Environmental Safety*. 128, 67-74.

Government of Malaysia. 2006. Ninth Malaysia Plan (2006–2010). Putrajaya, Malaysia: Economic Planning Unit.

Huang, Y., Ning, Y., Zhang, T., and Fei, Y. (2015). Public acceptance of waste incineration power plants in China: Comparative case studies. *Habitat International*. 47, 11-19.

Johari, A., Alkali, H., Hashim, H., Ahmed, S. I., and Mat, R. (2014). Municipal Solid Waste Management and Potential Revenue from Recycling in Malaysia. *Modern Applied Science*. 8, 37-49.

Lombardi, F., Lategano, E., Cordiner, S., and Torretta, V. (2013). Waste incineration in rotary kilns: a new simulation combustion tool to support design and technical change. *Waste Management & Research*. 31(7),739–750

Lothgren, C. J., and Bavel, B. V. (2005). Dioxin emissions after installation of a polishing wet scrubber in a hazardous waste incineration facility. *Chemosphere*. 61, 405-412.

Mackenzie, L. D., and David A. C. (2013). Introduction to environmental engineering. (5th).The McGraw-Hill Companies.

Mokhtar, M. M., Hassim, M, H., Taib, R, M. (2014). Health risk assessment of emissions from a coal-fired power plant using AERMOD modelling. *Process Safety and Environmental Protection*. 92(5), 476-485.

Omine, N., Romero, C. E., Kikkawa, H., Wu, S., and Eswaran, S. (2012). Study of elemental mercury re-emission in a simulated wet scrubber. *Fuel*. 91, 93-101

Rinzler, A.G., Liu, J., Dai, H., Nikolaev, P., Huffman, C.B., Macias, F.J.R. Boul, P.J., Lu, A.H., Heyman, D., Colbert, D.T., Saarnio, K., Frey, A., Niemi, J. V., Timonen, H., Ronkko, T., Karjalainen, P., Vestenius, M., Teinila, K., Pirjola, L., Niemela, V., Keskinen, J., Hayrinen, A., and Hillamo, R. (2014). Chemical composition and size of particles in emissions of a coal-fired power plant with flue gas desulfurization. *Journal of Aerosol Science.* 73, 14-26.

Senior, C. L., Sarofim, A. F., Zeng, T., Helble, J. J., and Paco, R. M. (2000). Gas-phase transformations of mercury in coal-fired power plants. *Fuel processing Technology*. 63, 197-213

Sharifah A. S. A. K., Sulaiman M. R., Ibrahim, R., Husain, M., Municipal solid waste treatment in selected Malaysian islands .In: Proceedings of seminar on appropriate waste management for establishing zero discharge system.Kyoto: Japan; 2002

Shaughnessy, W. J., Venigalla M. M., and Trump, D. (2015). Health effects of ambient levels of respirable particulate matter (PM) on healthy, young-adult population. *Atmospheric environment*. 123, 102-111

Syed Ismail, S. N., and Manaf, L. A. (2013). The challenge of future landfill: A case study of Malaysia. *Journal of Toxicology and Environmental Health Sciences*. 5, 86-96.

Tamrudi, Z., Abdullah, M. L., and Md Tap, A. O. (2009). An Overview of Municipal Solid Wastes Generation in Malaysia . *Jurnal Teknologi*. 51(F), 1–15

Tan, S. T., Ho, W. S., Hashim, H., Lee, C. T., Taib, M. R., and Ho, C. S. (2015). Energy, economic and environmental (3E) analysis of waste-to-energy (WTE) strategies for municipal solid waste (MSW) management in Malaysia. *Energy Conversion and Management*. 102, 111-120.

Wang, C., Liu, X., Li, D., Si, J., Zhao, B., and Xu, M. (2015). Measurement of particulate matter and trace elements from a coal-fired power plant with electrostatic precipitators equipped the low temperature economizer. *Proceedings of the Combustion Institute*. 35(3), 2793-2800

Zainu, Z. A., Wan Mohamad, W. M. S., and Songip, A. R. (2015). Present and Future Innovations in Solid Waste Management in Malaysia. *Int'l Conference on Waste Management, Ecology and Biological Sciences (WMEBS'15)*. May 13-14. Kuala Lumpur, Malaysia, 21-27.

Zhou, Y., Ning, X., Liao, X., Lin, M., Liu, J., and Wang, J. (2013).Characterization and environmental risk assessment of heavy metals found in fly ashes from waste filter bags obtained from a Chinese steel plant.*Ecotoxicology and Environmental Safety*. 95, 130-136.