MODIFIED GAUSSIAN PUFF METHOD FOR PREDICTION OF CO_2 EMISSION FROM SHIP

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DEDICATION

I dedicate my thesis to Allah, my Creator and my Master, my great teacher, Prophet Mohammed (May Allah bless and grant him), who taught us the purpose of life, my beloved parents, my family, my lectures and fellow friends for supporting me in a wonderful campus in UTM

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ABSTRACT

Carbon dioxide (CO_2) emissions from marine transport have become one of the critical issues to the entire world community and one of the main contributors that contribute to global warming and air pollution. The ocean is known sequestrating CO_2 more and faster than the forest. Methodology to Estimate Air Pollutions Emission (MEET) and Gaussian Model has been used to estimate the CO_2 emission and its distribution from marine transport. However, this model does not include natural CO_2 sinking rate in the air as a factor. The objective of this study was to propose a modified method to predict the CO_2 emission and sinking rate emitted from marine transport and subsequently to prove that the CO_2 will be sank naturally in the air via an airtight experiment. A ship database was developed from the Automatic Identification System (AIS) in the Straits of Malacca and Singapore. By using MEET methodology, the CO_2 emission rate can be determined and modified Gaussian Model can be used to estimate the CO_2 distribution. A modified method was tested by conducting a controlled experiment with an airtight PVC pipe to find an accurate CO_2 sinking rate. The experimental results showed that a significant rate of CO_2 sank naturally within a time period at sinking rates of 0.481ppm/s, 0.379ppm/s, and 0.25ppm/s at the distances of 5cm, 100cm, and 200cm. The time durations from the CO_2 started to sink and the height of the CO_2 sinking were varied in the modified method from the Gaussian model. In the first phase of the experiments, the CO_2 needed 32 seconds to sink at a distances of 5cm from the top of the PVC pipe. While in the second phase of the experiments, the CO_2 needed 651 seconds to sink at a distance of 100cm from the top of the PVC pipe. Lastly, in the third phase of the experiments, the CO_2 needed 1301 seconds to sink at a distance of 200cm from the top of the PVC pipe. The rate of CO_2 sink can be calculated where the CO_2 was constantly sunk at a rate of 0.15cm/s or 0.0015m/s. In conclusion, the modified method is able to determine a more accurate of CO_2 emission and its distribution from ship transport after integrating the CO_2 sinking factor into the existing Gaussian Model equation. From the result, it also can be concluded that the CO_2 can sink naturally in the air without using any other mechanism.

ABSTRAK

Pelepasan karbon dioksida (CO_2) dari pengangkutan laut telah menjadi salah satu masalah kritikal kepada seluruh masyarakat dunia dan salah satu penyumbang utama yang menyumbang kepada pemanasan global dan pencemaran udara. Laut diketahui menyerap CO_2 lebih cepat dan pantas daripada hutan. Metodologi untuk Menganggarkan Perlepasan Pencemaran Udara (MEET) dan Model Gaussian telah digunakan untuk menganggarkan pelepasan dan penyebaran CO_2 dari pengangkutan laut. Walau bagaimanapun, model ini tidak memasukkan kadar serapan CO_2 semulajadi di udara sebagai faktor. Objektif kajian ini adalah untuk mencadangkan kaedah terubahsuai untuk meramalkan kadar pelepasan dan serapan CO_2 yang dikeluarkan dari pengangkutan laut dan seterusnya membuktikan bahawa CO_2 akan diserap secara semula jadi di udara melalui eksperimen kedap udara. Pangkalan data kapal dibangunkan dari Sistem Pengenalan Automatik (AIS) di Selat Melaka dan Singapura. Dengan menggunakan metodologi MEET, kadar pelepasan CO_2 dapat ditentukan dan Model Gaussian yang diubahsuai digunakan untuk menganggarkan taburan CO_2. Kaedah yang diubahsuai diuji dengan melakukan eksperimen terkawal dengan paip PVC kedap udara untuk mencari kadar serapan CO_2 yang tepat. Hasil eksperimen menunjukkan bahawa kadar serapan CO_2 yang signifikan secara semulajadi dalam tempoh pada kadar 0.481ppm/s, 0.379ppm/s, dan 0.25ppm/s pada jarak 5cm, 100cm, dan 200cm. Tempoh masa CO_2 mulai menyerap dan ketinggian serapan CO_2 diubah-ubah dalam kaedah terubahsuai dari model Gaussian. Pada fasa pertama eksperimen, CO_2 memerlukan 32 saat untuk menyerap pada jarak 5cm dari bahagian atas paip PVC. Semasa dalam fasa kedua eksperimen, CO_2 memerlukan 651 saat untuk menyerap pada jarak 100cm dari bahagian atas paip PVC. Terakhir, pada fasa ketiga eksperimen, CO_2 memerlukan 1301 saat untuk menyerap pada jarak 200cm dari bahagian atas paip PVC. Kadar serapan CO_2 dapat dikira yang mana CO_2 menyerap secara sekata pada kadar 0.15cm/s atau 0.0015m/s. Kesimpulannya, kaedah yang terubahsuai dapat menentukan pelepasan CO_2 dan penyebarannya dari pengangkutan kapal dengan lebih tepat setelah mengintegrasikan faktor serapan CO_2 ke dalam persamaan Model Gaussian yang sediada. Dari dapatan ini, dapat disimpulkan juga bahawa CO_2 dapat menyerap secara semula jadi di udara tanpa menggunakan mekanisme lain.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AIS	-	Automatic Identification System
IMO	-	International Maritime Organization
SOLAS	-	Safety of Life at Sea
CO	-	Carbon Monoxides
CO_2	-	Carbon Dioxides
EEA		European Environment Agency
GHG		Green House Gases
g	-	Gram
g/s	-	gram per second
H_2S	-	Hydrogen Sulphide
HNO_3	-	Nitric Acid
km	-	Kilometer
km^2	-	Kilometre square
m	-	Meter
m/s	-	Meter per second
MEET		Methodology to Estimate Air Pollutions Emission
MMSI		Maritime Mobile Service Identity
NO	-	Nitric oxide
NO_2	-	Nitrogen Dioxides
NOx	-	Nitric Oxides
N_2O	-	nitrous oxide
O_2	-	Oxygen
O_3	-	Ozone
PM	-	Particulate matter
PPM		Part Per Million
RTD		Regional Transport District
SO_2	-	Sulphur Dioxides
SO3	-	Sulphur Trioxides
SOx	-	Sulphur Oxides

VOC	-	volatile organic compounds
VTS		Vessel Traffic Services
WHO	-	World Health Organization
$\mu g/m^3$	-	microgram per meter cube

LIST OF SYMBOLS

%	-	Percent
C_r	-	Concentration of emission
C_s		CO_2 sinking rate
Q	-	Emission rate
Δh	-	Effective stack height
Δt	-	Length of time of the release itself
σy	-	Horizontal standard deviation
σz	-	Vertical standard deviation
α	-	Wind direction
Ei	-	total emissions of pollutant *i*
f	-	Auxiliary engine fuel consumption
Fijlm	-	Average emission factors of pollutant *i* from fuel *j* in engines type *l* in mode *m*
i	-	Pollutant
j	-	Fuel
k	-	Ship class
L	-	Load factor
P	-	Auxiliary engine rated output
s	-	Reference reduction scenario
Sjkm (GT)	-	daily consumption of fuel *j* in ship class k as a function of gross tonnage
tjklm	-	days in navigation of ships of class *k* with engines type *l* using fuel *j* in mode operational *m*
U	-	Wind speed
xr, yr, zr	-	Cartesian coordinates downwind of the puff

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

This chapter contains a discussion of the background of the study, problem statement, objectives of the research, scope, and limitation of the study, and lastly, significance of the studies. Other than that, the content of each chapter will also be explained briefly in this chapter

1.1 Background of The Study

The Straits of Malacca is more than 900 kilometres long and around 2.8 kilometres wide strait located between Malaysia, Singapore, and Indonesia. At the Southeast end of the Strait of Malacca, it links to the Straits of Singapore and its stretch of water lying in between the west of Peninsular Malaysia and the east of Sumatra's island in Indonesia. The Straits of Malacca is well known as one of the narrow and busiest shipping lanes globally. It is the most economical and strategic shipping route that connects the Pacific and the Indian Ocean.

The Strait of Malacca and Singapore are among the congested straits used for international shipping globally. The straits connect the Indian Ocean with the Pacific Ocean through the South China Sea, and it is an essential and used shipping channel in the world. Annually every year, there is a minimum of over 60,000 vessels using and pass through the Straits of Malacca and Singapore (Mihmanli 2011), and in 2010 alone, it recorded over 74,000 ships (Rusli 2012). With this high amount of traffic, the straits play a role contributing to air pollution and shipping emission production, notably the Green House Gas (GHG).

According to the United Nations Conference on Trade and Development (UNCTAD), it is more than 80% of the international trade and the movement of the product is carried through the sea by marine transport and cargo ships since 2010. While the world maritime trade decreased slightly in 2018, the total volumes of goods movement have reached 11 billion tons. While air pollutions and global warming have become the most critical issues in the world community, the increase of marine traffic exhaust emission contributes more to air pollutions and global warming. Exhaust emission from ship consisted of Green House Gas (GHG) or Carbon dioxide ($CO2_)$, Sulfur Oxides (SO_x), Nitrogen oxides (NO_x), Particulate Matter (PM), carbon monoxide (CO), and hydrocarbons (HC). All these gases are known to contribute to health problems and environmental damage. This emission effect arises primarily in inland seas, Strait's area, canals, territorial waters, and port region. J.J.Corbett et al. estimated in 2007, around 64.000 cases of severe lung cancer death, cardiopulmonary, and around 92% of premature death around the world that caused by Particulate Matter (PM) from ships and marine traffic

Among the gases from the ship exhaust emission, CO_2 is significant because it affected the Earth's permanence and climate the most from other gases. CO_2 can remain and stay active in the atmosphere for a longer time. When the CO_2 released freed into the world atmosphere, more than 50% will take up to 30 years to disappear, another 30% will remain in the atmosphere for many centuries, and the last 20% of the CO_2 can last for several millions of years before it disappeared (Solomon et al., 2007). The other studies by the Second IMO GHG 2009 produced an advanced and comprehensive assessment of the level of CO_2 or GHG emitted from ships. The studies concluded that in 2007, international shipping alone is to be estimated to release around 870 million tons or around 2.7% of the global human-made emissions of CO_2. In terms of quantity and global warming potential, CO_2 is the primary source of GHG emission from ships exhaust.

1.2 Problem Statement

The Straits of Malacca and Singapore is a narrowed strait and one of the world's busiest and congested straits with the most massive marine traffic used for international shipping, where most significant hubs located within the area. Consequently, this will contribute to high air pollution levels around the area.

Previous studies by Street et al. (1997) calculated the shipping emissions of sulfur oxide (SO_x) on the Malacca straits by using ATMOS (Atmospheric Transport Modeling System) as a dispersion model for emission. The result is almost the same in Sumatra, Indonesia that is 32,000 t SO_x of Malacca straits area and 52,000 t SO_x per year in the Sumatra area. Bhatti et al. (1992) and Arndt et al. (1996) also stated in their studies that there are approximately one-quarter of the total emissions in each of Singapore and Malaysia

Another attempt by Hendra et al. (2013) on the distribution and estimation of exhaust ship gases emission from ships and marine traffic in the Straits of Malacca and Singapore by using an Automatic Identification System or AIS. In their study, Gaussian Puff Model is used to estimates the concentration and distribution of the ship emission on NOx, PM, CO, VOC, CO_2, and SO_x.

Another similar and latest study done by Leong et al. (2015) estimates and predicts the CO_2 emission from vessel and ship traffic in the Straits of Singapore using Automatic Identification Systems (AIS) data. The study only on the estimation and distributions of CO_2 emitted from ships and marine transport within the area of Straits of Melaka and Singapore.

The national meteorological service for the United Kingdom or The Met Office is one of the world's leading in the meteorological area. Over the past 60 years, CO_2 concentration has increased by 30%, and it forecast indicates that 2019 will see the most significant CO_2 concentration since 1958 that is an increase in CO_2 concentration of 2.75 ppm compared to 2018 in the previous year. The CO2 concentration will have an annual average of 411.3 ppm with a peak of 414.7 ppm.

These annually increased CO_2 concentrations will contribute more and huge problem to global warming.

There is still no study on the estimation and distribution of CO_2 emitted from marine transport in the Straits of Malacca with the sinking factor. From the previous studies, the ocean known to absorb CO_2 more than the forest trees and plants, known as carbon sinking. With the modified method, the prediction of CO_2 emission and distribution of marine transport can be included with the CO_2 sinking rate.

1.3 Objective of Research

The research objectives are:

i. To prove the CO_2 will sink naturally in the air and identify the duration CO_2 take to sink naturally.

ii. To propose a modified method based on the Gaussian method to predict and calculate the CO_2 emission and distribution from ship transport by introducing the CO_2 sinking rate.

iii. To verify the modified method with an experiment on CO_2 sinking.

1.4 Scope and Limitation of The Research

The scope and limitation of the study are:

i. Focus on the ship's CO_2 emission and distributions at the study area.

ii. The study area focuses on the Straits of Malacca and Singapore between Batam Island, Singapore, and Johor, Malaysia.

iii. To develop an experiment on Co_2 sinking and calculation on the modified method.

1.5 Significance of the Study

In this research, the CO_2 emission from all the ships is calculated from MEET Methodologies. Simultaneously, the Gaussian Puff Method is used to calculate the distribution of the CO_2 from the ship emission.

This research proposed a modified method to calculate the CO2 emission from all the ships by introducing the CO_2 sinking rate. From the modified method, the CO_2 average sinking rate can be determined and include in the calculation method. In future, the CO_2 emission and distribution can be calculated more accurately.

1.6 Thesis Organization

Overall this thesis contains six chapters. Chapter 1 explained the overview and discussion of the tasks conducted in this research. Chapter 1 also discussed the objectives of this research and the significance of the study to the topic. The scope and the field of study, including ideas, will be explained in this chapter and discussed in this thesis.

The Literature review is discussed extendedly in Chapter 2. The literature review focuses on the discussion on the studies and researches conducted by other researchers. The topic will further explain carbon dioxide (CO_2), Automatic identification systems (AIS), MEET Methodology, and the Gaussian puff model.

Chapter 3 in this thesis will discuss the research methodology extendedly. It will discuss the work conducted in the research to achieve all the research objectives, from the identification of the problem to the creating of the new method.

In Chapter 4, CO_2 sinking experiment and analysis will be explained and discussed furthermore step by step from ship data to the emission estimation. Chapter 4 also describe and explain the experiment conducted during the research.

The result and discussion of the experiment result will be discussed in Chapter 5. Then lastly in Chapter 6 are discussed the conclusion and recommendation in the research.

1.7 Summary

This chapter contains and explains the background and the problem of this study briefly to archive the research objective. The research objectives are stated in this chapter, and how to achieve them will be explained in other chapters. Other then that, the overview and discussion of the tasks conducted in this research.

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