INTEGRATED MALAYSIAN METEOROLOGICAL DATA ATMOSPHERIC DISPERSION SOFTWARE FOR AIR POLLUTANT DISPERSION SIMULATION

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UNIVERSITI TEKNOLOGI MALAYSIA
INTEGRATED MALAYSIAN METEOROLOGICAL DATA ATMOSPHERIC DISPERSION SOFTWARE FOR AIR POLLUTANT DISPERSION SIMULATION

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ABSTRACT

Air pollution prediction around point-source emission of industrial stack has been a great concern to evaluate impact of polluted gases to the surrounding environment. However, there is no software that is designed specifically for air pollution simulation in Malaysia to assist local environmental agencies in local air pollution prediction. This thesis presents a detailed study and analysis of the development of a new software for air pollutant dispersion simulation in Malaysia. It will be used in predicting outdoor air quality for stationary point source-type emission of industrial stack. Two major features greatly differentiate the software developed in this thesis with the existing softwares. The first feature is more information on local meteorological data for atmospheric dispersion prediction in Malaysia is included. The second is existing softwares require multiple run for different location analysis while the software developed in this thesis requires just a single run for location-based analysis. Gaussian Plume model algorithm was used as the basis of the software code using MATLAB. The dispersion parameters for urban and rural dispersions are calculated based on the Pasquill-Gifford curves and Briggs plume rise equations. The developed software is validated using approved United States Environmental Protection Agency (US EPA) atmospheric dispersion software, the Industrial Source Complex (ISC) software. Results show that the software predicts the ground-level concentration of pollutants as closely as ISC software with deviation of less than 10% in most cases. However, the software overpredicted the ground concentration in some cases especially for high emission rates. Even though overprediction occurs, in all simulated cases, the software was able to predict whether the ground concentrations exceed the guideline limits or not, the same as the ISC software. To further verify the software, a case study of three different locations is conducted and the software is able to suggest a location with the best ground concentration distribution based on its local meteorological data. The software developed is named as Integrated Malaysian Meteorological Data Atmospheric Dispersion Software (IMMDADS) and ready for use in local industrial applications after minor improvements in the user interface.
ABSTRAK

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LIST OF SYMBOLS

a,b,c,d - Pasquill constants
C - Pollutant concentration
d_s - Stack diameter
F_b - Buoyancy flux parameter
g - Gravitational force
Δh - Plume rise height
h_s - Stack height
h'_s - Modified stack height due to stack tip downwash
h_e - Effective stack height
i - Number of iteration
Q - Stack volumetric flowrate
σ_y - Horizontal dispersion parameter
σ_z - Vertical dispersion parameter
σ_{2e} - Modified vertical dispersion parameter
θ - angle in degree
p - Turbulence exponent
r - Radial distance
s - Number of pollutant source
S - Stability parameter
T_a - Ambient temperature
ΔT - Temperature difference
ΔT_c - Cross temperature difference
T_s - Stack temperature
u_s - Wind velocity at stack height
u_{ref} - Wind velocity at anemometer height
V - Vertical term
v_s - Stack exit velocity
x - x-cartesian coordinate
xf - Final distance of plume rise
X - Location of receptor points
X_o - Stack coordinate in x
y - y-cartesian coordinate
Y - Location of receptor points
Y_o - Stack coordinate in y
wd - angle in radian
z_i - Mixing height
z_r - Receptor points
z_ref - Anemometer height
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CHAPTER I

INTRODUCTION

1.1 Overview

Air pollution has become a subject of great concern for humankind since the rapid development of industrial age in 1960’s that produced sideline wastes of hazardous chemical substances such as sulfur oxides, nitrogen oxides, particulate matter etc. It is a global-scale problem as air pollutants can often migrate up to hundreds of miles away from their sources across countries and continents. The pollutants may lead to severe diseases such as lung cancer, respiratory malfunctioning, organ disabilities, skin infections, stroke and many more (Leroy et. al., 2010). Air pollutants come from various sources such as exhaust gases from road vehicles, factory stacks, open-storage of sand and others. Air pollution studies focus on manipulating emission sources so that the amount of air pollutants released into the atmosphere bring no harm to humankind as well as preserving the nature. This thesis narrows down the problems into outdoor air quality for stationary point source-type emission of industrial stack. In order to conduct air pollution simulation in Malaysia, local environmental agencies need to obtain meteorological data from Malaysian Meteorological Department (MMD) before using the dispersion model such as AERMOD, ISCST3 etc because those software are for general use. However, Integrated Malaysian Meteorological Data Atmospheric Dispersion Software (IMMDADS) provides more information for local meteorological data that has been programmed alongside the dispersion model specifically designed for the use in Malaysia. The complete sets of local meteorological data is very important for local use to allow easier preprocessing procedure during air pollution simulation.
Conventionally, air pollution index (API) is evaluated using either data sampling method or computer modeling. Air pollution data sampling may take up to months to provide acceptable sets of readings for analysis. It is generally known that computer modeling is preferable because it is less expensive, shorter evaluation time, and easier to conduct. In addition, it skips sampling device installation and collecting procedures that may include transportation and labor costs, as well as eliminates the laboratory analysis expenses.

In this study, a software to predict the dispersion of air pollutants around emitted sources in industrial plants will be developed. Software developed in this thesis will be able to predict the pollutant concentration distribution around stack as accurately as existing atmospheric dispersion software. In this study, IMMDADS software is compared with US Environmental Protection Agency (US EPA) approved software which is Industrial Source Complex (ISC) for validation purpose. AERMOD is not used as comparison mainly because complete simulation data by AERMOD is not available by AMR Environmental SDN BHD (AMR), an environmental consultant in Malaysia. Besides, IMMDADS is still in early development phase as only basic equations of Gaussian plume model are being programmed to avoid complex code debugging. It is more difficult to programmed a more advanced model such as AERMOD especially to confirm our code is correct to yield convincing results. If AERMOD software is to take as the benchmark, it will take longer programming time as well as more information on equations used by AERMOD to account more complex pollutant dispersion across buildings, terrains, changing state of the atmosphere and etc.

The software developed here will have additional feature compared to existing software which is Malaysian meteorological data integrated with the air dispersion model. IMMDADS software is designed for local used particularly in environmental impact assessment in Malaysia. The integration of both local meteorological data with air dispersion model that has been separated by existing software is seen as a powerful tool to ease the location-based analysis conducted by plant designers without repetative preprocessing procedure. Apart from giving early warning for any pollution hazards, the software may be able to suggest the best location to locate new plant for a given emission characteristics. Last but not least,
the software is capable to assist environmental consultation agencies in stack optimisation processes.

The software will be validated with ISC software as it receives international approval for regulatory air pollution assessment. The validation process will be done according to simulated cases classified by AMRusing ISC software. The maximum ground concentration values and its location will be used as comparison for both IMMDADS and ISC software to ensure the usage of IMMDADS software is admissible for industrial applications.

1.2 Problem Statement

Air pollution modeling is generally known as the alternative for conventional air pollution sampling because it is cheaper in cost as no sampling device installation procedure is needed and the industries do not need to deal with transportation and labor costs as well. Besides, it is also time consuming as the regulatory model such as Gaussian plume model developed in this study only takes a few minutes to run although the collection of meteorological data took years to compose. In addition, air pollution modeling is more reliable in terms of consistency compared to data sampling because the input data are discrete.

Existing air pollution software do not provide complete information on Malaysian meteorological data because they are for general purpose. Local environmental consultants need to provide meteorological data before using the software to analyse a certain location. IMMDADS features integration of Malaysian meteorological data to assist user in preprocessing procedure. The integration allows users to just select any location in Malaysia to simulate, then IMMDADS will automatically use its location meteorological data to perform the simulation. As a result, this feature provide easier platform for analyzing location for new plant design especially in Malaysia as IMMDADS has complete information on local ambient data. Existing software requires multiple runs for multiple locations while IMMDADS software may perform only single run for the same task. It will greatly
assists plant designers to choose the best locations without a need to repeatedly run the dispersion model by skipping the same preprocessing procedures. Furthermore, IMMDADS software fairly reduce the number of run during optimisation process of the plant design since the process may involve numerous trial and error procedures to acquire stack parameters with the lowest concentration of pollutant in the surrounding area.

1.3 Objectives

1. To develop software to predict the dispersion of air pollutants around emitted sources integrated with Malaysian meteorological data.
2. To predict the critical values and areas where the ground-level concentration of pollutants exceeds Malaysian Ambient Air Quality Guidelines values.
3. To investigate the effect of stack emission characteristics on the pollution level of the surrounding area.

1.4 Scope

The software developed in this study uses the Gaussian Plume model to evaluate the amount of contaminants on the ground in rural and urban areas. The equations developed by U.S. EPA, 1995 that approximately fit the Pasquill-Gifford curves (Turner, 1970) are used for rural areas. Meanwhile, for urban areas, equations by Briggs that represent the best fit to urban vertical diffusion data reported by McElroy and Pooler (1968) is used.

This study is limited to near-field applications (less than 10 km in downwind distance). The applications are also restricted to flat terrain without elevation and building structures effects, dry particles deposition, steady and continuous emission, and chemically non-reactive pollutants. The ambient wind is assumed constant from the point of emission to the point where the pollutant particles deposited to the ground. The calculations of hourly concentration are independent of the previous
hour. The pollutants studied are non-reactive chemical pollutants. There are particulate matter 10 micron in diameter (PM$_{10}$), nitrogen dioxide (NO$_2$), sulfur dioxide (SO$_2$), hydrochloric gas (HCl), arsenic (As), cadmium (Cd), plumbum (Pb), mercury (Hg) and dioxin-furan.

The study involves code development of Gaussian plume model using MATLAB programming, user interface development using one of MATLAB tools known as GUIDE and integration of local hourly meteorological data provided by Malaysia Department of Environment.

### 1.5 Significance of Study

This study provides platform for flexible modifications of an air pollution software by developing new software. It may assists environmental consultants in air pollution modeling. Besides, it also aids industries to incinerate dangerous air pollutants into the atmosphere without exceeding limits regulated by Department of Environment. In addition, it can be used in designing process of industrial plant either choosing location or decide on appropriate stack parameters so that the plant is safe to operate. Lastly, it may assists plant designers to select the best location based on Malaysian meteorological data that follow Malaysian Ambient Air Quality Guidelines.
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