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Original Article

Coal dust dispersion from a coal storage pile

Pet Techarat[1*] and Paitoon Tontiwachwuthikul[2]

[1] *Faculty of Environment and Resource Studies, Mahidol University, Salaya Campus, Phutthamonthon, Nakhon Pathom, 73170 Thailand*

[2] *Faculty of Engineering and Applied Science, University of Regina, Regina, Canada*

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Abstract

Open coal storage piling is considered as pollution concerned activity because when the air is dry and windy, the coal dust can disperse and cover large area causing air pollution. Knowing in advance the concentration and area affected by the coal dust emitted from a coal storage pile is important. It is, therefore, the purpose of this study to estimate the emission rate of coal dust from an open coal storage pile, and to simulate its dispersed concentration in the environment. The emission rate of 2.26539×10^{-4} g/m^2/s from an open coal storage pile was calculated from 16 coal samples. The simulated results by using the AERMOD model show that coal dust concentrations dispersing from a $120\times60\times10$ m^3 open coal storage pile are below the allowable concentration standard given by the Pollution Control Department of Thailand. The largest and smallest areas affected by the coal dust are in winter (2.124 km^2) and rainy season (0.116 km^2) respectively, but the winter and rainy season concentrations are 67 to 132 µg/m^3 and 133 to 98 µg/m^3 respectively. Dust protection measures should be applied to coal storage piles especially in winter.

Keywords: coal dust, emission, storage pile, dispersion, air pollution, AERMOD

1. Introduction

Coal is the most sustainable energy compared to other resources such as oil and gas (Dudley, 2017). At present, the world consumes coal about 7,800 million tones/year and tends to increase steadily (EIA, 2017). Transporting and piling coal produce coal dust spreading into the environmental and cause health problems. A number of efforts have focused on studying dust from open coal stockpile (EPA, 1988; Lee, Park, & Park, 2002). The coal in the surface layers of a stockpile experiences a range of climatic conditions. Intuitively, one would expect that the factors affecting dusting are the wind-exposed area, the coal particle size in the surface layer, the velocity of the prevailing wind, and the moisture in the surface layer. For dry coal, wind velocity is an important source of energy to erode and carry dust from the coal stockpile (EPA, 1988).

*Corresponding author
Email address: pet.tec@mahidol.ac.th

Coal dusts are coal particulate matters having the sizes less than 100 microns and can easily be carried by wind (Swuste, Corn, & Goelzer, 1995). The particle size is directly linked to their potential for causing health problems, small particles less than 10 microns pose the greatest problems, because they can get deep into human's lungs, and some may even get into the bloodstream. Thus exposure to such particles can affect both lungs and hearts (WHO, 1999). It is, therefore, very important to know in advance the dispersion of coal dust in the environment so that health risks can be prevented or avoided. Although coal dust concentrations can be directly measured in the field, but measurements require experts and sophisticated equipment, which cost a lot of time and budget. An alternative solution is to use an air quality model to simulate coal dust concentration dispersions. This is, therefore, the purposes of this study to (1) estimate the emission rate of coal dust from an open coal storage pile; (2) simulate the dispersion of coal dust using the AERMOD model. The results of this study can, not only be used to evaluate the areas affected by coal dust, but also be used as a guide to control coal dust emission from an open coal storage pile.

The size of the coal storage pile affects emission rates, the larger the storage pile, the larger the wind exposed area and the more emission rates. The size of the largest open coal storage pile in this study area is 120×60×10 m^3. The study started with measuring coal dust from 16 coal samples, followed by calculating emission rates. The AERMOD model was used to simulate coal dust concentrations in 3 seasons: summer, rainy season, and winter, then followed by discussion and conclusion.

2. Methods of the Study

The study area is located in Klongsakae, Nakornluang, Ayuthaya province, Thailand as shown in Figure 1. Almost half of imported coals are stored and distributed to customers from this site. This is an important coal hub of the country. The imported coals are unloaded from barges and stored as an open coal storage pile here as shown in Figure 2.

The methods used in this study are calculating coal dust emission rates from coal samples, and simulating coal dust concentration dispersions by using the AERMOD model.

2.1 Calculating coal dust emission rates

It is impossible to measure coal dust emission rates directly from an entire open coal storage pile because it is too large to be weighted. An alternative solution is to use a set of coal samples. The procedures start with blowing the sample with the highest frequency wind velocity that actually occurs in the field, then following by weighting the sample every equal time interval, in this case 10 minutes, to find the weight left. Repeat the weighting until there is no or very small change in the weight, then stop the experiment. Plot a relationship between weight left (y-axis) and time (x-axis). Find a function that fits very well with the plot, in this case, a decay function as shown in the following form (Ronald, 2000).

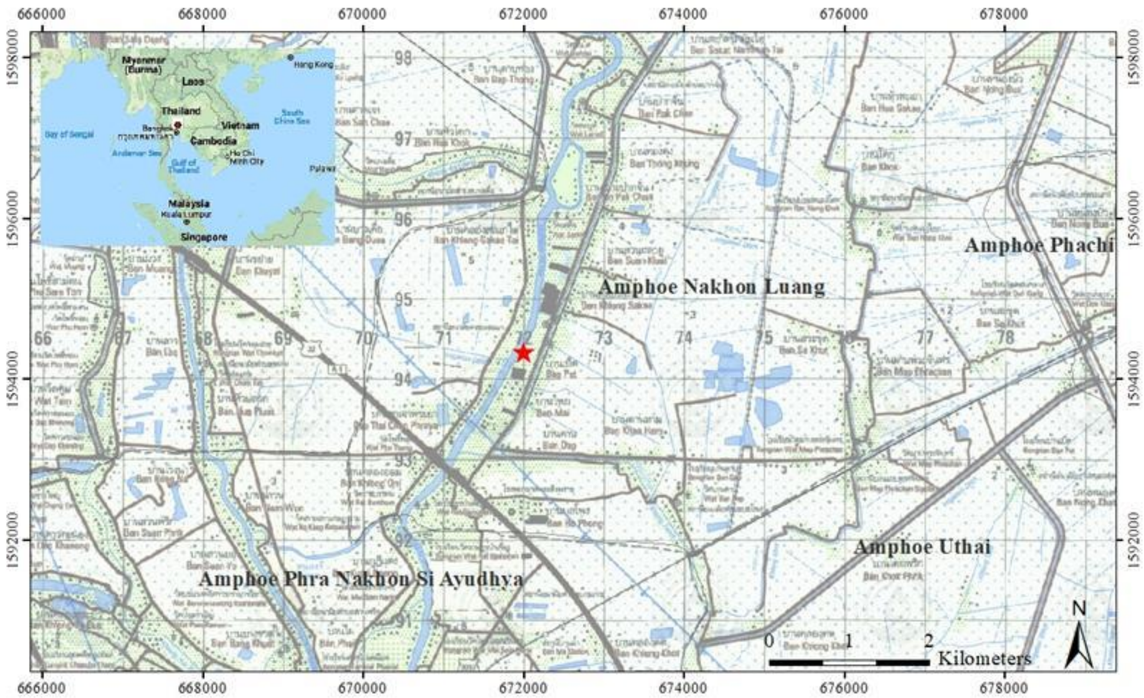

Figure1. Study area, Klongsakae, Nakornluang, Ayuthaya province, Thailand.

Figure 2. An open coal storage pile coordinates 14º 24' 54.73"N, 100 º 35' 45.14E"

$$W_t = a + be^{-ct}$$

The coal weight loss (which is equal to coal dust) equation is.

$$L_t = (W_o - W_t) = W_o - (a + be^{-ct})$$

Emission rate is the differentiation of the above equation with respect to time:

$$E = \frac{dL_t}{dt} = bce^{-ct}$$

where W_t is the weight left (g) of the coal sample at the time t; W_o is the initial weight (g) of coal sample at the time t=0; L_t is the weight loss (g) of coal sample which is equal to the weight of the coal dust (g) at the time t; The parameters a, b, c are constants of the equation obtained by using the curve fitting method; t is time (s); and E is the emission rate of coal dust (g/s) from the coal sample.

Repeat the procedures for all 16 coal samples, the results are shown in Table 1.

The calculated emission rates were divided by the wind exposed area of the sample tray (130 cm^2) to find the unit area emission rates ($g/m^2/s$) and tested for their similarity. At each hour, the emission rates of 16 samples should be the same so that their average values can represent those from the open coal storage pile. The test was done by randomly dividing the samples into 2 groups and the t-test was used to test the similarity. The t-test result shows that at each hour the emission rates are statistically the same at 95%, therefore the average emission rate from the samples can represent the emission rate from the coal storage pile without significant error. By using the curve fitting method, a relationship between average emission rate and time can be represented by the following equation.

$$E_m = 0.0183e^{-0.4801t} \qquad (r^2 = 0.998)$$

where E_m is the mean emission rate ($g/m^2/s$). The average emission rate for the 24 hours period can be calculated by integrating the above equation as follow.

$$E_{av} = \frac{1}{t}\int_0^t E_m dt = \frac{1}{t}\int_0^t 0.0183e^{-0.4801t} dt$$

$$E_{av} = \frac{1}{24}\left(-\frac{0.0183}{0.4801}e^{-24\times0.4801} + \frac{0.0183}{0.4801}e^{0}\right)$$

$$= 1.5882\times10^{-3}$$

IPCC (2002) and Cowherd, Muleski, and Kinsey (1988) suggested that if there is no experimental result, the emission rates of 1.111×10^{-5} and 5.555×10^{-6} $g/m^2/s$ respectively may be used. Huertas, Izquierdo, and González (2012), studied emission rates from several sources in Northern Columbia found that the average emission rate from 16 coal storage piles is 1.124×10^{-3} $g/m^2/s$, which is closed to that obtained from this study. The angle of repose of the coal stockpile is 30 degree (Mechanical, 2011). The largest size of the coal storage pile in this study is 120×60×10 m^3. Therefore, the calculated wind exposed area, total emission rate, and unit area emission rate are 1,027 m^2, 1.6310814 g/s, and 2.26539×10^{-4} $g/m^2/s$ respectively.

Table 1. Emission rate calculation equations obtained for 16 samples.

Sample No.	Emission rate equation (r^2 = 0.99)
1	$E = \frac{dL}{dt} = (3.0710)(1.2217\times10^{-4})e^{-(1.2217\times10^{-4})t}$
2	$E = \frac{dL}{dt} = (1.3515)(1.0430\times10^{-4})e^{-(1.0430\times10^{-4})t}$
3	$E = \frac{dL}{dt} = (2.6512)(1.1702\times10^{-4})e^{-(1.1702\times10^{-4})t}$
4	$E = \frac{dL}{dt} = (1.8498)(9.9397\times10^{-5})e^{-(9.9397\times10^{-5})t}$
5	$E = \frac{dL}{dt} = (4.0773\times10^{-1})(3.1124\times10^{-4})e^{-(3.1124\times10^{-4})t}$
6	$E = \frac{dL}{dt} = (2.5153)(9.4675\times10^{-5})e^{-(9.4675\times10^{-5})t}$
7	$E = \frac{dL}{dt} = (2.0410)(1.3898\times10^{-4})e^{-(1.3898\times10^{-4})t}$
8	$E = \frac{dL}{dt} = (2.0022)(1.0886\times10^{-4})e^{-(1.0886\times10^{-4})t}$
9	$E = \frac{dL}{dt} = (1.6622)(1.6743\times10^{-4})e^{-(1.6743\times10^{-4})t}$
10	$E = \frac{dL}{dt} = (3.4263)(8.4837\times10^{-5})e^{-(8.4837\times10^{-5})t}$
11	$E = \frac{dL}{dt} = (1.3026)(2.4782\times10^{-4})e^{-(2.4782\times10^{-4})t}$
12	$E = \frac{dL}{dt} = (1.3759)(1.1916\times10^{-4})e^{-(1.1916\times10^{-4})t}$
13	$E = \frac{dL}{dt} = (4.4112\times10^{-1})(3.9249\times10^{-4})e^{-(3.9249\times10^{-4})t}$
14	$E = \frac{dL}{dt} = (2.0121\times10^{-1})(1.7406\times10^{-4})e^{-(1.7406\times10^{-4})t}$
15	$E = \frac{dL}{dt} = (1.3695)(1.4759\times10^{-4})e^{-(1.4759\times10^{-4})t}$
16	$E = \frac{dL}{dt} = (1.8234)(1.0871\times10^{-4})e^{-(1.0871\times10^{-4})t}$

2.2 Simulating coal dust concentration dispersions

The AERMOD model was used in this study because the authors found that it is simple, requires less sophisticated data and gives correct results. Several researchers have successfully used the AERMOD model to simulate air quality distributions, for example Smith, 2014 successfully used the AERMOD model to predict the fugitive dust dispersions in the City of Chicago. Cong et al. (2012) used the AERMOD model to simulate coal dust distributions from different shapes of coal stock piles and found that the flat-topped oval piles can reduce dust emissions by 13 to 60% compared to those of conical piles. They also suggested that the pile layout should be arranged and located along the dominate wind direction in order to reduce the dust emission. Huertas *et al.*, 2012 studied emission rates from 6 open coal storage piles at pit coal mines and found the average emission rate of 1.124×10^{-3} g/m^2/s from coal storage piles. Data required by the AERMOD model are summarized in Table 2 (EPA, 2004).

Table 2. Data required by the AERMOD model.

Surface air	Upper air	Geographical dataset	Emission dataset
Wind speed	Wind speed	Elevation terrain data	Emission from coal storage pile
Wind direction	Wind direction	Domain coordinate point	
Temperature	Temperature	Land use categories	
Cloud cover	Dynamic height	Surface albedo	
Ceiling height		Bowen ratio	
		Roughness length (z_o)	

3. Results

The results of this investigation are the output from the AERMOD model which were simulated for summer (15 February to 15 May), rainy season (15 May to 15 October), and winter (15 October to 15 February) in Figures 3-5. The meteorological data (wind speed, wind direction, temperature, cloud cover relative humidity) used in the simulation were the mode (highest frequency data) over 20 years (from 1980 to 2000). The results are shown as follows.

The results show that coal dust concentrations are below the allowable standard concentrations (330 µg/m^3) given by the Pollution Control Department of Thailand (PCD, 2015). In summer, the coal dust distributes in NE direction. The concentrations of 199 to 264 µg/m^3 cover the area 0.132 km^2 and the concentrations of 133 to 98 µg/m^3 cover the area 0.535 km^2. In rainy season, the coal dust distributes in N direction. The concentrations of 199 to 264 µg/m^3 cover the area 0.020 km^2 and the concentrations of 133 to 98 µg/m^3 cover the area 0.116 km^2. In winter, the coal dust distributes in N, E, W direction. The concentrations of 67 to 132 µg/m^3 cover the area 2.124 km^2.

As shown in Table 3, the smallest area affected by coal dust is in rainy season because the rainwater and high moisture keep most part of the coal dust from being blown away. In contrast, the largest area affected by coal dust is in winter because of no rain and dry air, coal dust can move further away from the source.

Table 3. Average meteorological data of the study area.

Meteorological data	Summer	Rainy season	Winter
Wind speed (m/s)	1.14	1.64	1.22
Temperature (Celsius)	29.7	28.9	28.2
Cloud cover (%)	28.85	37.76	11.75
Relative humidity (%)	77	85	78.0

From: Thai Meteorological Department

Comparing the results with those of other studies, for example, the study made by Verma, Shrivastva, & Sharma, 2017 the AERMOD performs well for daily and

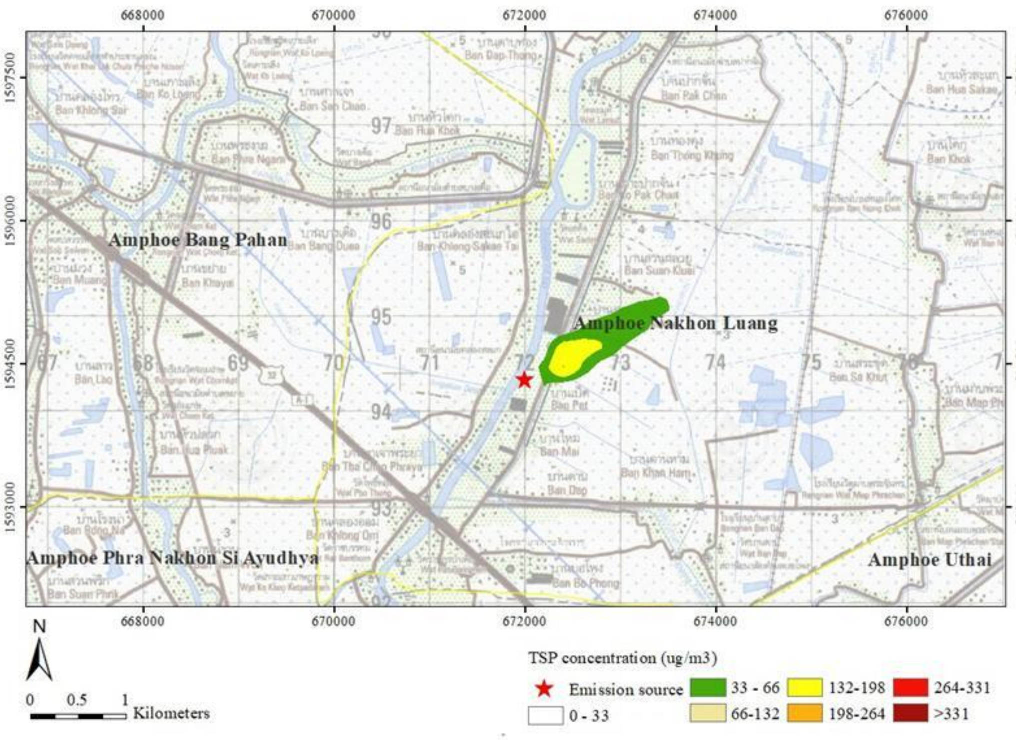

Figure 3. Coal dust dispersion in summer (15 February to 15 May).

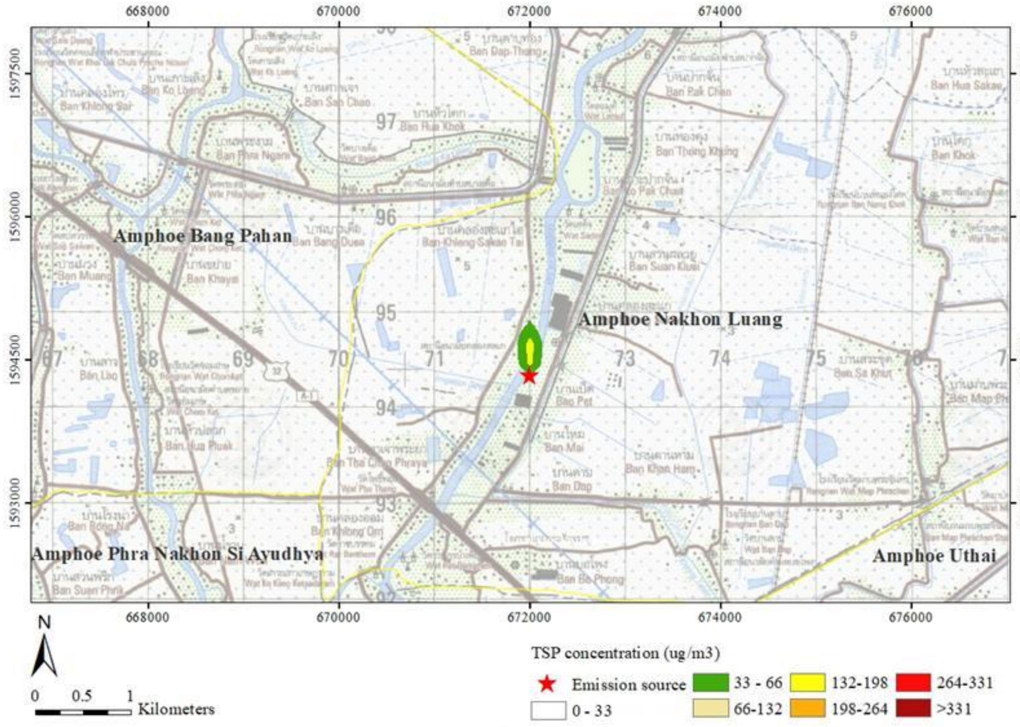

Figure 4. Coal dust dispersion in rainy season (15 May to 15 October).

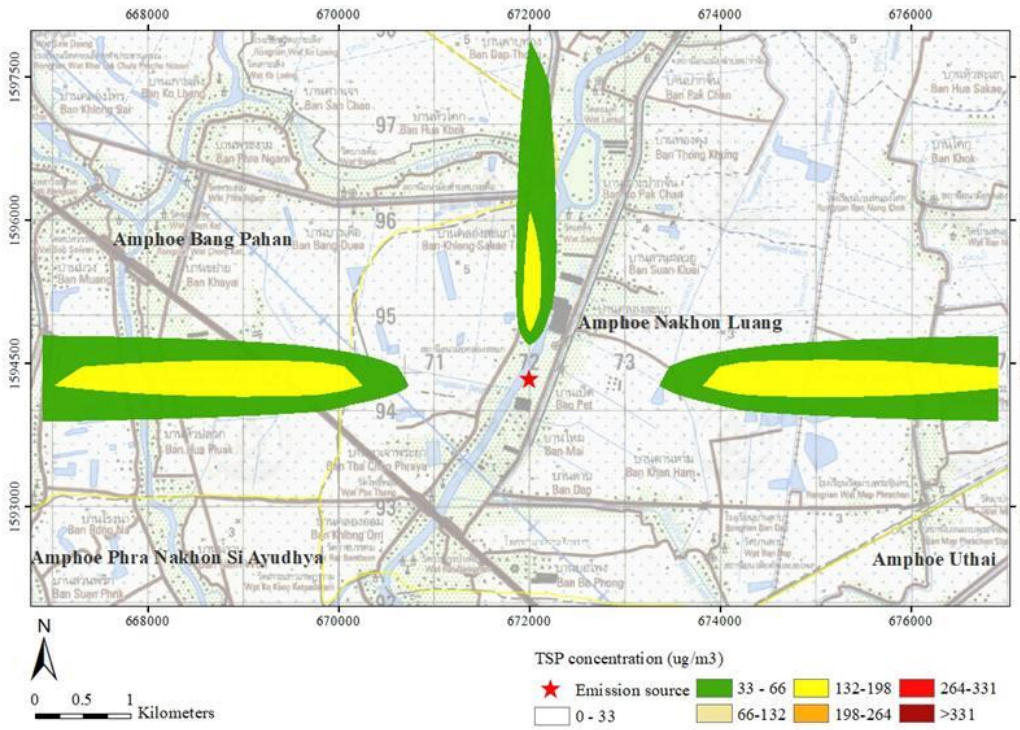

Figure 5. Coal dust dispersion in winter (15 October to 15 February).

monthly averaging time period but it does not predict dust dispersion accurately for smaller values. Irwin, 2014 used the AERMOD to simulate concentrations of a tracer substance. He found that the correlation coefficient between measured and simulated tracer concentrations was 0.90 (N= 44). According to Hadlocon *et al.*, 2015 simulation of the dispersion using AERMOD showed very good statistical agreement (FB < 0.03, MG < 1.3, NMSE < 1.5, VG < 4, and FAC2 > 50%) with observed concentrations for both PM_{10} and $PM_{2.5}$ at 10.5 m above the ground. Some previous studies showed that the AERMOD gave good predictions. However, to confirm the accuracy of prediction by AERMOD, verification of the AERMOD model was made and shown in the next topic.

4. Verification of the AERMOD Model

The verification was done by calculating the differences between coal dust concentrations obtained by using the AERMOD model and those obtained by measuring in the field. The measurements were carried out on 17-18 May 2017, 12-15 June 2017, and 6-7 October 2017 by using an air quality mobile van following the ASTM D4096.The comparison is shown in Table 4.

Table 4. Comparison between the simulated and measured concentrations.

Date	Time	Measured values ($\mu g/m^3$)	Predicted value ($\mu g/m^3$)
May17-2017	16:00	26.77	89.77
May17-2017	20:00	17.19	84.71
May18-2017	10:00	90.94	123.68
Jun12-2017	19:00	180.22	135.75
Jun12-2017	22:00	81.14	106.52
Jun13-2017	7:00	157.21	134.9
Jun13-2017	10:00	138.87	132.63
Jun13-2017	14:00	116.25	126.58
Jun13-2017	17:00	88.16	114.96
Jun13-2017	21:00	47.01	97.84
Jun14-2017	7:00	119.76	126.58
Jun14-2017	10:00	254.92	183.74
Jun14-2017	13:00	205.58	178.66
Jun14-2017	16:00	180.61	138.6
Jun15-2017	8:00	236.20	183.6
Jun15-2017	11:00	225.28	178.87
Oct6-2017	21:00	39.74	91
Oct6-2017	4:00	15.95	73.63
Oct7-2017	8:00	23.84	88.5
Oct7-2017	11:00	98.10	125.57
Oct7-2017	13:00	204.19	159.76
Oct7-2017	18:00	16.32	75.93
Oct7-2017	19:00	8.41	38.44
Average		111.85	121.31

The t-test was used to test the differences between the observed and measured values. The result of t-test shows that the simulated and measured concentrations are the same at 95%as shown in Table 5. It was found that during the field measurement, especially in the evening between 16-20 hours, the wind speed variation was very high causing large errors. As a result, large differences between simulated and measured values were observed. Therefore, in order to avoid the errors, the measurement should not be done during this period.

5. Conclusion and Discussion

A dry uncovered coal storage pile can cause air pollution. The dispersion of coal dust concentration depends

Table 5. The result of t-test.

	Measured	Predicted
Mean	111.854583	121.31375
Variance	6212.36643	1439.0139
Observations	24	24
Pearson correlation	0.95996311	
Hypothesized mean difference	0	
df	23	
t Stat	-1.0600724	
P(T<=t) one-tail	0.1500588	
t Critical one-tail	1.71387153	
P(T<=t) two-tail	0.30011761	
t Critical two-tail	2.06865761	

on the size of the coal storage pile, wind speed, relative humidity, and distance from the source. The AERMOD model can successfully be used to simulate the coal dust dispersions. The results show that the concentrations are below the allowable standard given by the Pollution Control Department of Thailand. The largest affected area occurs in winter while the smallest affected area occurs in rainy season. It may be concluded from the simulated results that even there are emissions from the open coal storage pile; the concentrations are still below the allowable standard. By using the t-test method, the simulated and measured results are statistically the same at 95%, therefore the AERMOD can successfully be used to simulate the concentrations without significant error.

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