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

NG CHEE SENG

A thesis submitted in fulfillment of the requirements for the award of the Degree of Master of Mechanical Engineering

Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

December 2013

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

(Meeker et al, 2010). In another related study performed by (Cena et al., 2011), LEV design and condition contributed to the effectiveness to capture airborne particles by sanding carbon nanotubes (CNT).

Although there are studies on application of LEV by comparing with and without usage of LEV system to determine effectiveness in protecting occupants' exposure to contaminants (Mazzuckelli et al., 2004, Khanzadeh et al., 2007, Meeker et al, 2010, Cena et al., 2011), however, there is only one study involving LEV design simulation using CFD methods (Inthavong et al., 2009). Furthermore, almost all of the CFD simulation in past studies involves mechanical ventilation system, e.g. ceiling fan, wall fan, exhaust fan, etc. Nevertheless, the techniques, turbulence model and boundary conditions performed by past researchers can be used as a guide in this study. Based on literature studies involving CFD methods, a 3D numerical analysis method was performed to investigate which kitchen hood system was suitable by comparing CFD analysis results (Lim et al., 2008). Another study performed at a hawker center in Singapore, CFD techniques were carried out to determine and predict which ventilation system was suitable to be used (Wong et al., 2006). Based on Wong et al. result, installing exhaust fans could improve air temperature performance most effectively. A hospital room using CFD methodology was also performed to optimize ventilation flow pattern (Mendez et al., 2008). It showed that CFD simulation of a partition wall with a small gap near ceiling achieved the most favorable ventilation flow pattern. Another investigation of effectiveness of ventilation design in a woodturning workstation was modeled and simulated using CFD approach (Inthavong et al., 2009). Five different ventilation designs were considered and modeled to evaluate airflow patterns and wood dust removal from the woodturning station. It was found that ventilation with local and angled outlet of 45° emanated from roof provided greatest total particle clearance and low particles in breathing plane.

1.2 Objective of Study

The main objectives in this study are as follows:

a) To validate CFD simulation results with actual experimental results.
b) To identify effectiveness of LEV systems using actual experimental results.

1.3 Problem Statement of Study

This study is aimed to find answers to several questions related. First, to identify effectiveness of LEV systems, what airflow parameter should be measured? Second, what is the correct method and procedure to obtain and measure airflow parameter in LEV hood and duct? Third, which LEV systems in three case studies achieve all recommended minimum hood velocity and recommended velocity along ducts as stated in Guidelines on Occupational Safety and Health for Design, Inspection, Testing and Examination of LEV system by Department of Safety and Health (DOSH)? Fourth, before CFD simulation is carried out, what are the simulation parameters (boundary conditions) that should be determined? Fifth, which is the most suitable CFD turbulence model should be used in LEV's compartment simulation? Sixth, can CFD tool capable to give accurate predictions or low percentage of errors compare with actual experimental results in terms of airflow parameter?

1.4 Scope of Study

The scopes of this study are mainly focused on airflow distribution and characteristics in LEV's compartment. Project scopes are as follows:

a) Three case studies were conducted at Ventilation Laboratory in National Institute for Occupational Safety and Health (NIOSH) Bangi, Selangor; Welding Laboratory and Thermal Environmental Laboratory at Universiti Tun Hussein Onn Malaysia, Johor.
b) Actual experiment methods were performed by referring to Guidelines on Occupational Safety and Health for Design, Inspection, Testing and Examination of LEV system by DOSH.
c) Measurement of velocity pressure (VP) and static pressure (SP) were measured and obtained from actual experiments.
d) Simulations of airflow distribution in LEV were performed using CFD tool.
e) Contaminants such as dusts, gases, fume and so forth were not taken into consideration in this study as equipment used (GrayWolf IQ-410 Indoor Air Quality Probe) were defective.
f) Heat sources surrounding the LEV, such as fluorescent lamp, light bulb and so forth were considered to have small effects and thus were neglected in this study. As stated in Guidelines on Occupational Safety and Health for Design, Inspection, Testing and Examination of LEV system by DOSH, measurement of hood velocity and velocity pressure (VP) along ducts were obtained to identify LEV system effectiveness.
g) No occupants were involved throughout all three case studies as this study was not a comparison between LEV system on and LEV system off by measuring personal breathing zone (PBZ).

1.5 Significance of Study

This study is important because:

a) It is conducted to measure and simulate a proper study related with engineering control equipment in workstations to control exposure reduction.
b) Effectiveness of LEV system can be identified through experimental measurements using anemometer and pitot tube to obtain hood velocity, velocity pressure (VP) and static pressure (SP) as stated in Guidelines on Occupational Safety and Health for Design, Inspection, Testing and Examination of LEV system by DOSH.
c) A better prediction of airflow parameter via the use of proper CFD model greatly reduces cost and time involved as compared to actual experimental methods.
d) After simulations are validated with actual experimental results, techniques of simulation, e.g. the correct and right turbulence model, boundary conditions, etc. are known. From here, it can be a guideline or benchmark so that future LEV design simulation can be drawn and simulated accurately.

CHAPTER 2

THEORY AND LITERATURE REVIEW

2.1 Local Exhaust Ventilation (LEV)

LEV is a system that uses extract ventilation to capture contaminants from being breathed by humans in workstations. The main elements of LEV system are hood, duct, fan and discharge. Figure 2.1 shows the common elements of LEV system.

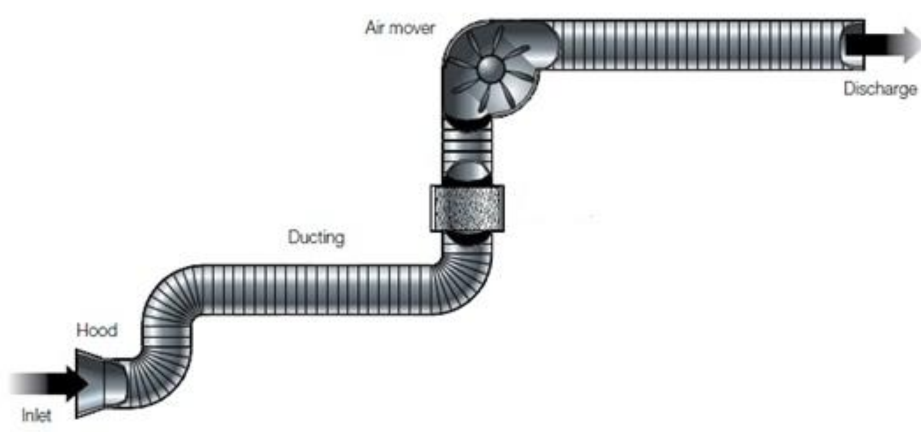

Figure 2.1: Common elements of LEV system (Guidelines on Occupational Safety and Health for Design, Inspection, Testing and Examination of LEV system, 2008)

2.1.1 Hood

Hood is used to capture contaminants generated in air stream directed towards the hood. The hood is the most important and critical element of LEV system because effectiveness of LEV depends on whether enough contaminants are retained or captured by the hood to ensure contaminants in workstations is below the acceptable limit. The recommended minimum hood velocity is 100 ft/min, based on Guidelines on Occupational Safety and Health for Design, Inspection, Testing and Examination of LEV system by DOSH. There are two types of hoods, which are enclosure hood and exterior hood. Enclosure hood is a hood that completely or partially encloses contaminant course, while exterior hood is located adjacent to contaminant source without enclosing it. Figure 2.2 and Figure 2.3 show examples of enclosure hood and exterior hood. The type of hood to be used depends on the physical characteristics of process equipment, contaminant generation mechanism and operator or equipment interface.

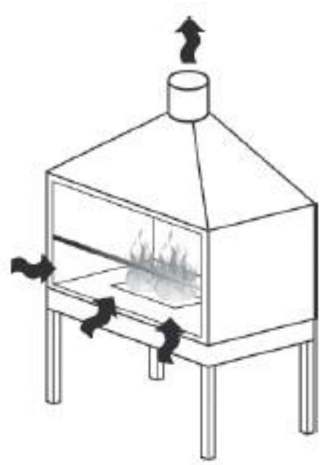

Figure 2.2: An example of enclosure hood (Guidelines on Occupational Safety and Health for Design, Inspection, Testing and Examination of LEV system, 2008)

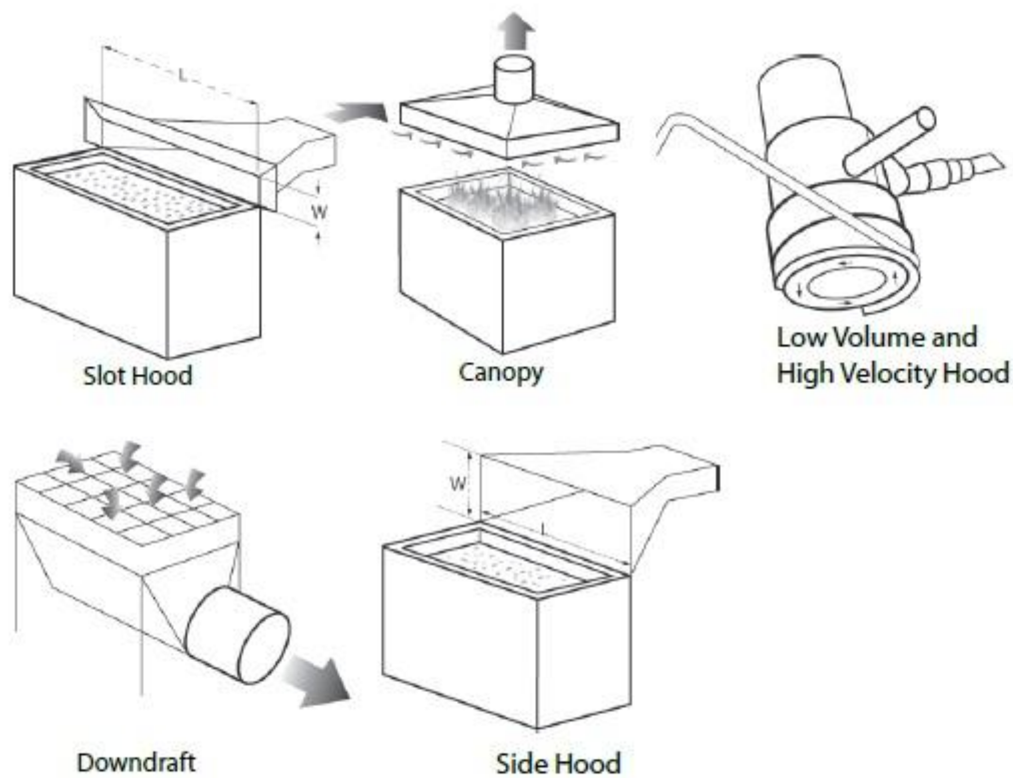

Figure 2.3: Example of exterior hoods (Guidelines on Occupational Safety and Health for Design, Inspection, Testing and Examination of LEV system, 2008)

2.1.2 Duct

Duct is a network of ducting system that connects the hood and other elements of LEV system. Duct transports contaminants and discharges to the atmosphere through discharge. The most important and critical consideration in ducting system design is to reduce losses of energy that will affect contaminated airflow in the duct. Reduction of flow losses will cause dust to settle in the duct and resulting in clogging problem and this will reduce hood suction rate. Therefore, velocity along ducts must be sufficient enough to transport contaminants out of workstations. According to Guidelines on Occupational Safety and Health for Design, Inspection, Testing and Examination of LEV system by DOSH, the recommended velocity along ducts for vapours, gases and smoke is 1000 ft/min, while 2000 ft/min is required for welding. Figure 2.4 shows an example of ducts at Welding Laboratory in UTHM.

Figure 2.4: An example of ducts at Welding Laboratory in UTHM

2.1.3 Fan

Fan provides energy to suck contaminants into hood by inducing pressure of suction in the duct. Fan converts electrical power into suction pressure and increases air velocity. Selections of fan include types of contaminants transported in LEV system, total air flow rate required by LEV system, and size of location where fan is placed. Figure 2.5 shows examples of fan used in LEV system.

Figure 2.5: Examples of fan used in LEV system (Guidelines on Occupational Safety and Health for Design, Inspection, Testing and Examination of LEV system, 2008)

2.2 Application of LEV System

In this study, application of LEV system are reviewed from past researchers' literature. The past researchers' literature can be used as a guide in this study.

2.2.1 Engineering Control of Disc Sander in a Plant

National Institute for Occupational Safety and Health (NIOSH) Ohio, United States conducted an engineering control evaluation of a company that produced vacuum-formed ceramic fiber parts. The request was made by the company itself to examine the efficacy of a LEV system they had developed to capture and collect airborne refractory ceramic fibers (RCFs) during sanding of vacuum-formed parts (Mazzuckelli et al., 2004).

The disc sander was mounted on a pedestal to allow workers to stand easily while sanding parts. The disc sander was operated at a speed of 1150 rpm using 20 inches diameter wheel. The disc sander was outfitted with a LEV system. At the lower rear of the disc sander, 6 inches flexible ventilation duct take-off was located which connected into a rigid aluminium main exhaust duct that provided exhaust outlets for other workstations within the plant, as shown in Figure 2.6.

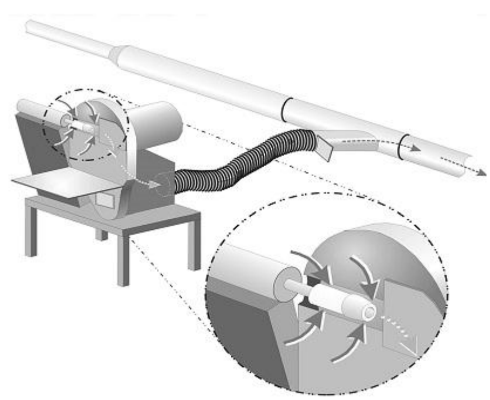

Figure 2.6: Sketch of disc sander with LEV system (Mazzuckelli et al., 2004)

Evaluation was conducted with the LEV system on (control-on) and with the system off (control-off). In order to minimize the effect of cross contamination between runs, the control-on trials were done before the control-off trials. The same exact operator was used in each trial to minimize the effect of human variation.

Results showed that with the control off trials, the personal breathing zone (PBZ) average concentration obtained was 44 fibers/cubic centimeter (f/cc) and with the control on trials, the PBZ average concentration obtained was 0.35 fibers/cubic centimeter (f/cc).

2.2.2 Engineering Control in Welding Industry

There are currently two methods to ventilate weld fume exposure for welding task in a closed space: dilution ventilation (DV) or LEV (Wurzelbacher et al., 2010). DV involves producing fresh air to flow into a closed space at very high velocity. Under certain circumstances, this air flow created by DV will produce a mixing or turbulence that forces any contaminated air out of any available openings in the space. This method is very useful when it is applied to a closed space that has only one single opening because DV does not depend on directional flow to draw contaminants away from workers. However, DV with arising turbulence can be very incompetent and ineffective in discharging contaminants from welders' PBZ. On the other hand, LEV system uses a fan with a decent capture velocity to discharge contaminated air through the fan and ducting and out of closed space. Wurzelbacher et al. conducted an evaluation to determine the effectiveness of DV and LEV in welding area.

Wurzelbacher et al. performed this study on three welders as they conducted their typical work shift in the shipyard. Each welder wore the appropriate personal protective equipment as stated by the shipyard's rules and regulations such as welding helmet, insulated overalls, gloves, ultraviolet (UV) protective face shield and personal respirator which included disposable welding mask with a particulate filter. For safety precaution sake, all welding tasks were executed in accordance with safe welding guidelines as recommended by the American Welding Society (AWS). Wurzelbacher et al. also videotaped welders' movements to monitor the relationships between welder posture or position, welding fume exposure and ventilation method usage.

Results showed that LEV method reduced total particulate concentrations (mg / m^3) by 75% over the DV method. This result could be supported by the fact that air flow rates achieved through the closed space were up to five times greater with the LEV than with the DV method. The effectiveness of both LEV and DV were also greatly contributed by individual work practices of the welders. DV is less effective because it does not remove fume efficiently from welders' PBZ due to welders' positioning effects. Worker's position (in reference to the air flow direction) and posture (in regard to the weld fume plume) significantly affect weld fume exposure. However, in closed spaces, optimal positioning of the workers with respect to ventilation flows is often not possible.

In another similar welding tasks study performed by another researcher (Wallace et al., 2002), data collected during seven sample runs showed that LEV helped to reduce weld fume exposures. The total welding fume exposures for the personal and area samples with the ventilation on were five times lower than with it off. When welders' were welding outside, windy air plays a major and significant role in how much weld fume would be transferred into workers' breathing zone. Besides that, the usage of LEV may not significantly reduce workers' exposure when welding outside due to the strong effect of wind currents.

2.2.3 Engineering Control of Exhaust Hoods of LEV System

In November 2006, NIOSH Ohio, United States researchers conducted an evaluation in a food flavourings production facility (Old et al., 2008). The company was a wholesale flavour and colour manufacturer that produces more than 1500 flavours in liquid, powder, natural and artificial forms. The company consisted of both stationary and mobile open tanks for mixing liquid flavouring ingredients. Small quantities of flavouring ingredients were poured and mixed by employees on top of a bench and then large pours were completed directly into the mixing tank.

In May 2007, a new LEV system was installed in the liquid production room. The newly developed LEV consisted of two main types of LEV hoods. The first hood was a ventilated bench top, back draft, slotted hood where it was used to control workers' exposure to chemicals during pouring activities where a majority of the workday was involved. A total of five such LEV systems were installed in the liquid compounding room.

On the other hand, the second hood was similar to a booth that allowed containment of large mobile mixing tanks where it was used to collect chemical vapours while the worker poured flavouring ingredients into large mixers. A total of three such hoods were installed in the liquid flavouring compounding room. The first and second hoods mentioned are shown in Figure 2.7 and Figure 2.8.

Figure 2.7: Small mixing ventilated exhaust hood (Old et al., 2008)

Figure 2.8: Large mixing ventilated booth-type exhaust hood (Old et al., 2008)

Evaluation was conducted quantitatively by using tracer gas to determine the capture efficiency of each hood. Tracer gas was released at a constant rate where contaminant control was desired. Then, the corresponding downstream of tracer gas concentration was measured inside exhaust duct. The tracer gas used was a mixture of 10% sulfur hexafluoride in air. The tracer gas concentration was measured using a MIRAN 205B Sapphire portable ambient air analyzer. The setup of tracer gas capture test is shown in Figure 2.9.

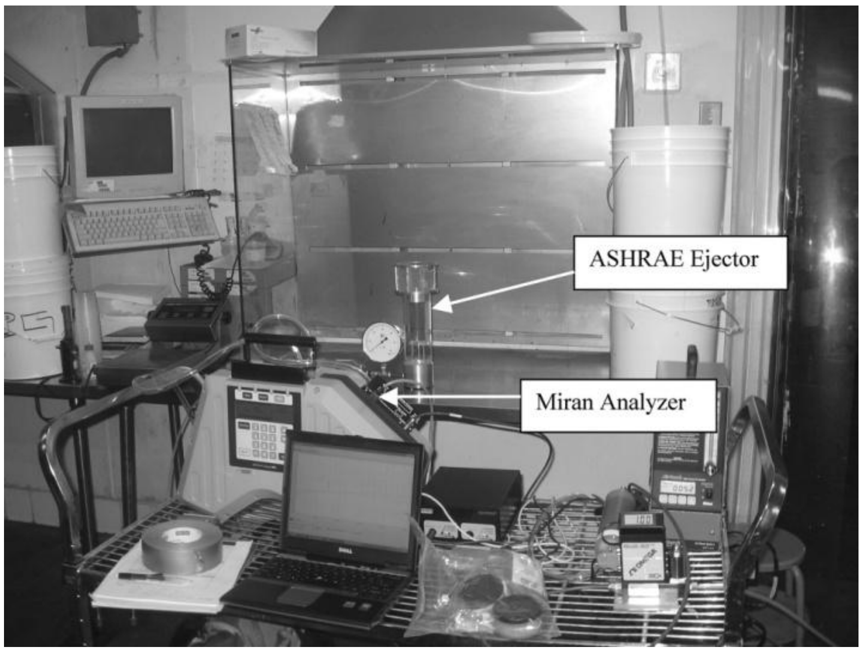

Figure 2.9: Tracer gas capture test setup (Old et al., 2008)

The quantitative collection efficiencies for each hood are shown in Table 2.1. The capture efficiencies ranged from 89% - 100% for all hoods. Several tests were performed at Hood 1 because it was believed that Hood 1 was likely to be affected by cross drafts than other hoods due to its closeness to the room opening.

Table 2.1: Quantitative collection efficiencies for each hood (Old et al., 2008)

Hood No. (Type)	Capture Efficiency (%)
Hood 1 (Bench Top)	89-97
Hood 2 (Bench Top)	98
Hood 3 (Bench Top)	100
Hood 5 (Bench Top)	98
Hood 6 (Booth Type)	97
Hood 7 (Booth Type)	96
Hood 8 (Booth Type)	98
Hood 9 (Bench Top)	98-99

A more detailed efficiency evaluation test was conducted by activating control on and control off of selected hoods. Three separate control on / control off tests were conducted to evaluate effectiveness of LEV system. Results are shown in Figure 2.10. When LEV system was activated, the average concentration was reduced by 96%, 93% and 90% in Tests 1,2 and 3 respectively.

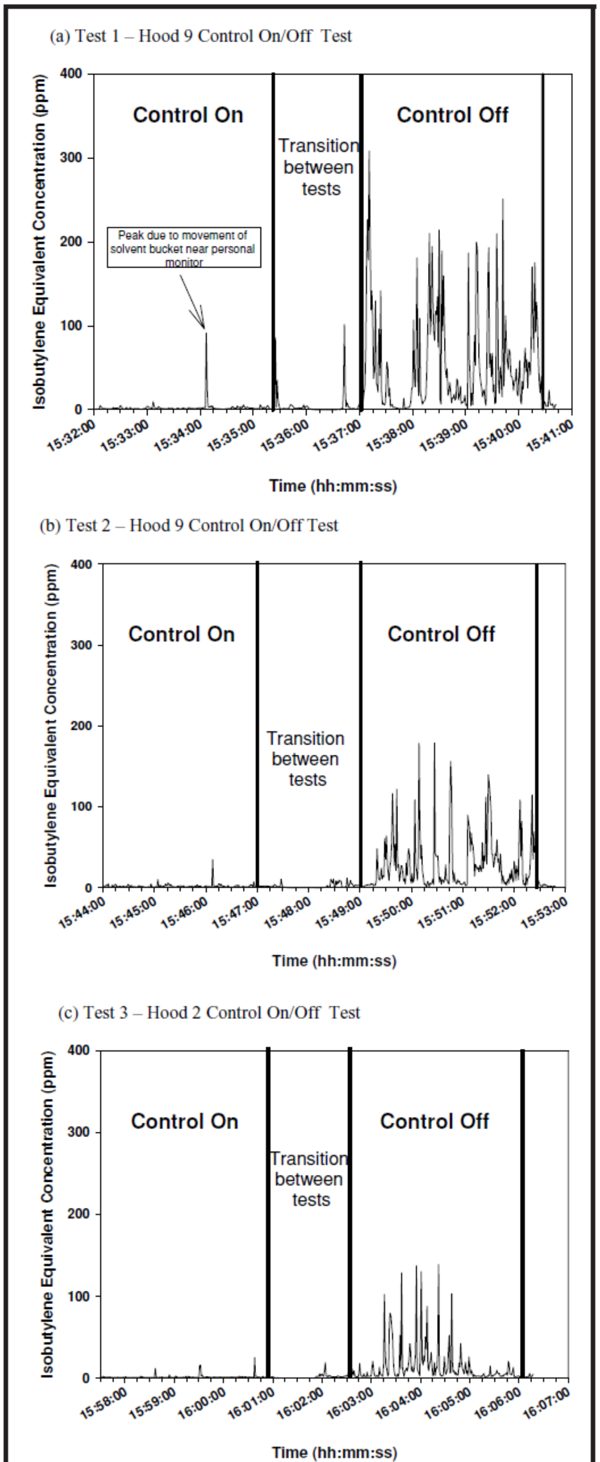

FIGURE 5. Real-time evaluation of bench top exhaust hoods — control on/off

Figure 2.10: Real-time evaluation of bench top exhaust hoods – control on / control off (Old et al., 2008)

Based on the results, it demonstrated that exhaust hoods on existing designs can greatly reduce workers' exposure during the use and mixing of flavouring chemicals. By using these exhaust hoods of LEV system, other operations such as packaging of powder flavourings and pouring of diacteyl and other high priority chemicals can be more safely performed. However, workers must be trained on proper use of LEV system and new operational safeguards must be implemented in order to get the best efficiency of LEV system. Critical and necessary training such as verifying fan operation status and making sure worker knows how to always position contaminant source between him and the exhaust hood are vital and important.

In another similar study performed by other researcher (Meeker et al, 2010), an assessment on effectiveness of LEV during welding tasks was conducted. In the study, Meeker et al. stated that the use of LEV was effective at reducing welders' exposure and should be incorporated into welding tasks on a routine basis. To take good advantage of LEV system, Meeker et al. found out that effectiveness of LEV was related to proper usage of exhaust hood. If the hood was placed below or too far away from the weld fume, the LEV's effectiveness could be greatly compromised. It was noted that LEV hoods were placed up to 2 feet (61 cm) away from the weld, therefore, welders should be taught or trained for proper usage and handling and basic guiding principles as well to maximize weld fume collection.

A three LEV tests (no LEV, custom fume hood and biosafety cabinet) conducted by (Cena et al., 2011) to evaluate the effectiveness of LEV hoods to capture airborne particles by sanding CNT nanocomposites. Results showed that release of airborne nanoparticles within a hood into the laboratory environment is highly dependent on hood design and hood condition such as height of hood being used, face velocity and so forth. In the study, Cena et al. also found out that a biological safety cabinet was more effective than a custom fume hood of LEV. Cena et al. pointed that the poor performance of the custom fume hood of LEV might be due to its lack of a front sash, its lack of rear baffles to distribute air flow and its low face velocity.

LEV, described by (Smandych et al., 1998), is much more cost efficient than with general building ventilation. Smandych et al. also stressed that the most important component of a LEV system is the hood. In order to obtain the optimal and maximum dust control, the type, size and location of LEV hood are critical and important. The shape of LEV hood affects dust plume containment, pressure losses and required air flow rate, while the location of LEV hoods affects maximum dust capture efficiency at minimum exhaust volumes.

Hood design for portable hand-held hammer drills, suggested by (Shepherd et al., 2008), needs to be examined for both technical and practical reasons. The practical issue of fitting LEV hood onto all different hammer frills currently being used must be a priority to gain acceptance in the field. In another study, (Ojima et al., 2007) stated that the effectiveness of LEV hood was not sufficient enough and workers' exposure could not be prevented completely by LEV alone.

2.2.4 Engineering Control of Wet Grinding, Ventilated Grinding and Uncontrolled Conventional Grinding in Construction Industry

A study was conducted to evaluate effectiveness of respirable silica dust and respirable suspended particulate matter reduction using grinders equipped with a continuous water flow system (wet grinder) and also grinders equipped with LEV system (LEV grinder), and after that the results would then be compared with those grinders with no local dust reduction accessories (uncontrolled conventional grinders) (Khanzadeh et al., 2007). Workers dealing with concrete products in certain construction areas have the potential to unacceptable exposure of crystalline silica dust levels. Extreme inhalation of this dangerous dust exposure has been associated to a lot of diseases such as silicosis, lung cancer, rheumatoid arthritis, scleroderma, Sjogern's syndrome, lupus, renal and so forth.

Concrete grinding activities were conducted in a laboratory of approximately 7.2 meter x 4.8 meter x 4.8 meter, which was located at the back of a general industrial building. A general ventilation system was installed in the field laboratory and could exhaust air to the outside. The general ventilation system had a volumetric suction flow rate of 40 room air exchanges per hour when activated. In the field laboratory, concrete surface grinding was performed between operator and general ventilation inlet.

Uncontrolled conventional grinding was performed using 11.4 cm and 17.5 cm size grinders. Wet grinding was performed using 17.5 cm size grinder with a water hose attached to the grinder, and the water flow was set by concrete grinding operator at 3 L/min. The reason 3 L/min water flow was used is because it was the critical water flow rate for this type of grinder, while keeping concrete surface wet during grinding and preventing water splash. LEV grinding was performed using a ventilated 15 cm size grinder. The LEV consisted of a dry type vacuum cleaner with a hose attaching the vacuum to the grinder. The LEV capacity used on the grinder was 50 L/s. Figure 2.11, Figure 2.12 and Figure 2.13 show uncontrolled conventional grinder, wet grinder and LEV grinder, respectively.

Figure 2.11: A 17.5 cm size uncontrolled conventional grinder (Khanzadeh et al., 2007)

Figure 2.12: A 17.5 cm size wet grinder with water hose attached (Khanzadeh et al., 2007)

Figure 2.13: A 15 cm LEV grinder with vacuum system (Khanzadeh et al., 2007)

Results showed that wet grinding was effective in geometric mean concentrations of respirable silica dust with a reduction of 98.2%. LEV grinding was even more effective with geometric mean concentrations of respirable silica dust with a reduction of 99.7%. Besides that, further detailed tests showed that wet grinding was effective in geometric mean concentrations of respirable suspended particulate matter with a reduction of 97.6%. LEV grinding was even more effective with geometric mean concentrations of respirable suspended particulate matter with a reduction of 99.6%.

The results of this study represent that the application of LEV grinding or wet grinding methods will reduce levels of respirable silica dust dramatically. However, Khanzadeh et al. suggested that workers should be educated and trained first on effectiveness and correct applications and usage of dust reduction accessories for concrete grinding. An appropriate respirator may also be needed to further reduce silica dust inhalation during concrete surface grinding.

In another similar research which was done by (Croteau et al., 2004), the application of LEV resulted in a mean exposure reduction of 92%. Croteau et al. found out that for many construction activities, LEV appeared to be the most effective way to reduce silica dust exposures and that the replacement of products with lower crystalline silica content might be possible for limited and special conditions, but it is not readily and applicable especially in many construction materials. Croteau et al. also suggested that water spray or wet grinder method could effectively reduce exposure levels but it is not suitable in many applications because water could result in material discoloration and expansion, building damage and waste water disposal problems. Despite the high percentage reduction when using LEV system, however, Croteau et al. recommended that workers should use respiratory protection with a protection factor of between 5 and 10 when they use hand-held grinders. When LEV system is not used, workers should use a respirator that has a protection factor greater than 10.

In a later research, (Khanzadeh et al., 2010) found out that although current engineering control could be the most promising method, however, it still could not reduce silica dust to below the American Conference of Industrial Hygienists (ACGIH) recommended silica dust exposure criteria of 0.025 mg / m^3. Therefore, Khanzadeh et al. recommended that until a very appropriate higher efficiency dust control methods are

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