UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

DEVELOPMENT OF PERFORMANCE STANDARD FOR CIRCULAR DUCTING LOCAL EXHAUST VENTILATION SYSTEM AT WORKPLACE

Nor Halim Hasan

Doctor of Philosophy

2016

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DEVELOPMENT OF PERFORMANCE STANDARD FOR CIRCULAR DUCTING LOCAL EXHAUST VENTILATION SYSTEM AT WORKPLACE

NOR HALIM HASAN

A thesis submitted in fulfillment of the requirements for the degree of Doctor of Philosophy

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

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DECLARATION

I declare that this thesis entitle “DEVELOPMENT OF PERFORMANCE STANDARD FOR CIRCULAR DUCTING LOCAL EXHAUST VENTILATION SYSTEM AT WORKPLACE” is the result of my research expect as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy

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Date : 31st March 2016

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DEDICATION

To my beloved wife (Zalina), daughter (Nur Amiera, Nur Ainaa, Nur Aisyah, Nur Adibah, Nur Adriana and Nurain Sofea), father and mother in law (Haji Khalil and Hajjah Halijah) and all my family. Special dedicated to my late mom (Hajjah Melor), late dad (Haji Hasan) and 3 of late brothers (Hasmi, Hamdan and Hasman).

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ABSTRACT

Engineering controls, such as local exhaust ventilation (LEV) system, are functioned to remove contaminants from work place, as it is vital that the level of contaminants must comply with legislation. Furthermore, LEV in industries has been designed, fabricated, and monitored to perform better in accordance to the American Conference for Governmental Industrial Hygienists (ACGIH) standard and the Guideline on LEV provided by Department of Occupational Safety and Health (DOSH). This study on LEV had been depicted from the Industrial Hygiene Technician assessment report due to issues on the effectiveness of LEV to remove contaminants. That includes problem of assessing, measuring the fan area, as well as the material fabricated. Thus, the objective of the study was to identify the current compliance of the national law with regards to LEV system. Moreover, besides determining the usage of ducting in LEV by looking into the characteristics of the material using American Society for Testing and Materials (ASTM) standard, the performance of LEV system was tested, as suggested in the ACGIH standard, through design, construct, and measurement data. Three different models (in laboratory scale model) of LEV system were designed according to the ACGIH Standard, and tested to determine the relationship between analytical, experimental, and numerical analyses in this study. As for the three models, they were designed and fabricated to measure velocity and flow of air. Meanwhile, as for numerical analysis, computer simulation i.e. Ansys CFX, Engineering Simulation Software version 14.0 (Ansys 14.0) was used to simulate these three models for verification and comparison. A comparative study was conducted to retrieve analytical, experimental, and simulation results to justify the performances of LEV on different velocity and static pressure values. The results showed that there was insignificant difference between the values of velocity that were calculated, measured, and simulated. The average difference for velocity data was 8%. Static pressure for analytical and experimental results also portrayed insignificant difference compared to simulation that was mostly influenced by the mesh of variable setting. The outcome of the study was to produce the Malaysian Standard on LEV system design, fabrication, measurement, and maintenance. The development of LEV Malaysian Standard through Standard and Industrial Research Institute of Malaysia (SIRIM) Berhad that proposes the evaluation of LEV performance should be carried out before any LEV system is developed due to cost consideration, besides benefiting employees and employers for their safety and health, and in preventing occupational diseases in the future.

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ABSTRAK

Kawalan kejuruteraan seperti Sistem Pengalihudaraan Ekzos Setempat (LEV), yang berfungsi untuk membuang bahan cemar dari tempat kerja, kerana ia adalah penting bahawa tahap bahan cemar mesti mematuhi undang-undang. Tambahan pula, LEV dalam industri telah direka bentuk, dibina, dan dipantau untuk prestasi yang lebih baik selaras dengan standard oleh "American Conference for Governmental Industrial Hygienists" (ACGIH) standard dan Garis Panduan LEV disediakan oleh Jabatan Keselamatan dan Kesihatan Pekerjaan (JKKP). Kajian di LEV telah digambarkan dari laporan penilaian oleh Juruteknik Higen Industri kerana mengenai isu-isu keberkesanan LEV untuk membuang bahan cemar. Ini termasuk masalah memasuki ke dalam kawasan, mengukur di kawasan kipas motor, dan juga bahan yang dibina. Oleh itu, objektif kajian ini adalah untuk mengenal pasti pematuhan semasa undang-undang negara berkaitan dengan sistem LEV. Lebih-lebih lagi, di samping menentukan penggunaan salur di LEV dengan melihat ke dalam ciri-ciri bahan yang menggunakan standard "American Society for Testing and Materials " (ASTM), prestasi sistem LEV diuji, seperti yang dicadangkan dalam standard ACGIH, melalui reka bentuk, membina, dan data pengukuran. Tiga model yang berbeza (dalam makmal model skala) sistem LEV telah direka mengikut Standard ACGIH, dan menentukan hubungan antara analisis analitikal, eksperimen, dan analisis berangka dalam kajian ini. Bagi tiga model, ia telah direkabentuk dan dibina untuk mengukur halaju dan aliran udara. Sementara itu, bagi analisis berangka, simulasi komputer iaitu Ansys CFX digunakan. Simulasi Kejuruteraan Perisian versi 14.0 (Ansys 14.0) telah digunakan untuk mensimulasikan ketiga-tiga model untuk pengesahan dan perbandingan. Satu kajian perbandingan telah dijalankan untuk mendapatkan analisis, eksperimen, dan keputusan simulasi untuk mewajarkan prestasi LEV pada halaju yang berbeza dan nilai-nilai tekanan statik. Hasil kajian menunjukkan bahawa terdapat perbezaan yang ketara antara nilai halaju yang dikira, diukur, dan simulasi. Perbezaan purata bagi data halaju dari hasil adalah 8%. Tekanan statik untuk hasil analisis dan eksperimen juga digambarkan perbezaan yang tidak ketara berbanding simulasi yang kebanyakannya dipengaruhi oleh jaringan sentiasa berubah-ubah. Hasil daripada kajian ini adalah untuk menghasilkan Standard Malaysia mengenai reka bentuk sistem LEV, fabrikasi, mengukur, dan penyelenggaraan. Pembangunan LEV Standard Malaysia melalui Institut Standard dan Kajian Industri Malaysia (SIRIM) Berhad yang mencadangkan penilaian prestasi LEV perlu dijalankan sebelum apa-apa sistem LEV dibangunkan kerana pertimbangan kos, selain memberi manfaat kepada pekerja dan majikan untuk keselamatan dan kesihatan mereka , dan dalam mencegah penyakit pekerjaan pada masa hadapan.

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ACKNOWLEDGEMENT

First and foremost, the authors would like to take this opportunity to express my sincere acknowledges the main supervisor Professor Dr. Md. Radzai Said from the Faculty of Mechanical Engineering Universiti Teknikal Malaysia Melaka (UTeM) for his essential supervision, support and encouragement towards the completion of this thesis. And also express the greatest gratitude to Associate Professor Engr. Dr. Abdul Mutalib Leman from the Faculty of Engineering Technology Universiti Tun Hussein Onn (UTHM), co-supervisor of this project for his guidance, advice and suggestion to complete this thesis and the following organizations and individual for their contributions and supports such as Government of Malaysia, Department of Public Services, Department of Occupational Safety and Health Malaysia, Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka and Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia.

Special thanks to all my peers, my family, siblings and all my friends for moral support in completing this thesis. Lastly, thank you to everyone who had been to the crucial part of realization of this project. Not forgetting, my humble apology as it is beyond my reach personally mentioned those who involved directly one to one.

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LIST OF ABBREVIATIONS

ACGIH	-	American Conference of Governmental Industrial Hygienists
ASTM	-	American Society for Testing and Materials
Bhp	-	Brake Horse Power
C	-	Celsius
CIMAH	-	Control of Industrial Major Accidents Hazards
DOSH	-	Department of Occupational Safety and Health
EDX	-	Energy-Dispersive X-ray
ENM	-	Engineered Nanomaterials
FMA	-	Factory and Machinery Act
FRC	-	Fan Rating Curve
FTP	-	Fan Total Pressure
HIRARC	-	Hazard Identification Risk Assessment Risk Control
HVAC	-	Heating, Ventilating, and Air Conditioning
IHT 1	-	Industrial Hygienist Tech 1
IHT 2	-	Industrial Hygienist Tech 2
in-wg	-	Inches Water Gauge
K	-	Kelvin
LEV	-	Local Exhaust Ventilation
MVAC	-	Mechanical, Ventilating, and Air Conditioning

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NIOSH	-	National Institute of Occupational Safety and Health
OSH	-	Occupational Safety and Health
OSHA	-	Occupational Safety and Health Act
OSH-MS	-	Occupational Safety and Health Management Standard
PCO	-	Photocatalytic Oxidation
Q	-	Volumetric Flowrate
Sp	-	Static Pressure
SST k-ε	-	Shear Stress Transport k Epsilon
SPSS	-	Statically Packaging Social Science
SIRIM	-	Standard and Industrial Research Institute of Malaysia
SOCSO	-	Social Security Organization Malaysia
$SrCrO_4$	-	Strontium Chromate
SEM	-	Scanning Electron Microscope
Tp	-	Total Pressure
TLV	-	Threshold Limit Value
USECHH	-	Use of Standard Exposure of Chemical Hazardous to Health
UTM	-	Universal Testing Machine
VOCs	-	Volatile Organic Compound
Vp	-	Velocity Pressure
V	-	Velocity
XRD	-	X-ray Diffraction
Zn	-	Zinc

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CHAPTER 1

INTRODUCTION

1.0 General

Workers at workplace, either in offices or industries, have the potential to be exposed to occupational health effects due to air pollutants and exposure of contaminants from the processing industry. There are appropriate rules, regulations, and guidelines that the employers and employees should know and understand how to protect themselves from these risks.

1.0.1 Background of the Study

In Malaysia, Occupational Safety and Health Act, Act 514, which is also known as OSHA 1994, has been enforced almost 20 years now since 1994 (OSHA 1994, 2006). According to the act, employers are required to ensure safety, health, and welfare of workers. Furthermore, the act prevents workers from being exposed to any risk of accident. In this study, a mechanism to control hazardous exposure to workers had been proposed by designing and implementing good ventilation system for better environment at workplace.

Local exhaust ventilation (LEV) is a system of controlling airborne toxic chemicals or flammable vapors by exhausting contaminated air away from the work area and replacing it with clean air (Oanh and Hung, 2005)(ACGIH, 2009) (Washington State Dept. of Labor, 2011). Other alternatives include process changes, work practice changes, substitution with less toxic chemicals, or elimination of the use of toxic chemicals. LEV is typically used to remove welding fumes, solvent vapors, oil mists or dusts from a work location and exhaust

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these contaminants to outdoor (Jafari et al., 2010)(Geyssant et al., 2007)(Sakwari et al., 2011).

The objective of a LEV system is to remove contaminants that are generated by a source. The system controls the air by controlling the gases and the vapors that exist in the environment. Special procedures are required to control large particles that are generated by the source. These particles are controlled for other than health purposes (ACGIH, 2009).

Lack of control of the contaminants would affect the health of the workers. In the United Kingdom, there was an issue related to occupational health, such as occupational asthma, due to exposure to isocyanate among workers who worked as vehicle paint sprayers in motor vehicle repair (MVR) body shops, and in commercial vehicle and trailer manufacturing industry. The risk was over 80 times greater than the industrial average (Health and Safety Executive, 2008). A study by Winder and Turner (1992) in Australia found that the typical contaminants of the chemical products used in this industry were encountered. The study looked into 46 spray painting workshops in Sydney and it showed that exposure to solvent was the highest when spraying acrylic paint in the open workshop, and the lowest when spraying two pack paint in a spray booth. The researchers monitored the personal protective equipment (PPE) available in all workshops, and wide variation in its use was observed. Material safety data sheets were reported to be unobserved in any of the workshops (Winder and Turner, 1992).

In controlling the contaminants, employers should comply with the local legislation. The industries need to install the LEV system to remove contaminants in a workplace, and this will definitely involve cost. Estimating cost must be considered in the system design before installation. Buy and Mathews (2005) claimed that without a detailed design and costing model, no accurate cost estimation can be done (Buys and Mathews, 2005). Besides that, industrials that are involved in and use ventilation systems are required to comply with

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Malaysian Legislation, such as OSHA Act 1994 (OSHA 1994, 2006), Use & Standards of Exposure of Chemicals Hazardous to Health 2000 (USECHH) Regulation (DOSH, 2006), and Factory and Machinery Act 1967 and Factories and Machinery (Safety, Health and Welfare) Regulation, 2009.

Thus, employers should comply with the regulation and act in order to ensure that their workers are in a safe condition. Applications on control of contaminants are approaches by the OSH system and other methods. The common approaches used are hazard identification, risk assessment, and risk control (HIRARC), as recommended by Department of Occupational Safety and Health (DOSH) (DOSH, 2008).

1.0.2 Hazard Identification, Risk Assessment, and Risk Control Approach

The general duties of employers, as mentioned in section 15(1), OSHA Act 514, are that they must ensure the practicable, safety, health, and the welfare of all their workers or other persons at the workplace. The requirements to comply include maintenance of plant and systems of work and any connection with the use or operation, handling, storage, and transport of plant and substance (OSHA 1994, 2006). Thus, in order to comply with the act, DOSH has proposed some Occupational Safety and Health Management Systems (OSH-MS) in controlling hazards and risks at workplace.

In OSH-MS, by the Malaysian Standard (SIRIM MS Standard, 2004), there are three methods in controlling hazards or risks at workplace. The three methods mentioned are Hazard Identification, Risk Assessment, and Risk Control (HIRARC). According to Bahari (2002), there are four stages in managing risks at workplace, which are identifying hazard, risk assessment, risk control, and achievement (Bahari, 2002) (OSHA 1994, 2006).

Control of Risk, as suggested by the MS Standard (SIRIM MS Standard, 2004) and Ismail Bahari (2002), includes eliminate hazard, substitute hazard, isolate hazard,

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engineering control, administrative control, and provide personal protective equipment (PPE). In addition, DOSH Malaysia has published a Guideline to comply with HIRARC for industry to use it as a guideline in managing risks at workplace. Therefore, in order to control hazard at source or contaminants, the LEV system was proposed as an engineering control to minimize and to control the risks exposed in the industry.

As no Malaysian standard has been provided related to the performance of LEV, this study was conducted to develop the standard for the performance of LEV.

1.1 Problem Statement

Common LEV systems are used widely in the industry. The purpose is to prevent workers from being affected by the contaminants or any volatile organic compound (VOC) due to the work activities performed. A survey conducted by Rhode Island Department of Environmental Management found that one-half of shops employed three or fewer people in the working environment with the potential of exposure to contaminants. Nearly all of these shops used spray-painting booths, 38% own booths, and in many cases, spray painters double as body repair technicians, therefore, increase the effective downdraft design (Enander et al., 1998). Besides, in a VOC related study by Yu and Crump (1998), available evidence indicated that VOCs can cause adverse health effects to the occupants of the building or workers, and may contribute to symptoms of 'Sick Building Syndrome'. Thus, workers are exposed to the contaminants if the management takes no prevention.

The study looked into the industrial ventilation systems, which were designed and compared between experimental, analytical, and simulation, used in local car manufacturing industry. Furthermore, the study that focused on painting activities suggested that further study is needed to predict the efficiency of alternative air cleaning device from advanced materials (e.g. organic compounds). This study involved a comparison between the current

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