ESTIMATION OF EXHAUST EMISSIONS FOR A PATROL SHIP OF MALAYSIAN MARITIME ENFORCEMENT AGENCY

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ESTIMATION OF EXHAUST EMISSIONS FOR A PATROL SHIP OF MALAYSIAN MARITIME ENFORCEMENT AGENCY

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ABSTRACT

The growth of transportation and machineries in the maritime industry contribute serious impact on air quality on sea, land and nearby port. Ship is one of the potential contributors to exhaust emission and most of ship is equipped with main diesel engine. The level of engine operation can affect the level of emission concentration. For this study, improved methodology is applied to estimate the amount of carbon monoxide (CO), nitrogen oxide (NO_x) and carbon dioxide (CO_2) emission from ship at different speed. The result is compared to previous studies or standard limits. The onboard measurement and equation of combustion are used in this study. The shipboard test is conducted on a patrol ship, KM Kukup at 700rpm, 900rpm and 1100rpm. The parameter at exhaust platform and engine are measured using gas analyzer and Kestrel 4500 pocket weather tracker. Emissions are calculated as g/kWh and overall shows CO_2 with 345.91±53.87 g/kWh have highest value followed by CO with 3.75±0.57 g/kWh. NO_x emitted the lowest value of 1.82±0.32 g/kWh. At speed level, CO_2 lowest (215.70 g/kWh) at 700rpm and highest at 1100rpm (429.52 g/kWh). At 900 rpm, CO is highest with 4.35±0.62 g/kWh and at 1100 rpm lowest with 2.88±0.34 g/kWh. NO_x was lowest at 700rpm (1.02±0.15 g/kWh) and highest at 1100rpm (2.05±0.41 g/kWh). An overall comparison showed that all emission was within typical range of diesel engine except for NO. Some comparison with the previous study show large differences due to the dissimilarity in work method and technique applied to estimate emissions. Using this activity-based methodology, the amount of exhaust emission was found depending on the sailing mode. Also, through this method the energy used of the ship was able to calculate.

ABSTRAK

Peningkatan pengangkutan dan mesin jentera dalam industri maritim memberi kesan serius kepada kualiti udara di laut, darat dan kawasan berhampiran pelabuhan. Kapal merupakan salah satu sumber kepada gas eksos dan kebanyakan kapal menggunakan enjin diesel. Tahap operasi enjin mampu mempengaruhi paras amaun gas tercemar. Melalui kajian ini, kaedah diperbaiki dan dijalankan bagi penganggaran nilai pembebasan karbon monoksida (CO), nitrogen oksida (NO_x) dan karbon dioksida (CO_2) pada kapal dengan kelajuan berbeza. Keputusan akan dibandingkan dengan kajian lepas atau had piawai bahan tercemar. Gabungan kaedah seperti pengukuran atas kapal dan persamaan pembakaran digunakan dalam kajian ini. Pengukuran atas kapal dijalankan pada kapal peronda iaitu KM Kukup pada 700 rpm, 900 rpm dan 1100 rpm. Parameter bagi kawasan eksoz dan bilik enjin diukur menggunakan *flue gas analyser* dan alat *Kestrel 4500 pocket weather tracker*. Pembebasan gas dikira sebagai g/kWj dan keseluruhan menunjukkan CO_2 adalah tertinggi iaitu 345.91±53.87 g/kWj diikuti CO dengan 3.75±0.57 g/kWj. NO_x adalah terendah iaitu 1.82±0.32 g/kWj. Berdasarkan kelajuan, CO_2 terendah (215.70 g/kWj) pada rpm 700 dan tertinggi pada rpm 1100 (429.52 g/kWj). Pada rpm 900, CO tertinggi dengan 4.35±0.62 g/kWj dan terendah pada rpm 1100 dengan 2.88±0.34 g/kWj. NO_x terendah pada rpm 700 (1.02±0.15 g/kWj) dan tertinggi pada rpm 1100 (2.05±0.41 g/kWj). Keseluruhan perbandingan menunjukkan semua gas tercemar berada pada julat tipikal diesel enjin kecuali NO. Sesetengah perbandingan dengan kajian lepas adalah berbeza kerana kerja dan teknik yang digunapakai adalah tidak sama bagi anggaran gas tercemar. Menggunakan pengukuran-aktiviti ini, didapati amaun gas yang dibebaskan bergantung kepada mod pemanduan kapal. Selain itu, melalui kaedah ini, penggunaan tenaga oleh kapal dapat dikira.

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APPROVAL

I certify that an Examination Committee has met on **27th April 2016** to conduct the final examination of **Daarulmuqaamah Binti Masaud** on her degree thesis entitled **'Estimation of Exhaust Emissions for a Patrol Ship of Malaysian Maritime Enforcement Agency'**. The committee recommends that the student be awarded the Master of Science (Maritime Technology).

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DECLARATION OF THESIS

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LIST OF ABBREVIATIONS

α	alfa
ρ air	Air density
API	Air Pollution Index
AQI	Air Quality Index
AS	Actual Speed
atm	atmosphere
bhp	brake horsepower
CEMS	Continuous Emission Monitoring System
DOE's	Department of Environment's
ENTEC	Engineering Technology Corporation
EQA	Environment Quality Act
GAIRD	Dry Air Mass Flow Rate
GEXHW	Exhaust Mass Flow Rate
GFUEL	Fuel Mass Flow Rate
GH_2O	Water Mass Flow Rate
g/kWh	gram per kilowatt-hour
IMO	International Maritime Organisation
ISO	International Standard Organisation
KM Kukup	Kapal Maritim Kukup
KW	Dry to wet correction factor
LF	Load Factor
MCR	Maximum Continuous Rated
MEQR	Malaysian Environment Quality Report
MMEA	Malaysian Maritime Enforcement Agency
MS	Maximum Speed
n	number of moles
P	Pressure
ppm	part per million
PWM	Pocket Weather Meter
R	Gas Constant
rpm	revolution per minute

RH	Relative Humidity
RIC	Reciprocating Internal Combustion
RMN	Royal Malaysian Navy
RSZ	Reduced Speed Zone
SATP	Standard Ambient Temperature and Pressure
Shp	shaft horsepower
STP	Standard Temperature and Pressure
T	Temperature
u	Gas concentration
US EPA	United States Environmental Protection Agency
USCG	United States Coast Guard
USCGC	United States Coast Guard Cutter
V	Volume of the gas

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Marine transportation is one of the most important sectors in Malaysia's economic system. The country's huge economic progress has intensified activities at Klang Port, thereby increasing the number of navigating vessels, ship traffic and machinery at the port. By world ranking, the port has been ranked as the 13th busiest transshipment port in 2004 and became the 16th busiest container port in the world in 2007 (PKA, 2008). Consequently, the progress leads to pollution issues at the port and the condition will worsen if there is no awareness and no appropriate control or action taken. Large amount of pollutants tend to harm both living beings and also the environment especially to the communities near the port (Pearce, 2009).

Environmental issues with regards to shipping are commonly associated with air pollution which poses challenges to air quality management in Malaysia, especially at port areas. In June 12, 2009, according to the Air Pollution Index (API) published in the Department of Environment's (DOE's) website, Port Klang became the first location in the country to record "unhealthy" air quality, rising from 82 (moderate) to 125 (unhealthy). For a given area, the overall air pollution is caused by the emission from several numbers of sources. It is known that, exhaust emissions from marine vessels come majorly from diesel

engine operating on the ship (Majewski & Khair, 2006). There are wide of measurement technique need to be considered when measuring diesel exhaust emissions.

Generally, diesel emission can be measured in laboratory testing or field testing. Laboratory testing includes regulatory testing, emission research and development of engine and emission control. However, field testing are more into mobile emission laboratories, on-vehicle measurements, remote emission measurement and others. In this study, field testing was selected because in theory it reflects to the real engine operation and associated emission level. Also, the equipment use is the main cost factor. Usually, laboratory emission testing uses very complex and sophisticated equipments especially on the repeatability results.

Therefore, shipboard test was conducted during the engine running in normal condition at or close the certification conditions specified in the International Standard Organisation (ISO) 8178 series. The basis of the method includes sampling and analysis. The sampling was conducted in the engine room for air flow rate parameters and at exhaust platform for exhaust flow rate parameters. It is assumes that exhaust flow equal to the intake air flow from the cylinder volume and recorded rpm, temperature and pressure of the inlet air. Carbon balance was used for the calculation of exhaust gas concentration which involved the fuel use rate for specific rpm. The selected gaseous emission was Carbon Monoxide (CO), Nitrogen Oxides (NO_x) and greenhouse gases, Carbon Dioxide (CO_2). These are among the common gases contributing to the critical air pollution.

This study was conducted with the cooperation of MMEA and used one of their ships which are located at Klang Port. A patrol ship, Kapal Maritim (KM) Kukup, the only ship was assigned for this purpose because of the exhaust type is fitted for the measurement, the ability

of engine operation to fit in schedule, location and also the cost and time of agency to conducting the sampling. The onboard measurements and emission calculations were done based on the ship's activities. The measurements were carried out according to the availability of data and relevant parameters of ship emissions.

1.2 Problem Statement

Diesel engine converts chemical energy in the fuel into mechanical power where this mixture of hydrocarbons compound in fuel emitted the emission of CO_2, H_2O and other unused portion of engine charges (Majewski & Khair, 2006). Known with the superior fuel economy and high power performance, diesel engine future design should meet with the emission regulation and limits for environmental responsibility. Today's new engine technology were design to meet the new emission regulation, performance requirement and market competition.

However, old engine technology such as KM Kukup has a challenged to meet this requirement. Emission of diesel engine is formed as a result of uneven air/fuel mixture during combustion and also expansion. The fuel ignition quality, mixture preparation, engine design and others are significant to the concentration of emission. Diesel engine is known to be high of NO_x emission compares to CO because diesel combustion is lean and has an abundant of air for air-fuel mixture. NO_x is highly active ozone precursor and contribute to the smog chemistry (Majewski & Khair, 2006). The primarily greenhouse gases, CO_2 come majorly from natural sources. Although man-made such as transportation contributes small percentage to it, the reduction action is hard to implement with the adding sources from man-made.

KM Kukup have suffered from low power output and inefficient combustion due to black smoke and heat when its travel at higher speed. Therefore, the measurement of this study was limited to below 1100rpm. Good performances of engine come with the efficient fuel combustion and enough oxygen supply are good condition for complete combustion where small toxic of concentration can be generated.

Exhaust emission contain numerous toxic compound that adverse human health and environment effects. The adverse health depends on the toxicity concentration and time exposure. The increased health and environmental quality generated from the development of sophisticated measurement technique level, equipment cost and regulation to categorized and control exhaust emission. However outdated data and high cost of direct measurement affect the quality of emission results. Also, the emission models that are used to produce emission inventory which generated from the assumption of vessels population, emission factor, vessel age and others gave no final or accurate method. Therefore, in this study the combination of measurement between sampling and calculation was approach to get the real-condition result and improved method.

1.3 Objectives

By implementing shipboard test to this study, direct measurement method is required. The evaluations on appropriate parameters are confined to the purpose of the study and its limitation. There are three objectives to support the research which are:

i. To estimate emission during typical operations at different speed levels.
ii. To innovate the method for estimation of ship pollutants.
iii. To compare shipboard test findings against standard limits and published emissions.

1.4 Scope

Generally, this research can expand the knowledge to get a better understanding about the process in developing estimation methodology for exhaust emission. The study of measurement associated with parameters that involved in the calculation as g/kWh. Therefore, the scopes of study represent all of exhaust platform and engine room parameters which are:

i. Location of study measurement. The study area is located at Teluk Nipah Westport Klang, Royal Malaysian Navy (RMN) National Hydrographic Centre, Jetty of Pasukan Gerakan Marin and the nearest area that follows the pathway of the ship's activity.

ii. The methodology of exhaust estimation. The study consists of two primary activities which are shipboard tests and emission calculation. The primary tests include the parameters at exhaust funnel, rotation speed, sea condition and ambient parameters near air intake. All parameters are used to calculate emission in g/kWh. The focus of the result is only for main diesel engine and at steady state cycle where emissions are analyzed for constant engine speed in rpm.

iii. The ship identification and characteristics. A patrol ship is involved in this study as a source of exhaust emission. The details on ship, engine, fuel and activity profiles are collected. The estimation on engine service hours for frequent voyage is determined for energy consumption. The ship activities such as maneouvering, reduced speed zone (RSZ) and cruising was categorized for frequent voyage. The activities are referred as ship's movement at specific time and speed based on the US EPA's (United States Environment Protection Agency) (2010) definition.

iv. The other analysis factors. The accuracy of emission estimation is depending on the data resources quality, experimental design, period factor, equipments accessibility, occupational safety and collaboration. The pollutants of concern are NO_x, CO and CO_2, and they are chosen due to their relationship with air quality and data limitation.

1.5 Summary

In general, emissions from ports are considered to be major sources of oxides of sulfur (SO_x), oxides of nitrogen (NO_x), carbon monoxide (CO) and carbon dioxide (CO_2), and are rather significant with growing shipping industries (Starcrest, 2005). To maintain good transportation along with the reduction of air pollutant emission, air pollution control technologies and planning strategies must be implemented. For this study, the estimation is depending on ship activity which determine by their three intermediate cruising and manoeuvring speed. Also, the performance of diesel engine is considered in the calculation where it is affected the criteria of pollutant that exhausted from ship activity.