A STUDY OF THE EFFECTIVENESS OF LOCAL EXHAUST VENTILATION (LEV) IN TRAINING FACILITIES BUILDING USING COMPUTATIONAL FLUID DYNAMICS (CFD) APPROACH

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To my loving father and mother

My love to you will always remain and shall never change.

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ABSTRACT

The purpose of this study is to identify effectiveness of local exhaust ventilation (LEV) systems and to validate computational fluid dynamics (CFD) simulation results with actual experimental results. Three case studies had been conducted at Ventilation Laboratory in National Institute of Occupational Safety and Health (NIOSH) Bangi, Welding Laboratory and Thermal Environmental Laboratory in Universiti Tun Hussein Onn Malaysia (UTHM). LEV is a ventilation system that captures contaminants, for example dusts, mists, gases, vapours or fumes out from workstations, so that they can't be breathed by occupants. Employers allocate and install LEV in order to protect occupants' exposure to contaminants, but it doesn't work properly. To overcome this issue, Guidelines on Occupational Safety and Health for Design, Inspection, Testing and Examination of LEV system and CFD can be implemented. The guideline stated that the recommended minimum hood velocity is 100 ft/min; while the recommended velocity along ducts for vapours, gases, smoke is 1000 ft/min and 2000 ft/min is required for welding. It was found that Ventilation Laboratory in NIOSH Bangi using Control Speed of 80%, Welding Laboratory and Thermal Environmental Laboratory in UTHM met all the minimum requirements set by the guideline, where LEV systems are effective to be used. In terms of CFD modeling, upon validation, average absolute error obtained from three case studies ranges from 2.804% and 4.862%. Validity of CFD modeling is acceptable, which is less than 5% and good agreement is achieved between actual experimental results and CFD simulation results. Therefore, it can be concluded that simple CFD modeling can be performed as a tool to simulate air velocity in LEV system, which saves labour costs and time consumption when it is used during earliest stage of LEV design development prior to actual construction. The outcome of this study can be used as a benchmark or guideline for training facilities building equipped with LEV system to protect occupants' health.

ABSTRAK

Kajian ini bertujuan untuk mengenalpasti keberkesanan sistem pengudaraan ekzos setempat (LEV) dan mengesahkan keputusan perkomputeran dinamik bendalir (CFD) dengan keputusan eksperimen sebenar. Tiga kajian kes telah dijalankan di Makmal Ventilasi yang terletak di Institut Keselamatan dan Kes Pekerjaan Negara (IKKPN) Bangi; Makmal Kimpalan dan Makmal Persekitaran Terma yang terletak di Universiti Tun Hussein Onn Malaysia (UTHM). LEV ialah satu sistem ventilasi yang menangkap bahan-bahan tercemar, seperti habuk, kabus, gas-gas, wap atau asap keluar dari tempat kerja, supaya bahan-bahan tercemar ini tidak dapat disedut oleh penghuni-penghuni. Majikan-majikan memperuntukkan dan memasang LEV supaya melindungi pekerja-pekerja daripada terdedah kepada bahan-bahan tercemar, tetapi LEV tidak berfungsi dengan betul. Untuk mengatasi isu ini, garis panduan "Guidelines on Occupational Safety and Health for Design, Inspection, Testing and Examination of LEV system" dan CFD boleh dilaksanakan. Garis panduan tersebut menyatakan bahawa halaju minimum tudung yang dicadangkan ialah 100 kaki/minit; manakala halaju sepanjang saluran untuk wap, gas-gas, asap yang dicadangkan ialah 1000 kaki/minit dan 2000 kaki/min untuk gas kimpalan. Keputusan didapati bahawa Makmal Ventilasi di IKKPN Bangi yang menggunakan Halaju Kawalan sebanyak 80%, Makmal Kimpalan dan Makmal Persekitaran Terma di UTHM mencapai semua keperluan minimum yang dicadangkan oleh garis panduan tersebut, di mana sistem-sistem LEV tersebut adalah berkesan untuk digunakan. Dari segi permodelan CFD, selepas pengesahan dilakukan, didapati julat ralat purata diperolehi daripada tiga kajian kes ialah dari 2.804% sehingga 4.862%. Kesahihan permodelan CFD boleh diterima, dimana ia adalah jurang daripada 5%. Oleh itu, permodelan CFD yang mudah boleh digunakan sebagai satu alat perisian untuk

mensimulasi halaju udara dalam sistem LEV, dimana kos buruh dapat dijimatkan dan penggunaan masa dapat dikurangkan apabila ia digunakan semasa peringkat terawal pembangunan rekabentuk LEV sebelum pembinaan sebenar dilakukan. Hasil kajian ini dapat digunakan sebagai garis panduan untuk bangunan kemudahan latihan yang dilengkapi dengan sistem LEV untuk melindungi kesihatan pekerja-pekerja.

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LIST OF SYMBOLS AND ABBREVIATIONS

AWS	-	American Welding Society
CAE	-	Computer-aided Engineering
CFD	-	Computational Fluid Dynamics
CNT	-	Carbon Nanotubes
DOSH	-	Department of Occupational Safety and Health
DV	-	Dilution Ventilation
LEV	-	Local Exhaust Ventilation
NIOSH	-	National Institute for Occupational Safety and Health
PBZ	-	Personal Breathing Zone
RANS	-	Reynolds-Averaged Navier-Stokes
RCF	-	Refractory Ceramic Fibers
R&D	-	Research and Development
SP	-	Static Pressure
UTHM	-	Universiti Tun Hussein Onn Malaysia
UV	-	Ultraviolet
V	-	Velocity
VP	-	Velocity Pressure
cm	-	centimeter
cfm	-	cubic feet per minute
E_{ABS}	-	absolute error percentage
f/cc	-	fibers/cubic centimeter
ft^2	-	square feet
ft/min	-	feet per minute

k	-	Turbulent Kinetic Energy
k-Ɛ	-	Turbulence Model k-Ɛ
L/min	-	Liter per minute
L/s	-	Liters per second
m/s	-	meters per second
mm	-	millimeter
rpm	-	revolution per minute
X_{CFD}	-	CFD simulated value for variable X
X_{exp}	-	actual experiment value for variable X
2D	-	two dimensional
3D	-	three dimensional
Ɛ	-	Turbulent Dissipation
°C	-	Celsius
“wg	-	inches of water gauge
%	-	Percentage

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CHAPTER 1

INTRODUCTION

Contaminants such as dusts, mists, gases, vapour, fumes and so forth are the most common organic in which humans are exposed due to extensive use at workstations. Each year, at least thousands of workers are infected with occupational asthma and other lung diseases (Health and Safety Executive, 2010). Studies have found that exposure to such contaminants mentioned above can cause health effects (Flynn et al., 2003). Although some machines may come with a dust or fume handling device attached together, it is often necessary to meet exposure level requirements.

An efficient and capable method to this problem is the installation of local exhaust ventilation (LEV). LEV captures airborne contaminants close to the source of emission. It is generally achieved by using hood, duct, air cleaner, fan and discharge which remove contaminants before they have a chance to escape in workstations. LEV is used in order to help reducing workers' exposure to contaminants at workstations. The use of LEV resulted in an overall exposure reduction of 92% (Croteau et al., 2004). However, the reduction is highly depending on the way it is installed and used by workers (Wurzelbacher et al., 2010). The design and usage of LEV are often underappreciated (Shepherd et al., 2008). More attention should be paid to proper use and maintenance of LEV in various sectors (Meijster et al., 2007).

In order to take advantage of LEV design to ensure higher efficiency and performance of LEV, computational fluid dynamics (CFD) can be used and performed.

CFD is a design tool used to describe and simulate fluid dynamic phenomena. Simulation is used to forecast or reconstruct the behavior of an engineering product or physical situation under assumed or measured boundary conditions. Moreover, CFD can provide information of airflow distribution and air quality within a room. CFD have been increasingly used to calculate airflow velocities and temperatures in indoor environment such as food court center (Wong et al., 2006), home appliances (Lim et al., 2008), stadium (Stamou et al., 2008), hospital room (Mendez et al., 2008), and aircraft cabin (Yan et al., 2009). Despite the extensive usage of CFD application in various indoor environments, there are only a few past studies involving LEV.

1.1 Background of Problem

LEV is often used in industries and training facilities building where trainings on the work tasks are provided to occupants. Examples of places where application of LEV is used are Ventilation Laboratory in National Institute for Occupational Safety and Health (NIOSH) Bangi, Welding Laboratory and Thermal Environmental Laboratory in Universiti Tun Hussein Onn. Case studies were performed at these three places to perform actual experiments and CFD simulations.

The usage of LEV significantly reduced exposure of fiber particles with LEV than with no LEV (Mazzuckelli et al., 2004). Although the reduction showed good indication of LEV usage, however, Mazzuckelli et al. suggested that proper design of LEV is the main vital point to LEV effectiveness. Another similar study showed that application of LEV decreased total particulate concentrations by 75% (Wurzelbacher et al., 2010). In a food flavourings production facility, an average concentration reduction by up to 96% was obtained after LEV system was installed (Khanzadeh et al., 2007). Based on Khanzadeh et al. result, it demonstrated that basic exhaust hood design can help reducing occupants’ exposure during the mixture of flavouring chemicals. Another researcher stated that effectiveness of LEV was effective at reducing welder’s exposure during welding tasks if proper design and usage of exhaust hood was implemented

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