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

UBAIDULLAH BIN SELAMAT

UNIVERSITI TEKNOLOGI MALAYSIA

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UBAIDULLAH BIN SELAMAT

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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 ismore 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

Ramalan pencemaran udara di sekeliling cerobong asap industri telah menjadi kebimbangan besar untuk menilai kesan gas tercemar kepada alam sekitar. Walau bagaimanapun, tidak ada perisian yang direka khusus untuk simulasi pencemaran udara di Malaysia bagi membantu agensi-agensi alam sekitar tempatan dalam meramal pencemaran udara tempatan.Tesis ini membincangkan kajian terperinci dan analisis pembangunan pakej perisian baru untuk simulasi penyerakan bahan pencemar udara di Malaysia. Ia akan digunakan untukmeramal kualiti udara luaran untuk pelepasan gas pencemar jenis titik pada cerobong asap kilang.Dua ciri utama yang membezakanperisian dalam tesis ini dengan perisian sedia ada. Ciri yang pertama ialahmaklumat mengenai data meteorologi untuk ramalan penyebaran atmosfera di Malaysia yang lebih lengkap dimasukkan. Yang kedua, perisian sedia ada memerlukan simulasi berulang-kali untuk analisis lokasi yang berbeza manakala perisian dalam tesis ini memerlukan hanya sekali proses simulasi untuk analisis lokasi yang berlainan. Algoritma Model *Gaussian Plume* telah digunakan sebagai asas kod perisian yang menggunakan MATLAB. Parameter penyebaran untuk penyerakan di bandar dan luar bandar dikira berdasarkan graf Pasquill-Gifford dan persamaan apungan kepulan Briggs. Perisian yang dihasilkan disahkan dengan perisian penyebaran atmosfera yang diluluskan oleh Agensi Perlindungan Alam Sekitar Amerika Syarikat (US EPA), perisian *Industrial Source Complex (ISC)*. Hasil kajian menunjukkan bahawa perisian yang dihasilkan meramalkan kepekatan pencemar pada paras bumi mirip perisian ISC dengan perbezaan kurang daripada 10% dalam kebanyakan kes. Walau bagaimanapun, perisian tersebut terlebih-ramal kepekatan paras bumi dalam kes-kes tertentu terutamanya untuk kadar pengeluaran bahan pencemar yang tinggi Walaupun terlebih-ramal berlaku, dalam semua kes yang disimulasi, perisian tersebut dapat meramalkan sama ada kepekatan paras bumi melebihi had garis panduan atau tidak sepertimana ramalan perisian ISC. Untuk mengesahkan lagi perisian yang dibina, satu kajian kes bagi tiga tempat berlainan telah dilakukan dan perisian tersebut mampu mencadangkan lokasi terbaik dengan kepekatan paras bumi yang lebih sekata berdasarkan data meterologi tempatan. Perisian yang dibina diberi nama Integrated Malaysian Meteorological Data Software (IMMDADS) dan siap untuk digunakan bagi aplikasi industri tempatan selepas pembangunan kecil untukantaramuka pengguna.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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 hight
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_{ze}	-	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
x_f	-	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

LIST OF APPENDICES

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 stil 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 seperated 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 softwareto 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), hidrochloric 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 Departmoent 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.

LIST OF REFERENCES

Arystanbekova, N. K. (2004). *Application of Gaussian plume models for air pollution simulation at instantaneous emissions.* Mathematics and Computers in Simulation 67: 451–458.

Asmala and Hashim, Mazlan and Hashim, Md Noorazuan and Ayof, Mohd Nizam and Budi and Agus Setyo (2006), *The Use of Remote Sensing and GIS to Estimate Air Quality Index (AQI) Over Peninsular Malaysia*. GIS development : 5

Barad, M.L. (1958).*Project Prairie Grass, a Field Program in Diffusion.* Geophysical Research Papers, No. 59, Vols. I and II. Air Force Cambridge Research Center Report AFCRC-TR-58-235, : 479

Bennet M. and Hunter G. C. (1997). *Some comparisons of lidar estimates of peak ground – level concentrations with the predictions of UK – ADMS*. Atmos. Environ. 31(3):429-439.

Beychok, M.R. (1994). *Fundamentals of Stack Gas Dispersion*, third ed. Milton Beychok, Irvine, CA : 193

Bowers, J.F., Bjorklund J. R., and Cheney C. S.(1979). *User's guide for the Industrial Source Complex (ISC) dispersion models,* Volume I-User Instructions, EPA-450/4-79-030, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Briggs, G.A., (1969).*Plume Rise*, USAEC Critical Review Series, TID-25075, National Technical Information Service, Springfield, Virginia 22161

Briggs, G. A.(1971).*Some Recent Analyses of Plume Rise Observations*, In Proceedings of the Second International Clean Air Congress, Academic Press, New York.

Briggs, G.A., (1974).*Diffusion Estimation for Small Emissions.* In ERL, ARL USAEC Report ATDL-106. U.S. Atomic Energy Commission, Oak Ridge, Tennessee.

Briggs, G. A. (1975).*Plume Rise Predications. In Lectures on Air Pollution and Environmental Impact Analysis*, American Meteorological Society, Boston, Massachusetts.

Britter R. E. and Hanna S. R. (2003).*Flow and dispersion in urban areas*. Annu Rev Fluid Mech 35:469–496

Carlson J. D. and Arndt S. D. (2008). *The Oklahoma Dispersion Model: Using the Gaussian Plume Model as an Operational Management Tool for Determining Near-Surface Dispersion Conditions across Oklahoma*.J. Appl. Meteorol. Climatol., vol. 47, no. 2 : 462–474

Chinese Ministry of Environmental Protection. China Environmental Yearbook. (2010). Beijing: China Environmental Yearbook Inc.

Chun P. L., Lin H. T. and Chou H. J. (2009).*Evaluation Of Buoyancy-Driven Ventilation In Atrium Buildings Using Computational Fluid Dynamics And Reduced-Scale Air Model.*Building andEnvironment, vol. 44 : 1970-1979.

Connan O., Leroy C., Derkx F., Maro D., Hébert D., Roupsard P., and Rozet M. (2011). *Atmospheric dispersion of an elevated release in a rural environment: Comparison between field SF6 tracer measurements and computations of Briggs and ADMS models.*Atmos. Environ., vol. 45, no. 39 : 7174–7183,

Cosemans, G., Lefebvre, W., and Mensink, C. (2012). *Calculation scheme for a Gaussian parameterization of the Thompson 1991 wind tunnel building downwash dataset.* Atmospheric Environment.59 : 355–365.

Daly A. and Zannetti P. (2007), *Air Pollution Modeling – An Overview.* vol. I, no. 2003 : 15–28

Doury A., Grand J. and Despres A. (1980). *Seminar on Radioactive Releases and Dispersion in the atmosphere following a hypothetical reactor accident.*Commission of the European Communities, Luxemborg, : 743-776

Fisher, B. E. A. (1983). *A Review Of The Processes And Models Of Long- Range Transport Of Air Pollutants,*Atmos. Enivironment 17, 1865–1880.

Guohui G. (2010). *Simulation Of Buoyancy-Driven Natural Ventilation of Buildings – Impact Of Computational Domain.*Energy and Buildings, vol 42 : 1290-1300.

Haidong K., R. Chen, and S. Tong. (2012). *Ambient air pollution, climate change, and population health in China.* Environ. Int., vol. 42 : 10–9

Hanna, S., and Baja, E. (2009). *A simple urban dispersion model tested with tracer data from Oklahoma City and Manhattan.*Atmospheric Environment, *43*(4): 778–786.

Huber. A.H. (1991). *Wind Tunnel and Gaussian Plume Modeling of Building Wake Dispersion.* Atmospheric Environment. 25(A): 1237– 1249.

Kan H, London S. J., Chen H, Song G, Chen G, Jiang L, et al. (2007). *Diurnal temperature range and daily mortality in Shanghai, China.* Environ Res;103:424–31

Kanyanee S., V. Surapipith K. Tantrakarnapa, and A. W. Lothongkum,.(2011). *Application of the AERMOD modeling system for environmental impact assessment of NO2 emissions from a cement complex.*J. Environ. Sci., vol. 23, no. 6 : 931–940.

Kim J. and Baik J.(2003). *Effects of inflow intensity on flow and pollutant dispersion in an urban street canyon.* Journal of Wind Engineering and Industrial Aerodynamics 91: 309-329

Leong C. P., M. D. Keywood, G. P. Ayers, J. L. Gras, R. Boers, (2003).*Haze in the Klang Valley of Malaysia.* Atmospheric Chemistry and Physics : 615-653

Leroy, C., Maro, D., Hébert, D., Solier, L., Rozet, M., Le Cavelier, S., and Connan, O. (2010). *A study of the atmospheric dispersion of a high release of krypton-85 above a complex coastal terrain, comparison with the predictions of Gaussian models (Briggs, Doury, ADMS4).* Journal of environmental radioactivity, 101(11) : 937–44.

Lingjuan W., D. Parker, C. Parnell, R. Lacey, and B. Shaw. (2006). *Comparison of CALPUFF and ISCST3 models for predicting downwind odor and source emission rates.* Atmos. Environ., vol. 40, no. 25 : 4663–4669

Lushi, E., and Stockie, J. M. (2010). *An inverse Gaussian plume approach for estimating atmospheric pollutant emissions from multiple point sources.* Atmospheric Environment, 44(8) : 1097–1107.

Magno Vieira de Melo, J. M. Santos, I. Mavroidis, and N. C. Reis Junior. (2012). *Modelling of odour dispersion around a pig farm building complex using AERMOD and CALPUFF.Comparison with wind tunnel results.* Build. Environ., vol. 56 : 8–20

Malaysia Department of Environment. (2007). *Air Pollution Index.* Archived from the original on 10 April 2007. Retrieved 18 April 2007.

Mazzoldi, A., Hill, T., and Colls, J. J. (2008). *CFD and Gaussian atmospheric dispersion models: A comparison for leak from carbon dioxide transportation and storage facilities.*Atmospheric Environment, 42(34) : 8046–8054.

McElroy J.L. and F. Pooler.(1968).*The St. Louis Dispersion Study. U.S. Public Health Service.*National Air PollutionControl Administration, Report AP-53.

Pasquill, F., (1976).*Atmospheric Dispersion Parameters in Gaussian Plume Modeling. Part II. Possible Requirements for Change in the Turner Workbook Values. EPA-600/4-76-030b,* U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

Perry S. G., Cimorelli, A. J., Lee R. F., Paine R. J., Venkatram A., Weil J. C., and Wilson R. B.(1996).*Current progress in the AERMIC model development program. Preprints*, 89th Annual Meeting Air and Waste Management Association, Pittsburgh, PA, Air and Waste Management Association : 1–27.

Raes F., Tassone C., G. Grippa, Zarimpas N., and Graziani G. (1991). *Updating long-range transport model predictions using real-time monitoring data in case of nuclear accidents with release to the atmosphere.*Atmos. Environ. Part A. Gen. Top., vol. 25, no. 12 : 2807–2814,

Rushdi M. M. and Belal M. H. (2010). *Modelling an environmental pollutant transport from the stacks to and through the soil.*J. Adv. Res., vol. 1, no. 3 : 243–253

Sadeghi N. and Sadrnia. M. (2011).*Cancer risk assessment for Tehran research reactor and radioisotope laboratory with CAP88-PC code (Gaussian plume model).* Nuclear Engineering and Design. Vol 241 :1795-1798.

Schauberger, G., Piringer, M., Knauder, W., and Petz, E. (2011). *Odour emissions from a waste treatment plant using an inverse dispersion technique.*Atmospheric Environment, 45(9) : 1639–1647.

Schnell K B and Dey P R.(2000). *Atmospheric Dispersion Modeling Compliance Guide.* McGraw-Hill, New York : 6-17–6-24.

Scire J. S., D. G. Strimaitis, and R. J. Yamartino. (2000). *A User ' s Guide for the CALPUFF Dispersion Model.*

Soulhac, L., Salizzoni, P., Cierco, F. X., and Perkins, R. (2011). *The model SIRANE for atmospheric urban pollutant dispersion; part I, presentation of the model.*Atmospheric Environment, 45(39) : 7379–7395.

Tartakovsky D., Broday D. M., and Stern, E. (2013). *Evaluation of AERMOD and CALPUFF for predicting ambient concentrations of total suspended particulate matter (TSP) emissions from a quarry in complex terrain*. Environmental pollution (Barking, Essex : 1987) : 179

Thompson, R.S.(1991). *Data Report. Project: Building Amplification Factors.* US EPA.

Thorsteinsson, T., Hackenbruch, J., Sveinbjörnsson, E., and Jóhannsson, T. (2013). *Statistical assessment and modeling of the effects of weather conditions on H2S plume dispersal from Icelandic geothermal power plants.*Geothermics, 45 : 31–40.

Turner, D.B. (1970). *Workbook of Atmospheric Dispersion Estimates. US Environmental Protection Agency*.Office of Air Programs, Publication No. AP-26.

Tsuang, B.J.(2003).*Quantification on the source/receptor relationship of primary pollutants and secondary aerosols by a Gaussian plume model.* Atmospheric Environment. Vol 37 :3981-3991.

U.S. Environmental Protection Agency.(1995). *User's Guide for the Industrial Source Complex (ISC3) Dispersion Models, Volume II - Description of Model Algorithms. EPA-454/B-95-003b.* U.S. Environmental Protection Agency, Research Triangle Park, NC.

U.S.Environmental Protection Agency.(2005). *Revision to the Guideline on Air Quality Models: Adoption of a Preferred General Propose (Flat and Complex Terrain) Dispersion Model and Other Revisions;* Final Rule (Federal Register). Vol. 70 : 215

Wong, T. W., Tam W. W., Chair, S. Y., Wong, and A. H. (2009)*Diurnal temperature range and daily cardiovascular mortalities among the elderly in Hong Kong.* Arch Environ Occup Health 2009;64:202–6

WHO,.(2000). *Hydrogen sulfide*. WHO Air Quality Guidelines for Europe, 2nd edition : 7