DISSERTATION

EXPOSURE RESPONSE OF *DIESEL ENGINE EXHAUST (DEE)* TOWARD UNDERGROUND MINERS IN PT FREEPORT INDONESIA

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by
Arif Susanto
Born in Salatiga

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1. Dissertation entitled '*Exposure Response of Diesel Engine Exhaust (DEE) toward Underground Miners in PT Freeport Indonesia*' is the original scientific paper and has never been submitted to obtain an academic degree (doctorate) at any college.
2. This dissertation does not contain works or opinions that have been written or published by others except the works or the opinions as a reference by mentioned by author's name and original title as well as listed in the bibliography.

This statement has been made in truth and if there was any distortion and untruth in this statement, I am willing to accept any academic sanction in the form of revocation of the degree I have obtained, and other sanctions in accordance with applicable norms at University of Diponegoro.

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FOREWORD

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The Author,

Arif Susanto

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

LIST OF APPENDICES

ABBREVIATION

Au	:	*Aurum*
AD	:	*Articulate Dump*
CAD	:	*Computer-aided Drafting*
CDS	:	*Callibration Data Sheet*
CFM	:	*Cubic Feet Meter*
CH_4	:	*Methane*
CO	:	*Carbon Monoxide*
CO_2	:	*Carbon Dioxide*
COPD	:	*Chronic Obstructive Pulmonary Disease*
CSD	:	*Commission on Sustainable Development*
Cu	:	*Cuprum*
DAE	:	*Diameter Aerodinamic*
DE	:	*Diesel Exhaust*
DEE	:	*Diesel Engine Exhaust*
DEMS	:	*Diesel Exhaust in Miner Study*
DEP	:	*Diesel Exhaust Particulate*
DOZ	:	*Deep Ore Zone*
DPM	:	*Diesel Particulate Matter*
DWP	:	*Dewatering Plant*
EC	:	*Elemental Carbon*
EC/TC	:	*Elemental Carbon to Total Carbon ratio*
EGFR	:	*Epidermal Growth Factor Receptor*
EPA	:	*Environmental Protection Agency*
FEV1	:	*Forced Expiratory Volume in First Second*
FID	:	*Flame Ionization Detector*
Ft	:	*Feet*
FPM	:	*Feet per Minute*
FVC	:	*Forced Vital Capacity*
FVC	:	*Forced Vital Capacity*

GIS	:	*Geogrpahic Information System*
GoI	:	*Government of Indonesia*
GOLD	:	*Global Initiative for Chronic Obstructive Lung Disease*
GRI	:	*Global Report Initiative*
HAPs	:	*Hazardous Air Pollutants*
HEAT	:	*Heavy equipments access trails*
HP	:	*High-powered*
HR	:	*Hazard Ratio*
H_2S	:	*Hydrogen Sulfide*
IARC	:	*International Agency for Cancer Reasearch*
ICMM	:	*International Council on Mining and Metals*
IISD	:	*International Institute for Sustainable Development*
IR	:	*Infrared*
IUCN	:	*International Union for the Conservation of Natural Resources*
JPOI	:	*Johannesburg Plan of Implementation*
LEL	:	*Lower Exposure Limit*
LHD	:	*Load Haul Dump*
LP	:	*Loading Point*
MEFR	:	*Maximum Expiratory Flow Rate*
MEFV	:	*Maximum Expiration Flow Volume*
MMSD	:	*Mining, Mineral and Sustainable Development*
MMSS	:	*Mining and Metals Sector Supplement*
MSHA	:	*Mine Safety & Health Administration*
NAAQS	:	*National Ambient Air Quality Standards*
NIOSH	:	*National Institute of Occupational Safety and Health*
Nm	:	*Nanometer*
NO	:	*Nitrogen Monoxide*
NOx	:	*Nitrous Oxides*
NO_2	:	*Nitrogen Dioxide*
OC	:	*Organic Carbon*
OEM	:	*Original Equipment Manufacturer*

OHS	:	*Overburden handling systems*
OSHA	:	*Occupational Health and Health Administration*
O_2	:	*Oxygen*
PAH	:	*Polycyclic Aromatic Hydrocarbon*
PBEC	:	*Primary Bronchial Epithelial Cells*
PEL	:	*Permissible Exposure Limit*
PID	:	*Photo Ionized Detector*
POC	:	*Product of Combustion*
PTFI	:	*PT Freeport Indonesia*
REC	:	*Respirable Elemental Carbon*
SD	:	*Sustainable Development*
SOF	:	*Soluble Organic Fraction*
SO_x	:	*Sulfur Oxide*
SO_2	:	*Sulphur Dioxide*
STEL	:	*Short Term Exposure Limit*
TC	:	*Total Carbon*
TGFα	:	*Transforming Growth Factor Alpha*
TWA	:	*Time Weighting Average*
UCL	:	*95% Upper Confidence Limit*
UG	:	*Underground Mine*
UN	:	*United Nations*
UNCED	:	*United Nations Conference on Environment and Development*
UNCSD	:	*United Nations Conference on Sustainable Development*
USEPA	:	*United State Environmental Protection Agency*
UTM	:	*The Universal Transverse Mercator*
VC	:	*Vital Capacity*
VOCs	:	*Volatile Organic Compounds*
WBCSD	:	*World Business Council for Sustainable Development*
WCED	:	*World Commission on Environment and Development*
WCS	:	*World Conservation Strategy*
WGS	:	*World Geodetic System*

WSSD	:	*World Summit on Sustainable Development*
µg/m^3	:	*Micrograms per Cubic Meter*
µg/ml	:	*Micrograms per Milliliter*

ABSTRAK

Sesuai Undang-undang Nomor 32 Tahun 2009 yaitu untuk menjaga fungsi maupun kualitas lingkungan yang berkelanjutan, khususnya udara yang merupakan sumberdaya alam yang harus dilindungi untuk kehidupan manusia dan mahluk hidup lainnya, maka kualitas udara harus memenuhi peraturan perundangan agar sesuai dengan standar kualitas lingkungan.

Di PT Freeport Indonesia, terdapat tambang logam mineral seperti tembaga (Cu) dan emas (Au), yang dilakukan dengan membuat terowongan menuju tambang bawah tanah. *Diesel engine exhaust* (DEE) merupakan campuran gas nitrogen oksida (NOx), karbon monoksida (CO), dan *diesel particulate matter* (DPM) yang dihasilkan dari penggunaan bahan bakar diesel untuk mesin berupa kendaraan alat berat bertenaga diesel yang beroperasi di lingkungan bawah tanah operasi tambang .

Tujuan studi ini adalah untuk menganalisis respon pemajanan *Diesel Engine Exhaust* (DEE) pada tambang bawah tanah di PT Freeport Indonesia terhadap kesehatan pernapasan pekerja tambang bawah tanah. Data diesel particulate matter (DPM) diukur dengan metode NIOSH No. 5040 dan menerapkan metode geostatistikal dalam memetakan kosentrasi di area tambang bawah tanah. Pengukuran spirometrik dilakukan untuk mendiagnosis *Chronic Obstructive Pulmonary Disease* (COPD) pada 314 pekerja.

Hasil menunjukkan bahwa konsentrasi diesel engine exhaust (DEE) khususnya diesel particulate matter (DPM) tinggi dan melebihi *permissible exposure limit* (PEL) yang ditetapkan yaitu 160 TC $\mu g/m^3$. Adapun hasil pengukuran spirometrik mengindikasikan bahwa sebanyak 26 pekerja (8.3%) mengalami COPD (post bronchodilator <0.70). Adapun hasil pengukuran keparahan gangguan aliran udara pada pekerja yang mengalami COPD, keparahan batasan aliran udara klasifikasi sedang didapati pada 14 pekerja (54%); klasifikasi parah (GOLD 3) didapati pada 10 pekerja (38%), dan klasifikasi sangat parah (GOLD 4) didapati pada 2 pekerja (8%).

Terkait topik, permasalahan dan tujuan penelitian dapat disimpulkan bahwa pengaruh paparan khususnya oleh DPM terhadap keparahan batasan aliran udara dengan COPD yaitu bernilai 0.03. Pemetaan konsentrasi DEE dapat diterapkan pada area tambang lain untuk mengukur dampaknya pada kesehatan pekerja berdasarkan pada perkiraan paparannya di operasi tambang bawah.

Rekomendasi yang dapat diberikan yaitu pekerja tambang bawah tanah yang telah mengalami keparahan gangguan aliran udara dapat berotasi ke area tambang terbuka atau tugas lainnya di luar area tambang. Untuk perlindungan bagi pekerja tersebut yaitu dengan program perlindungan pernapasan, melalui kewajiban penggunaan masker partikulat P100 yang memiliki efektifitas 99,9% dalam mencegah *respirable particulate* masuk melalui sistem pernafasan. Peningkatan pengetahuan gaya hidup bersih dan sehat juga dilakukan bagi pekerja yang menderita COPD untuk mencegah tingkat keparahan yang lebih tinggi.

Kata kunci: gangguan aliran udara; COPD; DEE; geostatistik; pekerja tambang bawah tanah.

ABSTRACT

Based on Act Number 32 year 2009, i.e. to keep the function and sustainable environmental quality, especially the air that has been natural resources that must be protected for human and other creatures' life, then the air quslity must comply regulations so that it is in line with the environment quality standard.

At PT Freeport Indonesia (PTFI), there is a mine for mineral metal like copper (Cu) and gold (Au), by doing tunnels towards the underground mine. Diesel engine exhaust (DEE) is a mixture of nitrogen oxide (NOx) gas, carbon monoxide (CO), and diesel particulate matter (DPM) resulted from the use of diesel fuel for machines in a form of diesel-powered vehicles (heavy equipments) in mine operation's underground environment.

The purpose of this study is to analyze the exposure response of *Diesel Engine Exhaust* (DEE) in underground mine at PTFI on the respiratory health of underground mine workers. The data of diesel particulate matter (DPM) is measured by using NIOSH No. 5040 and applying geostatictical method in mapping the concentration in underground mine area. Spirometric measurement is conducted to diagnose *Choronic Obstructive Pulmonary Disease* (COPD) on 314 miners.

The result shows that the diesel engine exhaust (DEE) especially diesel particulate matter (DPM) is high and exceed the stated permissible exposure limit (PEL), i.e. 160 $\mu g/m^3$. The result of spirometric measurement indicates that 26 workers (8.3%) have COPD (post bronchodilator <0.70). Furthermore, the measurement result of severity of airflow limitation with medium classification is found on 14 miners (54%); severe classification (GOLD 3) is found on 10 miners (38%), and very severe classification (GOLD 4) is found on 2 miners (8%).

Regarding the topic, problem and the objectives of this research, it can be concluded that the exposure influence especially by DPM on the airflow severity with COPD is 0.03. DEE concentration mapping can be applied in other mine area to measure its impacts for workers' health based on the estimation of its exposure in mine operation.

The recommendation that can be given is that the underground workers who have severity of airflow limitation can rotate to open pit mine area or other assignments outside the mine area. For protection of those workers, i.e. with respiratory protection program, is through the mandatory usage of P100 particulate mask that has 99.9% effectiveness, in preventing *respirable particulate* to go into the respiratory system. The improvement of clean and healthy life style knowledge can also be done for workers who have COPD to prevent a more severe level.

Keywords: airflow limitation; COPD; DEE; geostatistics; underground workers.

RINGKASAN

Di PT Freeport Indonesia, terdapat tambang bawah tanah untuk logam mineral seperti tembaga (Cu) dan emas (Au), yang dilakukan dengan membuat terowongan menuju penambangan mineral bawah tanah. Pengukuran konsentrasi polutan air di DOZ merupakan langkah pertama dalam mengidentifikasi bahaya dan resiko kesehatan dan lingkungan para pekerja tambang. Penggunaan bahan bakar diesel (DF) dan mesin diesel (DE) meningkat karena kehandalan dan efisiensi pembakaran bahan bakar hidrokarbon. Namun, terdapat kekhawatiran bahwa hasil pembakaran mesin diesel dalam bentuk diesel engine exhaust (DEE) yang berbahaya bagi kesehatan pekerja tambang.

Mesin diesel (DE) memiliki perangkat industrial termasuk dalam pertambangan (*off-road*). Kendaraan/alat berat bertenaga diesel (HE) yang beroperasi di lingkungan bawah tanah (UG) (tambang dan terowongan) ditentukan dengan cara mengkalikan tenaga kendaraan dengan tingkat ventilasi; yang dimandatkan oleh peraturan-peraturan atau ditentukan secara empiris dari kuantitas yang telah diketahui. Pada proses penambangan bawah tanah, (HE) seperti *loader* dan alat lainnya menggunakan mesin diesel (DE). Di samping *loader, haul truck, development jumbo, truck* dan kendaraan atau alat tambang lainnya yang menggunakan DE juga berada di terowongan bawah tanah.

Partikel-partikel dalam DEE adalah diesel particulate matter (DPM) yang terdiri atas pusat inti karbon yang disebut elemental carbon (EC) dan senyawa organik serapan yang disebut organic carbon (OC), dan sejumlah kecil sulfat, nitrat, logam dan unsur lainnya. DEE diklasifikasikan sebagai *carsinogenic* bagi manusia (Grup 1). Keputusan ini berdasar pada studi yang dilakukan oleh *National Institute for Occupational Safety and Health* (NIOSH) bersama US *National Cancer Institute* (NCI) yang menunjukkan hubungan respon paparan antara paparan EC terhirup dan tingkat kematian karena kanker paru-paru pada pekerja tambang bawah tanah. Tingkat tertinggi EC dilaporkan untuk lokasi kerja bawah tanah dalam pertambangan.

Penilaian paparan merupakan proses mengukur atau memperkirakan magnitudo, frekuensi dan durasi paparan manusia ke senyawa di lingkungannya. Evaluasi paparan manusia menjelaskan sifat dan ukuran populasi yang terpapar kontaminan atau pencemar lingkungan udara serta magnitudo dan durasi paparannya. Dosis, durasi dan waktu, sifat dan ukuran dari

pengukuran kritis paparan untuk karakterisasi resiko. DPM biasanya berlangsung kurang dari satu mikron, yang menyebabkannya mudah terhirup dan tersimpan di dalam tubuh. Saat ini industri pertambangan di Amerika Serikat berada dalam proses pembuatan peraturan yang lebih ketat terkait dengan partikulat diesel di tambang bawah tanah. Batas paparan DPM yang diadopsi oleh MSHA untuk tambang bawah tanah logam dan non-logam (*non-batubara*). PEL saat ini untuk DPM sesuai MSHA (30 CFR 57.5060(b)) adalah 160 µg TC/m^3, yang disebut sebagai kandungan karbon total (TC).

Penelitian ini dilakukan di DOZ, yang merupakan area produksi terletak di bawah tanah. Studi ini dilakukan di tambang bawah tanah DOZ pada titik koordinat 733250-734250 Easting; 951250-952250 Northing; UTM Zone 53 South. Lokasi penambangan berada di pegunungan Jayawijaya, Distrik Mimika Timur, Propinsi Papua, Indonesia. Pengukuran yang diambil meenggambarkan kondisi ambien dan analisis kimia komprehensif dilakukan. Data DPM sebagai TC disebut sebagai jumlah EC dan OC. EC dan OC diukur dengan nomor metode 5040 NIOSH.

Studi ini menerapkan analisis spasial dengan universal kriging untuk memetakan konsentrasi DPM di di DOZ. Data yang didapatkan dari perhitungan tersebut kemudian diproses ke dalam sebiuah kerangka menggunakan model spasial. Model tersebut telah digunakan paling sering untuk memberikan kondisi batasan ke pemodelan dinamis dari polutan udara. Dalam studi kali ini, ArcGIS digunakan untuk menghasilkan peta. Pengukuran spirometrik dilakukan untuk mendiagnosis COPD dan penilaian Batasan aliran udara didasarkan pada GOLD, yang dilakukan pada 314 pekerja tambang yang bekerja di DOZ.

Area aliran udara tambang DOZ memerikan cukup aliran udara yang diperlukan berdasarkan perhatian kecepatan minimum dalam jalur lalu lintas dan dilusi kontaminasi diesel. Kebutuhan aliran udara total adalah 1.498 m^3/detik. Aliran udara ke masing-masing tingkat utama, *undercut, extraction* dan *haulage* berdasar pada penyediaan 0,079 m^3/detik/kW pada kendaraan atau alat diesel dan minimum kecepatan udara 0,76 m/detik di area dimana personil dan non-diesel beroperasi. Aliran udara *intake* (masuk) dan *exhaust* (keluar) diperlukan untuk menyediakan aliran udara yang cukup. Hal ini disebabkan oleh *multiple parallel drifts* pada tingkat *extraction* (produksi) untuk mengendalikan tambang *block caving*. Terkait dengan jalur utama, aliran udara diperlukan untuk dilusi kontaminasi dan kecepatan minimum. Sistem ventilasi dirancang untuk memastikan semua personil yang bekerja di *truck haulage drifts* mendapat udara segar. Penentuan jumlah aliran udara dipengaruhi oleh peralatan tambang dan variasi luas dalam karekteristik emisi bahkan di antara kendaraan yang memiliki ukuran dan tenaga yang mirip. Jumlah parameter mempengaruhi total aliran udara yang diperlukan untuk jumlah DE.

Analisis interpolasi spasial menggunakan model dispersi dengan memproses data emisi dan meteorologis secara numerik. Metode kriging merupakan metode umum yang digunakan dan menggambarkan fenomena yang berlangsung terus-menerus secara spasial. Sebuah metode telah membuat dasar pemetaan polusi lingkungan di beberapa tahun terakhir. Metode ini menjelaskan model paparan kualitas udara di tambang DOZ untuk memprediksi konsentrasi DPM dimana para pekerja tambang terpapar. Analisis polusi udara dan titik pemantauan dan pengukuran (*truck haulage drifts and tunnels*) yang digunakan dalam studi ini adalah beragam polutan dari pengoperasian HE di lingkungan bawah tanah.

Pengukuran data polutan udara yang digunakan dalam penilaian menggunakan metode Geographic Information System (GIS)-based Kriging untuk menghasilkan informasi paling akurat dan berguna tentang pola interpolasi spasial dari konsentrasi DPM di DOZ. Pemetaan dibuat dalam ArcGIS, yang mengintegrasi data relevan pada *truck hauling drifts*, terowongan dan tingkat ventilasi. Hasilnya menunjukkan bahwa DPM dapat diperkirakan, dipetakan dan divisualisasikan dalam GIS-framework. Distribusi spasial polutan merupakan komponen integral dari aspek evaluasi risiko yang terkait dengan kesehatan dan lingkungan. Teknik yang digunakan untuk menggambarkan distribusi spasial memberikan makna dalam memperkirakan kemungkinan nilai atribut, yang melebihi batasan yang diperlukan dalam lokasi tertentu.

Hasil pemetaan konsentrasi polutan udara dengan universal kriging mengindikasikan konsentrasi yang tinggi, atau kondisi yang buruk pada area *truck haulage*. Hampir semua area memiliki konsentrasi DPM yang beragam dari 343,26 hingga 618,23 µg/m^3. Bahkan di beberapa area, tingkatnya 618,24 hingga 1168,18 µg/m^3. Walaupun kualitas udara di dalam DOZ dipengaruhi oleh keseimbangan total udara *intake* dan *exhaust*, sebagai bagian dari sistem ventilasi untuk mensuplai kebutuhan udara, kualitasnya masih tidak mampu mendilusi polutan udara, khususnya DPM. Kebutuhan udara semua pekerja tambang adalah untuk 650 individu dengan faktor operasional 100%, dimana total alitan udara per unit adalah 0,03 m^3/detik. Lagipula, kuantitas aliran udara untuk masing-masing tipe unit peralatan diesel yang tergantung pada faktor operasionalnya pada unit tenaga (dalam unit *horsepower*), yang berbeda dari tipe unit dan dipengaruhi oleh faktor operasional dari masing-masing unit peralatan.

Nilai aliran udara minimum adalah 0,03 m^3/s/pekerja dan 0,067 m^3/s/kW untuk dilusi DEE sesuai dengan Peraturan Pertambangan Indonesia. Sebenarnya, 0,08 m^3/s/kW merupakan nilai desain dan lebih tinggi daripada jumlah alat MSHA pada umumnya yang disediakan untuk kepatuhan gas. Untuk jalan *haulage truck*, kecepatan maksimumnya adalah 6,1 m/detik. Ventilasi untuk bengkel diesel berdasar pada dilusi gas exhaust untuk dua loader, yang memerlukan sekitar 40,0 m^3/detik. Ventilasi bengkel non diesel telah diputuskan 23,5 m^3/detik berdasarkan pengalaman di tambang tersebut. Aliran udara melalui area *lube shop* telah diputuskan 28,2 m^3/detik berdasar pada penggunaan alat yang diperkirakan. Faktor pengoperasian menggambarkan presentase waktu alat yang akan bekerja dan harus diterapkan untuk menentukan perkiraan kebutuhan aliran udara.

Paparan lingkungan oleh asap, gas, dan debu pada pekerja berkontribusi pada kerusakan fungsi paru. Faktor resiko lingkungan paling menonjol untuk COPD adalah merokok, yang terkait dengan tingkat kematian yang lebih tinggi, gejala gangguan pernapasan dan ketidaknormalan fungsi paru, serta penurunan fungsi paru. Pengukuran spirometrik untuk diagnosa COPD dilakukan kepada 314 pekerja tambang yang bekerja di DOZ.

Rata-rata para pekerja tambang telah bekerja di DOZ selama 15 tahun. Hal ini sesuai dengan umur tambang DOZ yang mulai beroperasi tahun 1998. Lamanya bekerja sesuai dengan jumlah waktu terpapar DEE. Paparan terhadap partikel merupakan faktor yang mempengaruhi perkembangan penyakit, walaupun juga dipengaruhi usia dan jenis kelamin, meskipun dalam studi ini, jenis kelamin tidak digunakan sebagai variabel independen karena semua pekerja tambang di DOZ adalah laki-laki. Kemunculan COPD lebih tinggi pada perokok dan mantan perokok dibandingkan dengan non perokok. Jumlah non perokok adalah 142 pekerja (45,2%) dari total pekerja, lebih sedikit dibanding pekerja yang perokok, yaitu 172 (54,8%) dari total pekerja, atau 9,8% lebih tinggi daripada pekerja non perokok. COPD dianggap dalam sejarah paparan sebagai faktor resiko untuk penyakit. Hasil pengukuran spirometrik, munculnya post-bronchodilator FEV1/FVC <0.70 mengkonfirmasi adanya batasan aliran udara yang tetap pada 314 pekerja, yaitu sebanyak 26 pekerja (8,3%). Jadi dapat dikatakan bahwa paparan oleh DEE dapat menyebabkan COPD pada pekerja yang bekerja di DOZ.

Untuk mengukur keparahan gangguan aliran udara ke pekerja tambang yang mengalami COPD, uji lanjut pada pekerja dengan FEV1 (% terprediksi) yang diujikan pada pekerja dengan FEV1/FVC <0.70, didapatkan hasil tingkat klasifikasi keparahan batasan aliran udara bagi pekerja dengan COPD adalah sebagai berikut: klasifikasi sedang (GOLD 2) 14 pekerja atau 54%, parah (GOLD 3) 10 pekerja atau 38%, dan sangat parah (GOLD 4) 2 pekerja atau 8%. Uji ANOVA dilakukan dengan memasukkan metode untuk menentukan jumlah waktu kerja (paparan) DPM terhadap keparahan batasan aliran udara dengan COPD serta apakah faktor lain seperti usia, kebiasaan merokok juga dapat mempengaruhi keparahannya. Hasil yang didapatkan dari uji-uji tersebut menunjukkan bahwa nilai R=0.173 dengan nilai F=2.395 pada nilai signifikansi (α) = 0.05, sehingga dapat disimpulkan bahwa kategori GOLD dipengaruhi oleh 3% dari lama paparan DPM, tinggi badan, kebiasaan merokok dan usia pekerja. Dari pengukuran keparahan gangguan aliran udara pada pekerja yang mengalami COPD, jumlah durasi kerja (paparan) DPM terhadap keparahan batasan aliran udara dengan COPD 3%, dimana faktor lainnya seperti usia dan kebiasaan merokok juga mempengaruhi keeparahannya. Dari hasil-hasil tersebut, disimpulkan bahwa pemetaan konsentrasi polutan dapat digunakan untuk mengevaluasi hubungan paparan-respon. Paparan polutan DEE direkomendasikan untuk dilakukan sebagai bagian studi untuk memprediksi apakah polutan memberikan dampak pada kondisi kesehatan pekerja tambang dalam paparan jangka panjang.

SUMMARY

In PT Freeport Indonesia, there are underground mines for mineral metal such copper (Cu) and gold (Au), done by making tunnels towards the mineral underground mining. Air pollutant concentration measurement in DOZ is first step in identifying environmental-health hazards and risk to the miners. The use of diesel fuel (DF) on Diesel Engine (DE) increases because of the reliability an efficiency of hydrocarbon fuel oxidation. However, there is a worry that the result of diesel engine oxidation is in the form of *diesel engine exhaust* (DEE) which is dangerous for miner's health.

Diesel engines (DE) have of industrial applications including in mining (*off-road*). Diesel-powered heavy equipment (HE) operating in underground (UG) environments (mines and tunnels) were determined by multiplying the vehicle power by a ventilation rate; that was either mandated by regulation(s) or determined empirically from known quantities. In the process of UG mining, (HE) such as loader as well as other equipments that uses diesel engine (DE). Beside loader, haul truck, development jumbo, truck and other mine equipments that use DE are also in the underground tunnels.

The particles in DEE are *diesel particulate matter* (DPM) consisting of the center of carbon nucleus defined as elemental carbon (EC) and absorbed organic compounds defined as organic carbon (OC), and a small number of sulphate, nitrate, metal, and other elements. DEE classified as carcinogenic to human (Group 1), the decision was based on National Institute for Occupational Safety and Health (NIOSH) and US National Cancer Institute (NCI) study showed exposure-response relationships between respirable EC exposure and lung cancer mortality in UG miners. The highest levels of EC were reported for enclosed UG work sites in mining.

Exposure assessment is the process of measuring or estimating the magnitude, frequency and duration of human exposure to a compound in the environment. Human exposure evaluation involved describing the nature and size of the population exposed to a air contaminants and magnitude and duration of their exposure. The dose, its duration and timing, the nature and size of the critical measures of exposure for risk characterization. DPM usually less than one micron, which causes them to be more easily inhaled and retained in the body. Presently the United States mining industry is in the process of phasing in stringent regulations relating to diesel particulates in underground mines. Exposure limits for DPM adopted by MSHA for metal or non-metal

underground mines (non-coal). The present PEL for DPM as per MSHA (30 CFR 57.5060(b)) is 160 μg TC/m^3, with the defined as total carbon (TC) content.

Research is carried out in DOZ, which is a production area of UG located The study was held at the DOZ UG mine on the coordinate points of 733250-734250 Easting; 951250-952250 Northing; UTM Zone 53 South. The mining site is situated in Jayawijaya Mountain, East Mimika District, Papua Province, Indonesia. Measurement were taken represent ambient conditions and a comprehensive chemical analysis was performed. Data of DPM as TC was defined as the sum of EC and OC. Both EC and OC were measured by NIOSH method number 5040.

This study applied spatial analysis by universal kriging for mapping DPM concentration in the area trcuk haulage drift at DOZ. The data obtained from these calculations were then processed into a frame using a spatial model. It has been most frequently used for providing boundary conditions to dynamic modeling of the air pollution. In the current study, ArcGIS were used for generating maps. A spirometric measurement were conduct to diagnose COPD and assessment airflow limitation based on GOLD, is conduct to the 314 miners that work at the DOZ.

DOZ mine airflow area provides sufficient for airways were required were based on minimum velocity concern in main travelways and dilution of diesel contamination. Total airflow demand is 1.498 m^3/s. Airflow to each primary level, undercut, extraction and haulage was based on providing 0.079 m^3/s/kW over diesel equipment and a minimum air velocity of 0.76 m/s in areas where personnel and non-diesel operate. Intake and exhaust airways were required to provide sufficient airflow. It caused by the multiple parallel drifts on the extraction (production) level to control block caving mines. Concerning to main trailways, airflow required for dilution of DEE contamination and minimum velocity. For ventilation system designed to assure all personnel working in truck haulage drifts in fresh air. Determination of airflow quantity that influence by mining equipment and wide variations in characteristics of emissions even amongst vehicle of similar size and power. The number of parameter affecting the total airflow required for a amount of DE.

Spatial interpolation analysis is using air dispersion model by numerically processing emission and meteorological data. Kriging method is a common method used and represents spatially continuous phenomena. A method has formed the basis for environmental pollution mapping in recent years. This method describe DOZ mine air quality exposure model for predicting DPM concentrations to which the miners' is exposed. Air pollution analysis and points of monitoring and measurement (*truck haulage drifts and tunnels*) used in this studies of various pollutants from HE operating in UG environments.

Air polutant data measurements are use in assesses use of Geographic Information System (GIS) based Kriging method to produce the most accurate and providing useful information about the spatial interpolation patterns DPM concentration in DOZ. A mapping was built in ArcGIS, integrating relevant data on truck haulage drifts, tunnels and ventilation rate. The result that show DPM can be estimated, mapped and visualized within a GIS framework. The spatial distribution of the pollutants is an integral component from risk evaluation aspect concerning health and environment. Technique used for illustrating the spatial distribution provides a meaning for estimating the probability of the attribute value, which exceeds required threshold in a particular location.

Results of the air pollutant concentration mapping was DPM with universal kriging. In general, it indicated a high concentration, therefore, denoting bad condition at the truck haulage area, even though no difference in DPM concentration was found. Almost areas had the DPM concentration ranging from 343.26 to 618.23 μg/m^3. Even at some areas the rates were 618.24 to 1168.18 μg/m^3. Although the air quality inside the DOZ was affected by balance of the total air intake and exhaust, as the part of ventilation system to supply the needs for air, the quality is still not capable of diluting air pollutants, in particular DPM. The air requirement of all mining workers was 650 individuals with operational factor of 100 %, where the total airflow per unit was 0.03 m^3/s. Besides, the airflow quantity necessary for each unit type of the diesel equipment depended its operational factor on the power unit (in horsepower unit), which was different from unit type and affected by operational factor of each unit equipment.

Minimum airflow value of 0.03 m^3/s/worker and 0.067 m^3/s/kW for DEE dilution as per Indonesian Mining Regulation. Actually, 0.08 m^3/s/kW is a design value and is higher than the typical MSHA equipment quantities provided for gaseous compliance. For truck haulage routes is 6.1 m/s as the maximum velocity. Ventilation for diesel shops based on the dilution of exhaust gaseous for two large loaders, which requires approximately 40.0 m^3/s. Ventilation of non-diesel shops has been established at 23.5 m^3/s based on experience at the mine. Airflow through the lube shop areas has been determined to be 28.2 m^3/s based on expected equipment usage. Operating factors represent the percentage of time that the equipment will be running and have to applied to determine approximate airflow requirements.

Environmental exposures to fumes, gases, air pollutants, and occupational dusts contribute to impaired lung function. The most prevalent environmental risk factor for COPD is cigarette smoking, which is associated with a higher mortality rate, a higher burden of respiratory symptoms and lung function abnormalities, and greater decreases in lung function. Spirometric measurement for COPD diagnosis is done to 314 miners that work at the DOZ.

The miners work in DOZ for 15 years ratably. This is in line with the mining age of DOZ which began operating in 1998. The years of working are in line with the amount of time exposed by DEE. Exposure to particles is a factor that affects disease progression, although it is also affected by age and sex, although in this study, gender is not used as an independent variable because all miners in DOZ are male. Prevalence of COPD was higher in smokers and ex-smokers compared to non-smokers. The number of non-smokers are 142 miners (45.2%) of the total miners, which is less when compared with the miners who smoke, 172 miners (54.8%) of the total miners are 9.8% higher than miners as non-smokers. COPD is considered in a history of exposure to risk factors for the disease. The results of spirometry measurement, the presence of a post-bronchodilator $FEV_1/FVC < 0.70$ confirms the presence of persistent airflow limitation on 314 miners as many as 26 miners (8.3%). Thus it can be said that exposure to DEE can cause COPD on the miners who worked in DOZ.

To measure the severity of airflow obstructive toward the miners who experience COPD, a follow-up test on miners with FEV_1 (% predicted) assessed on miners' with $FEV_1/FVC < 0.70$, and it is obtained the result of severity of airflow limitation classification for miners with COPD those are: for moderate (GOLD 2) is 14 miners or 54%, severe (GOLD 3) is 10 miners or 38%, and very severe (GOLD 4) is 2 miners or 8%. ANOVA test is conducted by enter method to determine the amount of working time (exposure) DPM against severity of airflow limitation with COPD and whether other factors those are age, smoking habits can also affect the severity. The results obtained from these tests shows that the value $R=0.173$ with value $F=2.395$ on the value of significance (α) = 0.05, so it can be concluded that the GOLD category is influenced by 3% of the length of exposure to DPM, height, smoking habits, and age of miners. From the severity measurement of airflow obstructive to miners experiencing COPD, the amount of working duration (exposure) DPM against severity of airflow limitation with COPD by 3%, in which the other factors are age and smoking habits also affects the severity. From these results, concluded that the concentration mapping can be used to evaluate exposure-response relationships. The estimated exposure of the DEE pollutant was recommended to perform as the part of the study on predicting whether the pollutant gives any impact on health condition of the mining workers in a longterm exposure.