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NO_X EMISSION MODELLING FROM INDUSTRIAL STEAM BOILERS

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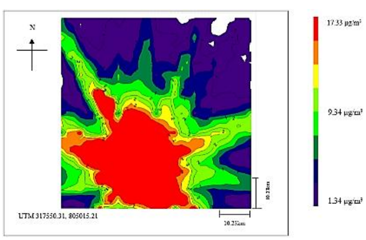
Graphical abstract



Abstract

Previous researches often emphasize on the sources and effects of air pollutants in the environment and human population. A part of those studies were done in order to explore the spread or distribution pattern of those pollutants, especially regarding the emission from industrial steam boilers. It is very important to evaluate the transfer trend of air pollutants at both local and global scales. In this study, Industrial Source Complex Short Term Version 3 (ISCST3) model has been used to predict the distribution of NO_x emitted from industrial steam boilers in the District of Hulu Langat, Selangor. The result of analyses indicates that the emission rates for steam boilers were ranging from 0.0083 kg NO_x/hour to as high as 0.2771 kg NO_x/hour while the total emission load was 1.9969 kg NO_x/hour. The evaluation on dispersion contour shows that the concentration of NO_x was higher in 1-hour reading than 24-hour value. The highest concentration of NO_x was predicted to be within 104.65 km² from the sources of NO_x (steam boilers).

Keywords: Air pollutant, industrial steam boilers, NO_x emission, industrial source complex short term version 3, distribution pattern

Abstrak

Kajian lepas sering menekankan kepada sumber dan kesan pencemaran udara di alam sekitar dan penduduk manusia. Sebahagian daripada kajian yang telah dilakukan untuk mengenalpasti coral penyebaran atau pengedaran dari bahan-bahan pencemar tersebut, terutamanya mengenai pelepasan dari stim dandang perindustrian. Ia adalah sangat penting untuk menilai corak pemindahan bahan pencemar udara di kedua-dua skala tempatan dan global. Dalam kajian ini, Sumber Perindustrian Kompleks Jangka Pendek Versi 3 (ISCST3) model telah digunakan untuk meramal taburan NOx dipancarkan dari stim dandang perindustrian di Daerah Hulu Langat, Selangor. Hasil analisis menunjukkan bahawa kadar pelepasan bagi stim dandang ialah antara 0,0083 kg NOx/jam untuk setinggi 0.2771 kg NOx/jam manakala jumlah beban pelepasan itu 1.9969 kg NOx/jam. Penilaian dalam penyebaran kontur menunjukkan bahawa kepekatan NOx adalah lebih tinggi dalam bacaan 1 jam berbanding nilai 24-jam. Kepekatan tertinggi NOx telah diramalkan berada dalam 104.65 km² dari sumber NOx (stim dandang).

Kata kunci: Pencemaran udara, stim dandang perindustrian, pelepasan NOx, perindustrian sumber kompleks jangka pendek versi 3, Pengagihan Corak

1.0 INTRODUCTION

Increasing in the size and capacity of industries requires a massive change in production processes. One of them would include the electricity supply to meet the requirement of these activities. Since the dependence on one source electricity power supply would cost a lot of companies' budget, these industries are tending to own the new and cheap technologies to act as a secondary power supply. One of the technologies is the installation of steam boilers to generate electricity.

Steam boilers can be operated based on several fuels such as diesel, petrol, wastes, and wood ashes. However, a different combustion source would emit a different concentration and types of air pollutants. It is important to have more research in this area since the direct impacts of air pollution from steam boilers are not clearly studied. In Malaysia, the emission standards for steam boiler operation was prescribed in under the Environmental Quality (Clean Air) Regulations 1978 in the Environmental Quality Act 1974 (EQA, 1974). The continuous monitoring of stack emission was done by the Department of Environment (DOE). The registration of the steam boilers was required under the Factories and Machineries Act 1967 (FMA, 1967) under the Factories and Machinery (Steam Boiler and Unfired Pressure Vessel) Regulations, 1970 which under the authority of the Department of Occupational Safety and Health (DOSH).

The air pollutants from steam boiler combustion may include nitrogen dioxide, carbon monoxide, sulphur dioxide, and also dust particles. Each specific pollutant has its own impacts on environmental quality and human health. For example, nitrogen dioxide can cause depletion of the ozone layer, or in large environmental degradation scale, contributing to global warming. However, for exposed population, they might experience several health problems such as coughs and some cardiovascular diseases.

Steam boilers are the complex operated components and systems which generate steam for electricity generation. Based on a book entitled "Improving Steam System Performance: A Sourcebook for Industry", there are 2 general types of boilers namely firetube and watertube. The difference between both was on the boiler tube's side part of which contained either combustion gases or the boiler steam [1]. Another reference classified steam boilers into two categories which based on the heat exchange configuration and the other one was based on the fuel - burning system. Under the heat exchange configuration, there were two sub-categories which were firetube and watertube boiler while under the fuel-burning system, there were several sub-types such as stoke boiler, pulverized coal (PC), and fluidized-bed combustors (FBC) [2].

Industrial Source Complex Short Term Version 3 model (ISCST3) has been used widely in air pollution modelling studies. In 2008, a study on the simulation of air pollution has been done that used the ISCST3 to determine the dispersion pattern. The authors have calibrated the model by comparing the result with the observed data [3].

The steam boilers were operated by applying the heat, which usually produced from the combustion of fuels, to heat up water temperatures to generate steam. There were various types of fire-based materials such as coal, diesel, petrol, wood, and electric-based boilers. However, most of the electric-based boilers were used to heat water for industrial purposes, not merely for electricity generation. It was determined that boilers differed from each other according to their configuration, size, and the quality of steam formed [2]. Steam boilers burn the several fuel or combustion materials such as oil, gas, wood, or coal to boil the water which the heat generated then using for electricity supply. It was estimated that the boilers accounted about 2.7 million tons of NO_x, 2.4 million tons of SO_2, and 0.3 million tons of $PM_{2.5}$ for the entire world. The respected emission represents more than 16 percent of total NO_x emissions, 16 percent of total SO_2 emissions, and 5 percent of total $PM_{2.5}$ emissions in the year 2010 [4]. This study result seemed to support the previous study in Qatar by ELZeini[5] where the emission of these air pollutants could cause several health problems and environmental degradation.

One study done in Qatar on steam boilers found that the emission of NO_x from the boilers were exceeding the limits in the NO_x emissions which was more than 200mg/Nm^3. ELZeini[5] has highlighted that NOx emission was among the primary pollutants. This researcher also justified that NOx emission plays a major role in several environmental and health problems such as acid rain, photochemical smog in lower atmosphere level, and also the deterioration of beneficial upper ozone [5].

There were several factors affecting the NO_x emission and steam boiler efficiency. One of them is the air ratio. It was determined that low excess air ratio will cause a reduction in NO_x formation. However, it affected the efficiency of steam boilers as combustion process is incomplete. Incomplete combustion will then further cause the CO emission to be increased. The study showed that a higher percentage of unburned carbon will produce a high percentage of CO and vice versa. The optimum excessive air ratio identified at 1.22 [6]. Another study done on 660MW boiler also revealed that that the increased in fuel to air ratio would decrease the concentration of NO_x emission. The study was done by controlling the concentration control valve (CCV) in boilers where the increase of the CCV opening from 0 to 40 percent has found to decrease NO_x concentration from 2594 mg/m^3 to 1895 mg/m^3 [7].

Based on a modelling study on boilers made in the USA, the author expressed that in the presence of low excess air, the NH_3 that evolved from fuel burning persisted a longer period of time due to less oxygen to oxidize it. The reaction occurred when NH_3 reacts with NO to deplete it. The consequences of this reaction were the less NO emission when less excess air available in boilers. The authors also summarized that many boilers were not properly designed, especially in air systems management. Many of the boilers were operated by using massive amount of oxygen which leads to higher NO_x emissions [8]. It also found that the NO_x concentration was lessen from 108 ppm to 22 ppm if 50 percent of air consumed in combustion were recirculated in boilers while the other 50% was the fresh air. While, NOx concentration also found to deplete through suppression of thermal NO by decrease the boiler temperature and oxygen concentration [9].

Another study implemented found that NO_x emission was higher in high volatility and nitrogen content coal compared to the lower one. It also determined that the emission was decreased when the boiler load decreased. There were rapid declined in NOx emission from high MW boiler than those in the range of lower one. The boilers load affected the furnace temperature while NO_x emission that affected by furnace temperature was influenced by the total air flow rate and total fuel rate [10]. The NO_x emission from steam boilers was predicted by using the Vista model. In the modelling, the researcher used four different types of coal with different qualities including the nitrogen content. It was predicted that coal with higher nitrogen content would have higher NO_x emission [11].

As compared to the heavy oil (no water ratio), the NO_x emission was decreased by 17% when the fuel used was emulsified with water content ratio of 10 volume percentage. Increasing the water volume percentage resulted in lower NO_x emission as water content ratios of 30 volume percentage showed the reduction of 36% [12]. The previous study identified that the NO_x emissions were ranging from 303 mg/m^3 of wet wood to 674 mg/m3 for dry wood. At the same time, the heat energy generated from dry wood burning was much greater than wet wood. Since the burning of dry wood can produce higher combustion temperature, the NO_x formation would be increased if the process is not properly managed [13].

It was predicted that the NO_x emission concentration was increased with the higher fuel quality (LHV) even with "dilution" effect of the flue gas. The reason of the situation may because of the flame temperature factor since the excess air ratio and fuel-N ratio of volume of dry flue gas was constantly controlled. It was identified that the emission was increased 70ppm when there was increased from 8 to 12 MJ/kg of the fuel. It has been concluded that the steam boiler used together with the fuel type contribute to the generation of several gases including NO_x [14]. Based on the result found in the similar study done in Kocaeli, Turkey, it can be concluded that different fuels used in combustion may emit different emission of air pollutants. The study compared the emission factor for several air pollutants such as nitrogen dioxide (NO_2), carbon monoxide (CO) and sulphur dioxide (SO_2) in term of milligram per kilogram of different types of fuels. The respected fuels included liquefied petroleum gas (LPG), diesel oil, and natural gas. It was found that the highest emission of particulate matter, nitrogen dioxide, and carbon monoxide was wood-based fuels. The highest emission of sulphur dioxide has been identified from the combustion of light fuel oil with the mean of 36, 295 mg/kg. However, there was only a small concentration of formaldehyde found from the burning of LPG, natural gas, and diesel oil [15]. However, the study has been done in a limited number of steam boilers, which may cause several deviations from actual results. The author also agreed that more similar studies are needed to be done for more accurate information.

One of the factors determining the NO_x production in steam boilers was the boiler load. Based on the study done, it was observed that 50 percent reduction in boiler load has reduced the emission rate of NO_x for both natural gas and fuel oil. However, the reduction was greater when the co-combustion of fuel oil together with natural gases was used (from 0.111 kg/s to 0.063 kg/s) [16].

The objectives of the study were to determine the emission rate from steam boilers, to establish the pollution contour using the ISCST3 modelling software, and also to analyse the NO_x dispersion based on contours created.

2.0 EXPERIMENTAL

2.1 The Study Area

Hulu Langat is the one of the districts in the State of Selangor. It covers the area of 82,620 hectares and has 7 sub-districts which are Kajang, Hulu Langat, Ampang, Cheras, Semenyih, Hulu Semenyih and Beranang. The District of Hulu Langat is the fifth largest district in Selangor and located under the province of Klang Valley. It shares the borders with Kuala Lumpur and District of Gombak at Northwest side, District of Petaling at West side, Putrajaya Administration Centre and District of Sepang at Southwest. In addition, the State of Pahang is located at the Northeast while the State of Negeri Sembilan is at South and East.

Based on the map in Figure 1, the land use pattern of the District of Hulu Langat is varied such as for residential purposes, industrial area, commercialization, and also agricultural. However, some parts of the district, especially in the sub-district of Hulu Langat and Sub-district of Semenyih are mainly a forest area. As concerned, the industrial sectors are distributed mostly in the sub-district of Cheras, Kajang, Semenyih, and Beranang. The blue colour line was the borderline between the District of Hulu Langat and other states and districts.

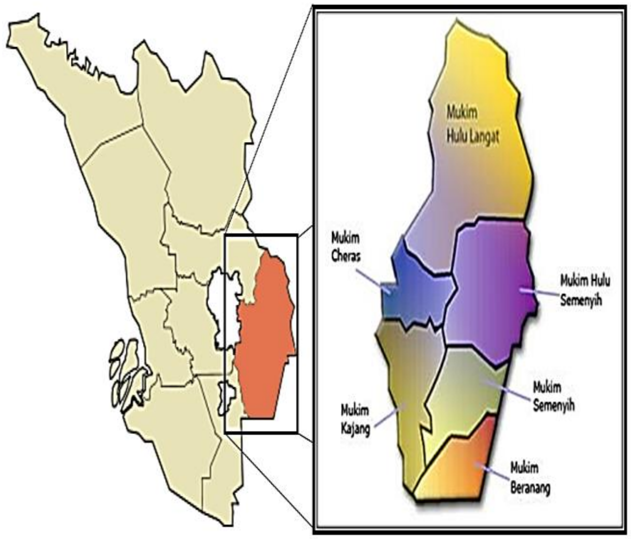


Figure 1 Map shows the sub-districts in the District of Hulu Langat

Table 1 showed the area for each sub-district in the District of Hulu Langat. The largest area was Hulu Langat followed by Hulu Semenyih while the smallest area was Ampang.

Table 1 The division area of sub-districts in the District of Hulu Langat

Sub-district	Area (in hectares)
Hulu Langat	29,542
Hulu Semenyih	18,405
Semenyih	9,599
Kajang	9,340
Beranang	6,184
Cheras	5,973
Ampang	3,901
Total	**82, 944**

2.2 Study Samples

The study samples were the steam boilers installed and operated in the District of Hulu Langat. There were several inclusive and exclusive criteria for steam boilers in this study. The inclusive criteria included all steam boilers available in the District of Hulu Langat, while those steam boilers, which running by using electricity were excluded from being the samples. After these inclusive and exclusive criteria, the total numbers of 32 steam boilers were taken as samples. 11 steam boilers were located in Kajang, 5 in Bangi, 4 in Bangi, 4 in Beranang, 3 in Bukit Beruntung, 2 in Seri Kembangan while for Ampang, Balakong, and Cheras has only one boiler.

2.3 Topographical and Meteorological Information

Topographical and meteorological information in Hulu Langat were obtained from several government agencies. The data on topographical information was gained from the Malaysian Department of Survey and Mapping while the data on meteorological conditions were obtained from the Malaysian Meteorological Department. The 2007 hourly meteorological data have been used as input since the limitation in obtaining the latest meteorological data. This was based on the assumption that the numbers of steam boilers were not significant changes throughout the years in the area. The contour maps generated by the model were compared side-by-side with the topographical map of Hulu Langat to illustrate the estimated scenario of dispersion and the area or population under influenced.

2.4 Steam Boiler and Receptor Coordinates (x,y)

Based on the secondary data obtained from DOSH, the addresses of the industries which operating the steam boilers has been identified. The coordinates of each steam boiler were measured and recorded since those positions were crucial in ISCST3 model. The position of each steam boiler was taken by using Global Positioning Satellite (GPS) instrument and the reading was taken in Universal Transverse Mecator (UTM). The exact coordinates of the boilers were taken to provide the actual position of individual steam boilers. The domain map, then was set up to prepare the map for contour generation. In this study, the Receptors were determined based on the suitability of the map to represent the population in residential area within the District of Hulu Langat. The coordinates obtained, then were entered into the ISCST3 Model for subsequence model generations.

2.5 NO_x Emission Estimation

In order to determine the emission from steam boilers, the information regarding the types of combustion fuels used and the amount of the materials have been accessed. The data were obtained from the Malaysian Department of Occupational Safety and Health (DOSH) and from the industrial boiler owner themselves. In order to estimate the NOx emission from boilers, the following equation as approved by the Australian Government has been used.

$$E = A \times EF \times (1-CE) \qquad \ldots(1)$$

From the above equation, E is the annual emission level of NO_x in kg/year. A is the operation hour or tonnage of fuels used over a year, and EF is the emission factor for NO_x. The CE is the steam boiler emission control efficiency. The following table (Table 2) listed the emission factor recommended by the Australian Government and were used in this study.

Table 2 Emission factors for different types of fuel used in steam boilers

Type of fuels	Operation system	Emission Factor 1 (kg/t)	Emission Factor 2 (kg/Gj)
Natural gas	tangential fired	3.68E+00	8.28E-02
	≤30MW wall fired	2.16E+00	4.86E-02
	>30MW wall fired	5.95E+00	1.34E-01
Petroleum refinery gas	-	2.24E-03	-
Liquid Petroleum Gas (LPG)	Butane	4.43E+00	2.52E+00
	Propane	4.46E+00	2.30E+00
Residual oil	≤30MW	7.32E+00	6.59E+00
	>30MW	4.26E+00	3.83E+00
Diesel	≤30MW	2.72E+00	2.27E+00
	>30MW	3.26E+00	2.73E+00

Source: National Pollutant Inventory, 2011

2.6 ISCST3 Model

In this study, Industrial Source Complex Short Term Version 3 (ISCST3) model has been used to assess the pollutant concentrations in the District of Hulu Langat. ISCST3 modelling method was based on the steady-state Gaussian plume model. The air pollutant dispersion was assessed for the total of 32 steam boilers within the area of the District of Hulu Langat. The model was run by entering the inputs in 6 different pathways namely Control, Source Information, Receptor, Meteorology, Terrain Grid and Output. The Source, Receptor, Meteorology, and Terrain Grid options have been selected based on the particular study. The Control inputs were determined based on the study aimed while Source Information is based on the industrial and pollutant in concerned. Receptor pathway required inputs about receptor locations while Meteorology and Terrain Grid pathway was referring to meteorological and topographical information respectively. However, in this study, since the assumption that the location was a flat area (no elevation), the Terrain Grid pathway was not required to be filled. The Output pathway was the last step in modelling where the selection of result or output being presented.

2.6.1 Control Pathway

Under this pathway, there were several keywords which were required to be filled with information regarding the modelling option. The title has been specified for each run in the TITLE keyword. The selection of several particular run was done on MODELOPT keywords for controlling the study parameters. The study averaging periods was identified and inserted into the AVERTIME keyword while the POLLUTID keyword required the type of air pollutant in concern, where in this study was NO_x. At the end of the pathway, the "run" option was selected to indicate the end of study options setup.

2.6.2 Source Information Pathway

All steam boilers information was managed to be filled in this pathway. In LOCATION, one of the four inputs was chosen in the modelling which POINT, VOLUME, AREA, or OPENPIT. POINT source was selected in modelling emission from stacks and isolated vents. In order to study modelling of emission from a variety of industrial sources, such as building roof monitors or multiple vents, VOLUME source are selected. While the AREA and OPENPIT source were selected for modelling of low level or ground level releases with no plume rise such as lagoons or storage piles and in modelling of emission from open pits such as a mining area respectively. The location for steam boilers were entered in X (east-west) and y (north-south) coordinates to specify the exact boilers location within the District of Hulu Langat. The method was continued by filling-in the source release parameters. It must be emphasized that the different selection of the types of source was required in this step.

In this step, the specified building downwash information was entered into the model. The purpose of this step was to study the effects of building downwash on emission from nearby or adjacent point sources. However, this step only required in the POINT source study. Another data needed was the hourly emission rate for each steam boiler under the HOUREMIS keyword.

2.6.3 Receptor Pathway

In this study, the populations at risk of exposure to air pollutant were called receptors. The actual coordinates of receptors were defined and the networks of gridded receptors were entered. The available networks were Cartesian Grid Receptor Network, Polar grid Receptor Networks, and also Multiple Receptor Networks. In this study, the application on the first one was selected from the study population was covering the large area were plotted in based on exact coordinate in Cartesian Grid.

2.6.4 Meteorology Pathway

All meteorological information obtained from Meteorological Department was entered in the options in this pathway. Since this study was a short-term modelling, the uses of hourly meteorological data were crucial as a basic model inputs. The INPUTFIL keyword needed several options to be selected. Five options that available are the use of default options, specifies the Fortran READ format, the use of free-formatted READS, the unformatted file generated, and use of "card image". The specific height of the anemometer above ground where the wind speed was collected was clearly stated in the ANEMHGHT keyword in meters. The modelling procedures were continued by specifying the station information under the SURFDATA keyword while the information for upper air station used in the determination of mixing heights was put in the UAIRDATA keyword. All those meteorological data entered, then being specified in options, either to allow the model to read the whole available data or to set up the period of time required in the days.

2.6.5 *Output Pathway*

ISCST3 model contained 3 keywords on types of tabular output for the main output file while 4 keywords that control separate output file options for specialized purposes.

3.0 RESULTS AND DISCUSSION

3.1 Emission Rate from Steam Boilers in District of Hulu Langat

Table 3 listed the emission rate for NO_x for each steam boiler in District of Hulu Langat. The total emission load for the whole steam boilers on NO_x emission was 1.9969 kg/hour. However, the calculated value may not present the actual total emission of NO_x since these only made based on the study samples which are steam boilers. There is no standard in Malaysia that considers the emission rate for each steam boiler.

Table 3 The calculated emission rate for individual steam boilers

Steam Boiler	Emission rate of NO_x (kg/hour)
1	0.0086
2	0.0083
3	0.0169
4	0.0166
5	0.0250
6	0.0321
7	0.0333
8	0.0507
9	0.0510
10	0.0635
11	0.0695
12	0.0776
13	0.0886
14	0.0944
15	0.1143
16	0.1467
17	0.2153
18	0.2771
19	0.0088
20	0.0097
21	0.0173
22	0.0168
23	0.0276
24	0.0329
25	0.0388
26	0.0519
27	0.0524
28	0.0650
29	0.0776
30	0.0907
31	0.0907
32	0.0272
Total Emission Rate	**1.9969**

3.2 Modelling of NO_x Dispersion in District of Hulu Langat

In the map of District of Hulu Langat given above, the brown colour area was covered with forest or plantations, while the yellow colour represents the location of human population. The blue colour line was created to clarify the boundaries between the District of Hulu Langat with other districts (District of Petaling and Gombak) and states (Kuala Lumpur and Negeri Sembilan).

Based on the Figure 2, the NO_x concentrations were ranged from a minimum of 7.58 µg/m^3 to a maximum of 73.49 µg/m^3. In the Figure 3, the concentrations of NO_x were ranged from as low as 1.34 µg/m^3 to a high of 17.33 µg/m^3. It was clearly observed in both models that the highest concentration contour (red colour) covered the area of Semenyih, Kajang, Cheras, and Beranang. The highest concentration of NO_x (indicated with red contour) was predicted to be within 104.65 km^2 from the all sources of NO_x (steam boilers). However, the lower NO_x concentration was widely spread, affecting the District of Hulu Langat itself together with the neighbouring district and state. Other affected nearest districts and states are District of Petaling and Gombak and State of Kuala Lumpur and Negeri Sembilan respectively. However, it was predicted that the dispersion was not only distributed to the area shown on map in above, but potentially affecting the other region in Malaysia.

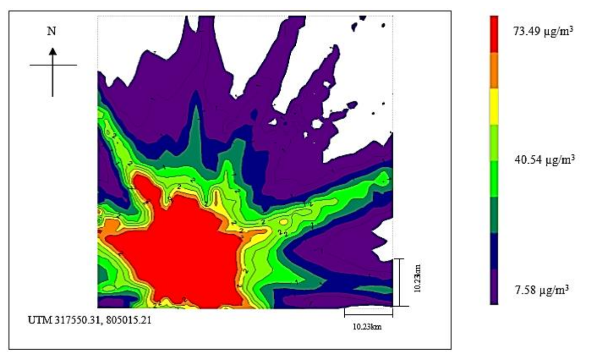


Figure 2 Model of Air Dispersion of NOx based on 1-hour reading with the map of Hulu Langat

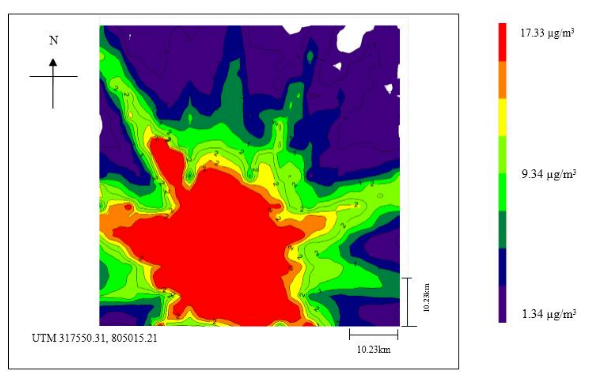


Figure 3 Model of Air Dispersion of NOx based on 24-hour reading with the map of Hulu Langat

In order to determine the characteristics of NO_x dispersion, it is the best to study the models in temporal analysis.

3.3 Temporal Analysis

The temporal analysis was done in order to identify the changes in concentrations of NO_x in two difference time average, which are 1-hour and 24-hours reading. It was identified that both models were having a different minimum and a maximum concentration value of NO_x. As stated in the result above, there were different value for minimum and maximum concentration predicted for both 1-hour and 24-hours reading. The 1-hour NO_x concentration seemed to be greater than the minimum and maximum concentration in 24-hours average respectively.

One of the possible contributing factors to this situation may because of the effect of dilution by air. In 1-hour reading, the percentage of dilution by air on NO_x concentration was slowed as compared to the longer time period. Within 24-hours, the volume of air and NO_x ratio may become greater than 1-hour dilution. The air was known to be a good dilution factor for air pollutants. Those areas located near to the sea coast (meant by having the great wind flow), the natural wind flow will assist in diluting the air pollutants spread [17]. Another potential factor may include the wind movement. Even though the mean surface wind speed was around 1.6 m/s, the changes in wind speed may promote or impede the above factor (air dilution factor). It was determined that those locations which had high wind speed has a greater air pollutant dilution compared to lower wind speed area [18].

3.4 Density of Boilers

As referred to the models prepared, the concentration of NO_x is higher in the south than north, east and west for both 1-hour and 24 hours reading. Since most of the steam boilers were located at the south-side, it can be concluded that the density of steam boilers affecting the concentration in the area compared with the other region. It must be emphasized that other factor such as the height of the emission released from boilers also determined the dispersion characteristics. The severity of air pollution was identified depending on the height where the air pollutants horizontally dispersed [19].

3.5 Buffer Characteristic of Forest

In another view, when studying the movement of pollutant to northward, the concentration of NO_x was rapidly decreased as compared to other direction. Most of the north part of the Hulu Langat District was covered with forest area. In addition, in 24-hours reading, some part of the north-side was estimated not having NO_x dispersion. Together with the clear observation made, it can be stated that the concentrations of NO_x were decreased rapidly when passing through the forest area. The forest areas which act as a buffer zone for air pollutants such as NO_x may become one of the factors of the condition to occur. The forest, especially within urban area act as a treatment area for air pollutants, as well as for environmental stabilization [20].

3.6 Geographical factors

The NO_x concentration was diverted when dispersing northward, represent in white colour contour. This contour was predicted to have no NO_x concentration at all. This was possibly due to the mountain effect which blocks the wind movement together with air pollutant (NO_x). The subsequent effect is that the diversion of NO_x travels pathway to more clear wind movement area (between two mountains). This condition was usually known as wind tunnel effects. The wind movement for each different structure created a different dispersion. It was identified that the dispersion were higher in those areas having more blocked structure. This experiment simulated the same situation as in mountain areas where the structures of mountain influence the air pollutant dispersion [21]. However, there was a greater lateral dispersion of air pollutants in open areas than the area under the effect of wind tunnel [22].

3.7 Human Population at Risk

Based on the observation made, high density of human population was identified in the Northwest and the west side of the Hulu Langat District specifically at Ampang, Cheras, Kajang, and Kuala Lumpur.

Based on the Table 4, the highest population under the District of Hulu Langat was at Kajang followed by Cheras with the total population of 229, 655 people and 163, 550 people respectively. At the same time, as referred to concentration contour in both 1-hour and 24-hours reading, it was estimated that the total of 456, 352 people under the risk of exposure to highest NOx concentrations (Kajang, Cheras, Semenyih, Beranang). Even though the estimated NO_x concentration were below the standard in Malaysian Ambient Air Quality Standard (MAAQS) by DOE, the continuous exposure for several longer periods such as annually may potentially contribute to significant health problems.

The dispersion of any air pollutants, including NO_x were directly influenced by climatic conditions in the specific area. Even though Malaysia has almost similar meteorological condition every year, a small change in several meteorological parameters may cause different dispersion of pollutants in concern. For example, the increase in quantity and frequency of rainfall will promote the removal rate of air pollutants through deposition. A study concluded that the removal of air pollutants from ambient air were greatly depend on the extent of rainfall [23].

Malaysia experiences two types of monsoon winds seasons. One of them is the Southwest Monsoon while the other one is Northeast Monsoon. Southwest Monsoon occurred from May to September while

Northeast Monsoon present from November to March. The Northeast Monsoon brings in more rainfall compared to the Southwest Monsoon. The transition between both monsoons occurred within the period from March to October.

The modelling study was based on estimation of NO_x dispersion in some particular area. It may not represent the total actual NO_x in ambient air since there are multiple potential sources of NO_x such as from transportation, other combustion processes, and any industrial activities involving heating the fuels. The dispersion from several sources may differ from one source since the emission load and total emission rate may change.

Table 4 The total human population in the District of Hulu Langat

Sub-district	Total population
Kajang	229,655
Cheras	163,550
Semenyih	49,076
Beranang	14,071
Hulu Langat	3,408
Hulu Semenyih	46,766
Ampang	43,522
Total	**550,048**

Source: Kajang Municipal Council

3.8 Ambient Air Quality Standard Comparison

The maximum NO_x ambient concentration predicted by model for 1-hour average (73.49 µg/m^3 or 0.036 ppm) was complied or under the standard limit stated in the above table (Table 5). After the conversion of the maximum value for NO_x in 24-hours reading to ppm, the concentration is found to comply the standard limit in Malaysian Ambient Air Quality Standard (MAAQS) which is 0.009 ppm. However, this situation only represents the emission caused by steam boilers. The actual concentration would be higher since there are many possible sources of NO_x around the area such as transportation.

Table 5 Ambient air quality standard for local and national

Standard	Averaging time	NO_2 Standard	
Malaysian Ambient Air Quality Standard (MAAQS)	1 hour	0.17 ppm	320 µg/m^3
	24 hour	0.04 ppm	-
National Ambient Air Quality Standards (NAAQS)	Annual	0.053 ppm	100 µg/m^3
	-	-	-

4.0 CONCLUSION

There were several limitations identified in this study. The study was done by using the previous year meteorological data for the latest meteorological data required high payment to access it. Since there was limitation in study budget, the results obtained were based on the assumption that Hulu Langat did not experience any massive changes in meteorological condition. So, the previous year meteorological data was used as input for running the model. Several data related to steam boilers were kept by several government agencies. However, some of the data obtained were not properly managed, for example, the missing of several data in one particular parameter. In order to search the missing data required a lot of time which has already become one of the limitation.

It is the best way for future study to increase the study period considering the annual comparison for several years or comparison between the changes of dispersion in difference seasonal conditions. In Malaysia, the seasonal changes may refer to wet or dry season where the seasonal changes may potentially affect the dispersion pattern on air pollutants in the study area. The future research also should view the study in wider spatial characteristics. This may include the comparative study between two or more regions with similar climatic condition or even the comparison of locations with different meteorological conditions. For example, in Malaysia, the climates between the Peninsula and the East differ due to the effect of wind. Peninsular Malaysia (west-side), is directly affected by wind from the mainland, while the East is contrasting to more maritime weather.

Modelling technique was known to only represent the estimated pollutant in concerned. In order to estimate the accurate NOx concentration, it would be the best for considering the multiple sources instead of focusing on one source. It is highly suggested for future study to concern on other several air pollutants such as oxides of sulphur (SOx) and PM_{10}. Difference pollutants may have difference toxicity to human health as well as having a difference dispersion trend depending on factors such as climatic conditions.

It can be concluded that the steam boilers contribute to signify level of NOx emission and the NOx emitted would disperse from the source area with directions based on climatic condition and geographical structure. The concentration would be varied depending on these factors. The dispersion of NO_x depends on the earth surface structure, meteorological conditions, and the capacity of the steam boiler operation themselves. Although steam boilers were identified to be one of the sources of NO_x, the other sectors such as transportation may enhance the dispersion and concentration level of NO_x.

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References

[1] U.S. Department of Energy 2004. Improving Steam System Performance: A Sourcebook for Industry. *Washington: U.S. Department of Energy*. http://www1.eere.energy.gov/manufacturing/techdeployment/pdfs/steamsourcebook.pdf. accessed in 19 April 2012.

[2] Energy and Environmental Analysis Inc. 2005. Characterization of the U.S Industrial Commercial Boiler Population. *Virginia: Energy and Environmental Analysis Inc*.

[3] Sumit, S. and Avinash, C. 2007. Simulation of Air Quality using an ISCST3 Dipersion Model. *Clean 2008*. 36(1): 118-124.

[4] Center for Clean Policy 2004. Identification of Potential Areas for Further Federal Actions: Industrial, Commercial and Institutional Boilers. *Washington: Center for Clean Air Policy*.

[5] Elzeini, H. Y. 2010. Q-Chem Steam Boilers NOx Emissions Reduction. *Proceedings of the 2nd Annual Gas Processing Symposiums*. Doha, Qatar.

[6] Li, S., Xu, T. M., Hui, S. E., Wei, X. L. 2009. NOx Emission and Thermal Efficiency of a 300 MWe Utility Boiler Retrofitted by Air Staging. *Applied Energy*. 86: 1797-1803.

[7] Ren, F., Li, Z., Liu, G., Chen, Z., Zhu, Q. 2011. Combustion and NOx Emissions Characteristics of a Down–Fired 660-MWe Utility Boiler Retrofitted With Air-Sourrounding-Fuel Concept. *Energy*. 36: 70-77.

[8] Allan, R. W. 2007. Optimizing CO and NOx Emissions from Hog Fuel Boilers. 2007 *TAPPI Engineering Pulping & Environmental Conference*. Florida, USA.

[9] Shinomori, K., Katou, K., Shimokuri, D., Ishizuka, S. 2011. NOx Emission Characteristics and Aerodynamic Structure of a Self-Recirculation Type Burner for Small Boilers. *Proceedings of the Combustion Institute*. 33: 2735-2742.

[10] Zhou, H., Cen, K., Fan, J. 2004. Modeling and Optimization of the NOx Emission Characteristics of a Tangentially Fired Boiler with Artifitial Neural Networks. *Energy*. 29: 167-183.

[11] TransAlta Centralia 2007. Boiler Emissions Modelling Study, (Final Report) (Project No. 146702.0030) *Centralia: Black & Veatch.*

[12] Chelemuge, Namioka, T., Yoshikawa, K., Takeshita, M., Fujiwara, K. 2012. Commercial-Scale Demonstration of Pollutant Emission Reduction and Energy Saving for Industrial Boilers by Employing Water/Oil Emulsified Fuel. *Applied Energy*. 93: 517-522.

[13] Environchem Services Inc. 2008. Emissions from Wood-Fired Combustion Equipment. *British Columbia: Environchem Services Inc*.

[14] Kuprianov, V. I. and Tanetsakunvatana, V. 2006. Assessment of Gaseous, PM and Trace Element Emissions from a 300-MW Lignite-Fired Boiler Unit for Various Fuel Qualities. *Fuel*. 85: 2171-2179.

[15] Karademir, A. 2006. Evaluation of the Potential Air Pollution from Fuel Combustion in Industrial Boilers in Kocaeli, Turkey. *Fuel*. 85: 1894-1903.

[16] Chovichien, N., Kuprianov, V. I., Kaewboonsong, W. 2006. Modeling Major Gaseous Emissions from a 310-MW Boiler Unit Co-firing Medium-sulphur Fuel Oil and Natural Gas with Variable Ration of Fuel Feed Rates. *The 2nd Joint International Conference on "Sustainable Energy and Environment (SEE 2006)*.

[17] Gupta, J. P. 2005. Dilution with Air to Minimize Consequences of Toxic/Flammable Gas Releases. *Journal of Loss Prevention in the Process Industries*. 18: 502-505.

[18] Isikwue, B. C., Tsutsu, O., Utah, E. U., Okeke, F. N. 2011. Preliminary Study on the Estimation of Horizontal Dilution Potential of Air Pollutants Over Some Cities in Nigeria Using Wind Data. *Physical Review & Research International*. 1(3): 61-73.

[19] Delmelle, P., Stix, J., Baxter, P., Garcia-Alvarez, J., Barquero, J. 2002. Atmospheric Dispersion, Environmental Effects and Potential Health Hazard Associated with the Low-altitude Gas Plume of Masaya Volcano, Nicaragua. *Bulletin of Volcanology*. 64: 423-434.

[20] Albert, H. T. 1993. The Role and Function of Forest Buffers for Nonpoint Source Management in The Chesapeake Bay Basin. *Chesapeake Bay Program*.

[21] Mavroidis, I., Griffiths, R. F., Hall, D.J. 2003. Field and Wind Tunnel Investigation of Plume Dispersion Around Single Surface Obstacles. *Atmospheric Environment*. 37: 2903-2918.

[22] Macdonald, R. W., Griffiths, R. F., Hall, D. J. 1998. A Comparison of Results from Scaled Field and Wind Tunnel Modelling of Dispersion in Arrays of Obstacles. *Atmospheric Environment*. 32(22): 3845-3862.

[23] Shukla, J. B., Misra, A. K., Sundar, S., Naresh, R. 2008. Effect of Rain on Removal of a Gaseous Pollutant and Two Different Particulate Matters from the Atmosphere of a City. *Mathematical and Computer Modelling*. 48: 832-840.