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VIDEO EXPOSURE MONITORING AS A TOOL IN WORKPLACE EXPOSURE ASSESSMENT

by

Ramesh Zakir bin Shamsul

A thesis submitted in partial fulfillment
of the requirements for the Master of
Science degree in Occupational and Environmental Health
(Industrial Hygiene)
in the Graduate College of
The University of Iowa

July 2010

Thesis Supervisor: Professor Patrick T. O'Shaughnessy

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Graduate College
The University of Iowa
Iowa City, Iowa

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

Ramesh Zakir bin Shamsul

has been approved by the Examining Committee
for the thesis requirement for the Master of Science
degree in Occupational and Environmental Health
(Industrial Hygiene) at the July 2010 graduation.

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Nathan B. Fethke

To my wife, Siti Rohani Amin; my children, Asyraf, Hazrain, Nurina, and Danish; my mother, Fethome Rohani Ramthan; my aunt, Siti Zaleha Ramthan; and my late father, Shamsul Abdullah @ Dewan Baljit Singh Gill

By the declining day
Lo! Mankind is in a state of loss
Save for those who believe and done righteous deeds, and exhort one another to truth and exhort one another to endurance

The Qur'an 103: 1 – 3

ACKNOWLEDGMENTS

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Plus, my gratitude and thanks goes to the Director-General and staff of the Department of Occupational Safety and Health Malaysia, past and present, for the support given in enabling me to pursue my further studies in the United States. Not forgetting, my appreciation to the Public Services Department, Malaysia.

Last but not least, a special thank you to my wife, Siti Rohani, and my children, Asyraf, Hazrain, Nurina, and Danish, for their encouragement and love. They make the effort worthwhile.

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CHAPTER 1
LITERATURE REVIEW

One of the duties of an industrial hygienist is to evaluate the health hazards and risks in the workplace. In the use of hazardous substances, for instance, the industrial hygienist would carry out exposure monitoring on each worker to ascertain the level of his exposure. In the United States, rules in the Occupational Safety and Health Standards on the use of chemicals dictate the requirement of such exposure monitoring. The two ways of conducting exposure monitoring are through indirect and direct monitoring.

Indirect monitoring, also known as "time–integrated samples", involves drawing a certain volume of air through a collection media (filters for aerosols or activated carbon tubes for vapors) for a predetermined time period, usually a working duration of 8 hours, using a recognized protocol. The media laden with the chemical is then sent for analysis in a laboratory. The laboratory then releases a report detailing the amount of concentration of chemical sampled.

Direct monitoring, on the other hand, involves drawing air mixed with the chemical into an instrument for a certain period of time. A series of instantaneous readings are produced giving the amount of chemical concentration. Over the sampling period with modern direct-

reading instruments, an industrial hygienist could generate reports of such exposure results, detailing out the average concentration over the monitoring period, the maximum and minimum readings, and the times when such readings occur.

The result of the exposure monitoring of the chemical is then compared to established standards set for the chemical concerned. In the United States, such standards are the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL), the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLV), and the National Institute of Occupational Safety and Health (NIOSH) recommended exposure limit (REL). The industrial hygienist would then recommend steps to the management to control exposure to the chemical if the result of the monitoring exceeds the established standard for that chemical.

Using the conventional way of monitoring, either through the direct- or the indirect-reading methods, poses problems to the industrial hygienist in that he is unable to identify the work task that has contributed towards the high exposure reading. He may not be able to recall exactly what the worker was doing at the time measurements were taken. In addition, the notes taken during the whole duration of the exposure monitoring may not be complete and comprehensive so as to enable the industrial hygienist to identify the work task. The problem of pinpointing the actual task is further complicated when personal

exposure monitoring is being performed on 2 or more workers during the same period: it is impossible for the industrial hygienist to be around all the workers.

Video Exposure Monitoring

Basically, video exposure monitoring (VEM) consists of taking video recording of a worker performing a task at the same time while personal monitoring is performed using a direct-reading instrument. The video and the exposure data are then merged and synchronized and analyzed together. The industrial hygienist conducting the VEM is able to identify any high level of exposure and note the time when the excessive level happened. The corresponding task of the worker is then identified based from the video shot taken at the same time as the exposure data.

VEM has been mentioned in the literature in various forms and versions. Several researchers have used the VEM term itself in their studies (National Institute for Occupational Safety and Health [NIOSH], 1992; Gressel, Heitbrink, & Jensen, 1993; Heitbrink et al., 1993; Xu & McGlothlin, 2003). The technique is also known by other names, including real-time video radiation detection system when used to sample radiation workers (Wang, McGlothlin, & Traylor, 2002; Wang, McGlothlin, Smith, & Matthews, 2006).

Other studies have used the terms Video Exposure Assessment (Ryan, Burroughs, Taylor, & Kovein, 2003), CAPTIV (*Centrale d'Acquisition au Poste de Travail Informé par Vidéo*) (Martin, Brand, & Servais, 1999), PIMEX (Picture Mix Exposure Method) (Rosén, 1988, 1993; Hjortsberg & Karlsson, 1995), and ELV (Exposure Level Visualisation) (Gray, Unwin, Walsh, & Worsell, 1992; Walsh, Clark, Flaherty, & Gentry, 2000; Walsh, Forth, Clark, Dowker, & Thorpe, 2009).

The body of knowledge on the subject of VEM does not reveal much about the origin of this technique. The Swedish-based National Board of Occupational Safety and Health (now known as the Institute for Working Life) began exploring the use of video and computer technology in the early 1980's (Rosén & Lundström, 1987; Rosén, 2002). In the United States, NIOSH began studying the potential in using such a technique in the 90's to study and control workers exposure to airborne chemicals. A publication was written by NIOSH (1992) to describe the methodology and the equipment used. There were spin-offs of studies being done elsewhere on the use of VEM, such as by the United Kingdom's Health and Safety Laboratory (HSL) and the French-based Institut National de Recherche et de Sécurité (Martin et al., 1999).

Application

A literature review of VEM reveals its uses in studies covering the use of chemicals, radiation, ergonomics, and in the construction, mining, and agriculture sectors. In studies involving chemicals at work, such studies could be divided into the following categories:

- The efficacy of engineering control measures, including local exhaust ventilation;
- The redesigning of work stations;
- The review of work practices/methods/operations;
- The comparison of methods of production/process;
- As a training aid;
- As an enforcement tool.

VEM for Controls

The VEM technique has proved useful for assessing the effectiveness of local exhaust ventilation system and other types of engineering control measures. Rosén and Andersson (1989) reported that labor inspectors in Stockholm have used this technique in evaluating the techniques and equipment used in extracting the solvents used in screen printing process away from workers. The VEM technique was also used to evaluate a prototype ventilation system to be used to

reduce the exposure of slate splitting workers to quartz (Walsh et al., 2000). Gray and colleagues (1992) have used VEM to identify activities where workers using styrene in the construction of fiberglass reinforced plastic boats are exposed to elevated levels of that chemical. Unsatisfactory control measures were found to be a contributing factor. In a study involved with the assessment of the performance of control measures during restoration work of old furniture, it has been shown through the VEM technique that workers are exposed to excessive levels of dichloromethane, the chemical commonly used as a paint stripper, due to poor performance of the local exhaust ventilation system (Gray et al., 1992).

VEM for Work Station

The VEM technique has also been used in application involving the redesigning of work stations handling chemicals. Rosén and Lundström (1987) used VEM to investigate the exposure levels of solvents, in the form of varnishes, pigmented paints, and stains, in the surface finishing process of furniture manufacturing operation. They discovered that the drying of the newly painted doors in the open and its location relative to air movement and the workers were the contributors towards the high exposure of solvents. Walsh and colleagues (2009) studied the exposure to excessive dust during powder transfer operations in the pharmaceutical industry. In particular, VEM was used to determine the

effect of erecting a curtain barrier around the work station where the operations are carried out. The investigators were able to show the benefits of having the barrier with an hour's worth of measurements using VEM. Gressel and colleagues (1987) utilized VEM in their study on sources of dust generation during the process of weigh-out and transferring of acrylic copolymer powder in a plastics manufacturing plant. Due to bad workstation design, they were able to show the existence of pockets of eddies, laden with dust, within the breathing zone of workers.

VEM for Work Practices

The VEM technique has been utilized in the review of work practices or operations involving the use of chemicals at work. In Sweden, the labor authorities have used this technique to evaluate various methods of screen printing that could reduce excessive emission of solvents during screen printing work (Rosén & Andersson, 1989). VEM was also used in the study involving workplace exposure to hexavalent chromium among welders. Of interest, elevated levels of the chemical in welding fumes have been observed despite the use of local exhaust ventilation during welding work. Through VEM, Rosén (1993) was able to pinpoint the improper way of using the suction equipment to be a reason for such a high level. In studies conducted on the exposure to tetrachloroethylene in dry cleaning operations, Walsh and colleagues

(2000, 2002) used VEM to investigate the occurrence of elevated tetrachloroethylene levels during the loading and unloading processes. Suggestions to reduce worker exposure included increasing distillation time and having smaller batches of clothes to be dry-cleaned.

VEM was also used to investigate how the level of rubber fume emitted in the manufacturing of tires varies according to the tire size. The production of bigger tires was found to be release lesser amount of fumes, as more time is needed to release them from the autoclaves where the curing process has taken place (Walsh et al., 2000).

In studies done in furniture restoration work, Gray and colleagues (1992) discovered poor working practices to be a factor behind the ineffectiveness of the extraction system used to control levels of dichloromethane, used in the paint stripping operation. Videos and exposure measurements have been taken by Gray and colleagues (1992) during studies involving the use of styrene in the construction of fiberglass reinforced plastic boats. They were able to identify poor working practice to be a contributor towards excessive exposure levels of styrene amongst workers in three work units. Through the VEM technique, it has been revealed that the amount of contaminants being collected during personal monitoring on a worker could differ depending on the location where the personal monitoring equipment is placed and the handedness of the worker. The equipment placed on the right-hand side of a right-hander has been found to collect more contaminants

compared to the same equipment type placed on the opposite side (Gray et al., 1992).

VEM for Method Comparisons

The VEM technique was used in several studies in comparing methods of production or process involving exposure to substances. Gray and colleagues (1992) were able to show, using VEM, that worker exposure to wood dust from hand sanding operation is reduced 10 percent with the use of vacuum extraction instead of using dust collection bag as a method of control. Gressel and colleagues (1988) reported on the evaluation done using VEM on the use of vacuum enclosures and wet methods to control dust during servicing of brakes. They were able to show that the air-powered impact wrench used is a main reason for the pronounced levels of dust in the workplace. In another study, Gressel and colleagues (1988) carried out a comparison between the evaporative pattern-casting process and the green sand process in the foundry industry and the amount of emission of carbon monoxide.

VEM in Ergonomics

VEM has also found applications in the studies of ergonomics. Hjortsberg and Karlsson (1995) used this technique in their study

involving hand-arm vibrations from the use of hand-held grinders by Swedish workers. The scope of their study covered the effects of using various types of grinders on metal surfaces, as well as at idle speed.

VEM as a Training Aid

Several authors discussed the use of VEM as a health and safety training tool to employers, workers, and safety and health practitioners. In particular, videos produced as training aids could be categorized into two types; namely in ways of showing workers the right and wrong ways of performing given tasks (Gray et al., 1992; Rosén, Andersson, & Juringe, 1990; Rosén, 1993, 2002); and in improving competency training modules for workers, to reflect actual work situations and hazards (Wang et al., 2006). Likewise, videos produced from VEM have been used in encouraging active participation from workers to improve workplace conditions (Rosén & Andersson, 1989; Rosén, 2002; Walsh et al., 2009). They are shown videos taken while they are working, with the overlay of bar graphs illustrating the levels of exposure being experienced. Soon after the video shows, discussions are held where workers are encouraged to ask questions about the tasks they have performed which have contributed towards excessive levels. The workers are later invited to offer opinions and views on ways to reduce such exposure levels.

Other Uses of VEM

In addition, the VEM has been used as an inspection and enforcement tool by authorities. Gray and colleagues (1992) reported on the use of VEM by agricultural inspectors when investigating the excessive dust generated in agricultural facilities producing animal feeds. These inspectors were able to identify the causes of such high dust levels; namely, due to work related to unloading of the bulk grain and manual mixing operations of antibiotics and hormones into ground feed.

Ryan and colleagues (2003) also used VEM to investigate the regular complaints received about the air quality of the anatomy laboratory used by students practicing on formaldehyde-preserved sharks and cats. Earlier personal and area monitoring done in the laboratory yielded results below the standard set by OSHA. The technique helped them to identify three tasks where short-term exposures of students and teaching assistants went over the OSHA limits.

VEM Technology

In the past, VEM utilized analogue video cameras, video recorders, and direct-reading instruments, personal computers, and television

monitors. In the United States, both the video cameras and recorders used were in the national Television System Committee (NTSC) standard. The video systems used among VEM researchers in Europe and elsewhere were in the Phase Alternate Line (PAL) standard. In addition, the direct-reading instruments employed in VEM were either analogue or digital ones, and most came equipped with built-in data loggers. All analogue signals produced by such equipment were converted into digital ones using video mixers. Signals from the direct-reading instruments and video cameras were relayed either through wires or via telemetry (wireless). Information obtained from direct-reading instruments was either in digital or analogue form: digital data was able to be transferred to personal computers for further analysis through special software; however, analogue ones had to be transformed first into digital form by the use of converter cards and hardware operating software. Graphs produced by specially written computer programs from monitoring data were overlayed onto the video recording. The video image superimposed by graphs was then saved and stored into video cassettes or tapes. Television monitors were used for monitoring results during the videotaping sessions, or used to playback the recording made on the video cassettes to workers or employers (Gressel, 1988; NIOSH, 1992; Rosen 1987, 1989, 1993).

These days, digitalization of direct-reading instruments brings about better reliability in the transfer of data from instrument to

computer. Also, it makes the calibration of the VEM system easier (Walsh et al., 2002). Software programs have been specially written to incorporate the overlay bar graphs representing exposure level obtained by the direct-reading instruments onto video images captured by digital cameras. Compact discs (CDs) and DVDs are becoming the media of choice in the archiving and presenting the outcome of VEM to workers, employers, and health and safety professionals (Rosén et al., 2005).

Study Objectives

The objective of this thesis was to study the implementation of a low cost means of conducting VEM in workplaces with hazardous chemicals in use, by utilizing commercially-available direct reading instruments, a digital video camera, and either off-the-shelf software or freeware downloadable from the internet. It was intended that VEM done by such means would still have the same ability of conveying workplace exposure results and, at the same time, capable of pinpointing work areas where controls could be initiated to reduce excessive levels of contaminants. For the purpose of this thesis, two direct-reading instruments were evaluated for their usefulness as part of a VEM system. Although other researchers have conducted complex analysis of multiple events using, among others, multiple regression and time series analysis

(Heitbrink et al., 1993), such analysis was beyond the scope of this thesis.

CHAPTER 2

THE DEVELOPMENT AND TESTING OF A VEM SYSTEM

Introduction

One of the duties of an industrial hygienist is to evaluate the health hazards and risks in the workplace. In the use of hazardous substances, for instance, the industrial hygienist would carry out exposure monitoring on each worker to ascertain the level of his exposure. In the United States, rules in the Occupational Safety and Health Standards on the use of chemicals dictate the requirement of such exposure monitoring. The two ways of conducting exposure monitoring are through indirect and direct monitoring.

Indirect monitoring, also known as "time–integrated samples", involves drawing a certain volume of air through a collection media (filters for aerosols or activated carbon tubes for vapors) for a predetermined time period, usually a working duration of 8 hours, using a recognized protocol. The media laden with the chemical is then sent for analysis in a laboratory. The laboratory then releases a report detailing the amount of concentration of chemical sampled.

Direct monitoring, on the other hand, involves drawing air mixed with the chemical into an instrument for a certain period of time. At the

end of the sampling period, instantaneous reading is produced giving the amount of chemical concentration. With modern direct-reading instruments, an industrial hygienist could generate reports of such exposure results, detailing out the average concentration over the monitoring period, the maximum and minimum readings, and the times when such readings occur.

Using the conventional way of monitoring, either through the direct- or the indirect-reading methods, poses problems to the industrial hygienist in that he is unable to identify the work task that has contributed towards the high exposure reading. He may not be able to recall exactly what the worker was doing at the time measurements were taken. In addition, the notes taken during the whole duration of the exposure monitoring may not be complete and comprehensive so as to enable the industrial hygienist to identify the work task. The problem of pinpointing the actual task is further complicated when personal exposure monitoring is being performed on 2 or more workers during the same period: it is impossible for the industrial hygienist to be around all the workers.

The video exposure monitoring (VEM) technique could be used by the industrial hygienist to aid him during workplace evaluation. Basically, VEM consists of taking a video recording of a worker performing a task at the same time while personal monitoring is performed using a direct-reading instrument. The video and the

exposure data are then merged and synchronized and analyzed together. The industrial hygienist conducting VEM is able to identify any high level of exposure and note the time when the excessive level happened. The corresponding task of the worker is then identified based from the video image taken at the same time as the exposure data.

A literature review of VEM reveals its uses in studies covering the use of chemicals, radiation, ergonomics, and in the construction, mining, and agriculture sectors. In studies involving chemicals at work, such studies could be divided into the following categories:

- The efficacy of engineering control measures, including local exhaust ventilation;
- The redesigning of work stations;
- The review of work practices/methods/operations;
- The comparison of methods of production/process;
- As a training aid;
- As an enforcement tool.

Research on VEM

In the past, VEM utilized analogue video cameras, video recorders, and direct-reading instruments, personal computers, and television monitors. In this country, both the video cameras and recorders used were in the national Television System Committee (NTSC) standard. The video systems used among VEM researchers in Europe and elsewhere

were in the Phase Alternate Line (PAL) standard. In addition, the direct-reading instruments employed in VEM were either analogue or digital ones, and most came equipped with built-in data loggers. All analogue signals produced by such equipment were converted into digital ones using video mixers. Signals from the direct-reading instruments and video cameras were relayed either through wires or via telemetry (wireless). Information obtained from direct-reading instruments was either in digital or analogue form: digital data was able to be transferred to personal computers for further analysis through special software; however, analogue ones had to be transformed first into digital form by the use of converter cards and hardware operating software. Graphs produced by specially written computer programs from monitoring data were overlayed onto the video recording. The video image superimposed by graphs was then saved and stored into video cassettes or tapes. Television monitors were used for monitoring results during the videotaping sessions, or used to playback the recording made on the video cassettes to workers or employers (Gressel, 1988; NIOSH, 1992; Rosen 1987, 1989, 1993).

These days, digitalization of direct-reading instruments brings about better reliability in the transfer of data from instrument to computer. Also, it makes the calibration of the VEM system easier (Walsh et al., 2002). Software programs have been specially written to incorporate the overlay bar graphs representing exposure level obtained

by the direct-reading instruments onto video images captured by digital cameras; such propriety software includes those incorporating the AutoCAD concept of dragging and placing icons representing graphs and video playback button (National Instruments, 2010). Compact discs (CDs) and DVDs are becoming the media of choice in the archiving and presenting the outcome of VEM to workers, employers, and health and safety professionals (Rosén et al., 2005).

There are, however, issues in obtaining and using such novel technology. The pricing of specially written software per license (that is, the fee to be paid to install the software on each computer to be used in VEM) (National Instruments, 2010) or a complete VEM system, with or without the necessary direct-reading instruments (McGovern, 2004), may not be affordable to the small enterprise or the industrial hygienist practicing his trait in developing countries. Certain VEM software requires the user to be competent: in order to be able to use such software, however, necessitates the user to go through thick volumes of books which comes separate from the purchase of the software (National Instruments, 2010).

Objective of Study

The objective of this thesis was to study the implementation of a low cost means of conducting VEM in workplaces with hazardous chemicals in use, by utilizing commercially-available direct reading

instruments, a digital video camera, and either off-the-shelf software or freeware downloadable from the internet. It was intended that VEM done by such means would still have the same ability of conveying workplace exposure results and, at the same time, capable of pinpointing work areas where controls could be initiated to reduce excessive levels of contaminants. For the purpose of this thesis, two direct-reading instruments were evaluated for their usefulness as part of a VEM system. In particular, the VEM system was evaluated relative to its ability to achieve perfect time synchronization between the video images and the animated graph of exposure levels.

Methods

Equipment

A Personal DataRAM pDR-1200 Monitor (Thermo Fisher Scientific Inc., Waltham, MA.) was used for VEM experiments involving the measurement of an aerosol in the workplace. Weighing about 680 g, this instrument could be used either as an active or passive sampling instrument. An SKC Airchek Sampler Pump (SKC Inc., Eighty Four, PA.) was connected to this instrument to enable it to perform active sampling. Prior to use, the zeroing process was performed on the Personal DataRAM pDR-1200 Monitor in the laboratory, by attaching a zeroing filter to the inlet of the instrument. After each monitoring session, the measurement data stored within its data logger was transferred to a

computer through the RS-232 interface port. At the computer, data manipulation was done using communication software, provided as part of the instrument standard accessories. The measurement data was then saved as a .csv format, which could be opened using Microsoft Excel 2003 (Microsoft Corporation, Redmond, WA.) or higher, or any compatible spreadsheet software.

A Q-TRAK IAQ Monitor Model 8551 (TSI Inc., Shoreview, MN.) was used to test VEM when used to measure gas concentrations in the workplace. A built-in data logger came standard with this instrument. The transfer of data to a computer was done through an RS-232 interface cable. At the computer, data manipulation was possible by means of the accompanying software, supplied together with the instrument free during procurement. As the measurement data was saved in the .txt file format, further manipulation was needed before the data could be analyzed using a spreadsheet software. The data was imported into the spreadsheet software where it was separated and transformed into columns. A new file was then created.

An Elmo SUV-Cam II Micro Video Camera (Elmo Co. Ltd., Nagoya, Japan) was used to film the experiments performed for this research. Weighing about 130 g, this camera came standard with a 2.6-foot cable linking it with a 3.8-mm lens. An LCD monitor on the camera enabled the viewing of the recording done. The recording of any one session was saved as an .asf file format. The video produced did not have any timestamp stated; that is, there was no date and time of the video taken recorded on the video. The filename given for each video session was the only indication given of the date and start time of the video. Video files were able to be transferred to a computer via a USB 2.0 port.

Computer

A Dell Dimension 4500 (Dell Inc., Round Rock, TX.), powered by Pentium 4, was used in the setting up of parameters of the direct-reading instruments. With a maximum memory of 1024 MB, it came equipped with Windows XP (Microsoft Corporation, Redmond, WA.). However, any personal computer equipped with an operating system higher than Windows XP could be used.

Software

The playing back of the video recordings was made using the Windows Media Player Version 9.00.00.4508 (Microsoft Corporation, Redmond, WA.). However, as the playback was in the .asf file format, the necessary audio codec had to be downloaded on the computer initially. Editing of the video recording, however, was not possible using this viewer software. However, other software could be used for this purpose, if necessary.

For the analysis of measurement data collected by the direct-reading instruments, Microsoft Excel 2007 (Microsoft Corporation, Redmond, WA.) was used. A program was developed by Prof. O'Shaughnessy, a senior lecturer at the Department of Occupational and Environmental Health, The University of Iowa College of Public Health. A set of macro codes was written into the program using Visual Basic (Microsoft Corporation, Redmond, WA.) to produce animated graphs from the measurement data obtained.

Figure 1 shows an example of the animated graphs produced by the spreadsheet program. In the middle of this figure, lies a graph of concentration versus time. This graph charts the level of the measured contaminant spread over the monitoring period. The animated bar graph is located on the right hand side of this figure. This graph shows the current exposure level at the given moment of time. The bar of this graph moves up and down, depending to the exposure level. The height of the bar corresponds to the value shown on the left hand side of Figure 1. Before using this program, the user first sets the maximum and minimum concentration values of the axes of the two graphs, and the time period to be displayed on the x-axis of the graph. The "Start Graph" button is then clicked to start the animated graphs.

The macro code written into the spreadsheet program is shown in the Appendix. At the beginning of the program, a code was written to "slow down" the generation of graph curve and movement of the animated bar graph, by incorporating a delay or wait for subsequent set of data to be planted on the graph after the previous ones. For this thesis, the sample delay was chosen to be 1 second. The continual planting of data points was made possible by having the program running a loop sequence.

Experimental Methods

General

To achieve the objectives of this thesis, several experiments were performed. The first of such experiments involved investigating the behavior of a direct-reading instrument. Tests were done to determine how fast the instrument responded in recording measurement level when its start button was activated. Also, tests were carried out to ascertain the response time taken for such an instrument to stop recording when the instrument was switched off. The experiments were done involving two types of instruments, namely the Personal DataRAM pDR-1200 Monitor and the Q-TRAK IAQ Monitor Model 8551.

For the second part of experiments, VEM was conducted of aerosol emitted from smoke tubes and carbon dioxide gas. These experiments were done in various laboratories within the Institute for Rural and Environmental Health (IREH), located at the University of Iowa Research Park, Coralville, IA. The Personal DataRAM pDR-1200 Monitor was used to detect aerosols, while the Q-TRAK IAQ Monitor Model 8551 was utilized in the VEM of carbon dioxide gas. Results of VEM at different averaging display time of the Personal DataRAM pDR-1200 Monitor were also studied.

For the third and last part of experiments, a demonstration was conducted to show the capability of the VEM system employed in this thesis. Using the Personal DataRAM pDR-1200 Monitor, a task of cutting a block of stone was chosen for this demonstration. The stone

cutting activity was conducted outside the IREH building. Conducted in a laboratory within the IREH, the orientation of the Personal DataRAM pDR-1200 Monitor inlet relative to the location of contaminant release and its effect on VEM result was also studied. A demonstration was also conducted of the view captured by the Elmo SUV-Cam II Micro Video Camera when its probe was mounted on a hard-hat.

Instrument Behavior Procedures

Before the commencement of the experiments, the date and time of each instrument were adjusted and synchronized to the date and time of a reference computer. A Dell Dimension 4500, with Windows XP as the operating system, was used in this thesis as the reference computer. For the Personal DataRAM pDR-1200 Monitor, the synchronization was made using the pDR-COM Software Version 1.61 (Thermo Fisher Scientific Inc., Waltham, MA.). Later, the instrument was set to have an average display time and logging interval of 15 seconds and 1 second respectively. The date and time adjustment for the Q-TRAK IAQ Monitor Model 8551 was done using the TrakPro Data Analysis Software Version 3.40 (TSI Inc., Shoreview, MN.). By the same means, the time constant was set at 2 seconds (the minimum possible value), while the logging frequency was set at 1 second.

The first component of the experiments was then performed, starting with the Personal DataRAM pDR-1200 Monitor. The start/stop button of the instrument was pressed, and the computer time noted. The instrument was left to run for 60 seconds, after which the

instrument was turned off. The experiment was repeated 4 times. Data stored within the instrument was downloaded onto the reference computer, printed out and analyzed.

The same experiment was then conducted on the Q-TRAK IAQ Monitor Model 8551. The computer time when the instrument was switched on was noted, and after 60 seconds the instrument was turned off. The experiment was repeated twice. The information obtained from the 3 experiments was transferred to the reference computer, and later printed out and analyzed.

Video Recording Procedures

Prior to any experiments involving video recordings, a check was done on the internal battery of the Elmo SUV-Cam II Micro Video Camera to ensure sufficient power. Its date and clock were manually adjusted and synchronized to be the same as those of the reference computer.

The camera probe was securely mounted to the camera. The camera was then turned on. The “on/off” button on the camera was later pushed, enabling the industrial hygienist to view images captured. The camera probe was adjusted until the visual image is on the upright position. The orientation of the probe which produced the upright image position was then identified.

Once it was ready to be video recorded, the camera probe was positioned to object to be captured on video. The “on/off” button on the camera was pushed once again to activate the recording mode. Information on the date and recording and the video file name appeared

on the bottom left hand side corner of the video screen. To stop recording, the "on/off" button was pushed once again. Using the USB cable provided with the camera, the video file was transferred onto the reference computer for storage and analysis. It was then safe to switch off the camera.

Monitoring Procedures

Prior to any experiments involving a direct-reading instrument, a check was done on the internal battery of the instrument to ensure sufficient power. Its date and clock were adjusted and synchronized to be the same as those of the reference computer. For the Personal DataRAM pDR-1200 Monitor, the synchronization was made using the pDR-COM Software Version 1.61. The date and time adjustment for the Q-TRAK IAQ Monitor Model 8551 was done using the TrakPro Data Analysis Software Version 3.40.

For experiments using the Personal DataRAM pDR-1200 Monitor, zeroing process was performed by inserting the zero filter on the inlet of the instrument. Monitoring was conducted by activating the "start" button of the direct-reading instrument. After each monitoring session, the measurement data stored within the data logger of the instrument was transferred to the reference computer through the RS-232 interface port for storage and analysis.

Playback Procedures

The measurement data from direct-reading instrument was firstly transferred into the macro-enable spreadsheet program. The "time delay" on the program was chosen to be 1 second. If necessary, the "reset" button was pushed prior to the execution of the animated graphs.

The file containing the video recording of the exposure measurement made was opened using Windows Media Player. The video was played back until the scene where the direct-reading instrument was switched on appeared on view. At that moment, the "Start Graph" button on the spreadsheet program was clicked. Both video and graphs were analyzed together. If more than 2 seconds had lapsed between the time when the contaminant had been generated and the rise in the bar graph level, the synchronization process was deemed to have failed.

VEM Procedures

Before the experiments on VEM began, a check was conducted on the battery of the Elmo SUV-Cam II Micro Video Camera. Its date and clock were manually adjusted and synchronized to be the same as those of the same reference computer used earlier to synchronize the date and clock of the direct-reading instruments.

The setting of the VEM experiment involving aerosol emitted from smoke tubes was done in a fume cupboard. The SKC Aircheck Sampler Pump was connected to the Personal DataRAM pDR-1200 Monitor to enable active sampling. The Elmo SUV-Cam II Micro Video Camera was

then set up near the fume cupboard in such a way that it was able to capture the view of the inlet of the Personal DataRAM pDR-1200 Monitor. The suction fan of the fume cupboard was switched on. Video recording was then started before the pump and the Personal DataRAM pDR-1200 Monitor were switched on. Moments later, aerosol from the smoke tube was released into the direct-reading instrument. It was then repeated for a few times at regular intervals. At the conclusion of the experiment, both the pump and the direct-reading instrument were switched off first before the video recording was terminated.

For the next VEM experiment using the Q-TRAK IAQ Monitor Model 8551, a regulator was affixed to the carbon dioxide gas supply tank. The regulator was to supply carbon dioxide gas at a pressure of about 10 psi. The gas supply outlet was then located in a fume cupboard. The suction fan of the fume cupboard was switched on and left working throughout the duration of the experiment.

The probe of the Q-TRAK IAQ Monitor Model 8551 was positioned about 2 – 3 inches from the carbon dioxide gas outlet using a retort stand. Video recording was done of the direct-reading instrument. Moments later, the carbon dioxide gas supply was turned on. The gas supply was left on for a few seconds. Once the carbon dioxide level indicated on the instrument had fallen to around 500 ppm, the gas supply was turned on. Again the supply was left for a few seconds. The process of turning on and off of the gas supply was done 4 to 5 times. Afterwards, the main supply at the gas tank was turned off, and the Q-TRAK IAQ Monitor Model 8551 was switched off. A few moments later, the video recording was stopped.

Finally, the data recorded by both direct-reading instruments and the video recordings were downloaded onto the computer for storage and analysis. Finally, synchronization was carried out between the video playback and the animated graphs of measurement data taken earlier.

VEM Demonstration Procedures

Before the start of demonstration, steps were taken to ensure that the worker performing the stone cutting task had donned suitable overalls, respirators, and other necessary personal protective equipment. The Personal DataRAM pDR-1200 Monitor, with the connecting SKC Airchek Sampler Pump, was mounted on the worker's belt. The camera, handheld, was turned on first. The switching on of the direct-reading instrument was captured on camera. The worker was left to perform his stone cutting job while recording of the activity was going on. At the end of the demonstration, the Personal DataRAM pDR-1200 Monitor was switched off first, followed by the termination of video recording. Data from the direct-reading instrument data logger and video files were downloaded onto the reference computer for storage and analysis. The synchronization of both data graphs and videos followed soon after.

Procedures for Studying Effect of Direct-Reading Instrument Positioning on VEM Result

This study was conducted inside a fume cupboard of a laboratory in IREH. The date and time of both Personal DataRAM pDR-1200

Monitor and the Elmo SUV-Cam II Micro Video Camera were adjusted and synchronized to be the same as those of the reference camera. Zeroing was done to the direct-reading instrument. The source of aerosol for this study was positioned in front of the direct-reading instrument.

The video recording began first, followed by the activation of the direct-reading instrument. Aerosol was introduced 4 to 5 times into the fume cupboard every 30 seconds. At the end of this experiment, the Personal DataRAM pDR-1200 Monitor was switched off first. Then, the video recording was stopped.

Later, the source of aerosol was relocated to the side of the Personal DataRAM pDR-1200 Monitor. The whole experiment was repeated, again by switching on the video recording followed by the measurement by the direct-reading instrument. At the conclusion of this experiment, the instrument was switched off first, and later the digital camera was turned off.

Information stored in the Personal DataRAM pDR-1200 Monitor and the Elmo SUV-Cam II Micro Video Camera was transferred onto the reference computer for further analysis.

Procedures for Studying Effect of Averaging Display Time of Personal DataRAM pDR-1200 Monitor

This study was also conducted inside a fume cupboard of a laboratory in IREH. The date and time of both Personal DataRAM pDR-1200 Monitor and the Elmo SUV-Cam II Micro Video Camera were

adjusted and synchronized to be the same as those of the reference camera. Zeroing was done to the direct-reading instrument. The source of aerosol for this study was positioned in front of the direct-reading instrument.

The Personal DataRAM pDR-1200 Monitor was set to have an average display time and logging interval of 1 second and 1 second respectively. The video recording began first, followed by the activation of the direct-reading instrument. Aerosol was introduced 4 to 5 times into the fume cupboard every 30 seconds. At the end of this experiment, the Personal DataRAM pDR-1200 Monitor was switched off first. Then, the video recording was stopped. These procedures were repeated at average display time values of 5, 10, and 30 seconds.

Information from the Personal DataRAM pDR-1200 Monitor and the Elmo SUV-Cam II Micro Video Camera was transferred onto the reference computer for analysis and synchronization.

Results and Discussion

Table 1 shows the behavior of the Personal DataRAM pDR-1200 Monitor during the on/off operation. It can be shown that on each occasion when the instrument was switched on, the time of the first reading on its result printout was either 1 or 2 seconds earlier than the actual clock time when it was switched on. With this 2-second difference, it is suggested that synchronization would be able to be achieved. At the termination of recording, however, the instrument

recorded its last reading 8 to 9 seconds earlier than the actual clock time when it was switched off. As a result, only 54 data points were recorded during its 60-second run. This observation suggested that somehow the Personal DataRAM pDR-1200 Monitor stopped recording earlier that it should. It also implied that important information about workplace exposure would be lost at the last few seconds before the end of monitoring period, especially so if significant incidence that would have contributed towards the overall excessive levels of exposure happened towards the dying seconds of monitoring. It can be suggested, though, that stretched over minutes of regular patterns of release and non-release (or exposure and non-exposure) of contaminant, such a loss in data may not be significant. The result was an unusual finding, as the literature reviewed did not offer explanations on data not being captured and recorded during any point of measurement being done. More work could be done in the future to explore the reasons for such an occurrence.

Almost the same phenomenon was observed with Table 2. This table shows that the Q-TRAK IAQ Monitor Model 8551 exhibited a second faster in starting to record measurements compared to the actual clock time when it was switched on. This instrument also stopped recording a second before the actual switching off. What set the response of this instrument apart from those shown by the Personal DataRAM pDR-1200 Monitor was the ability of the Q-TRAK IAQ Monitor Model 8551 to produce 60 data sets during its 60 second run. In other words, 1 data point was recorded per second, and without any loss in data. With the 1-second difference, it is suggested that synchronization would be able to be achieved. The result implied that if the industrial hygienist plans to

start measurements using the Q-TRAK IAQ Monitor Model 8551 at, say 10:00:00, this instrument would have to be switched on at 10:00:01 in order to capture the exposure level at the actual start of measurement. However, such a difference is not significant.

Figure 2 shows the result of VEM on smoke using the Personal DataRAM pDR-1200 Monitor. The level of smoke emitted from smoke tubes exceeded 350 mg/m^3 on several occasions during the experiment. There was a delay of 1 second between the time smoke was visible in the video and the actual rise in smoke level exhibited by the bar graph. Perhaps this delay was due to human reaction in trying to match the time of the first measurement data point with its corresponding video shot and trying to start the bar graph animation together with the video. It is suggested that a way of minimizing such a delay is through the development of a program whereby a button is created that could activate both the playback of the video and the start of the animated graphs. Such a program could be developed from scratch and written using an existing programming language or through the use of freeware with the ability to “talk” to both Windows Media Player and the spreadsheet program. Again, the 1-second delay is not significant.

Changing the values of average display time for the instrument did not result in changes in the concentration versus time graph, as could be seen in Figures 3, 4, 5, and 6. Referring to these figures, a distinctive peak could be seen after 2 data points every time an aerosol was released into the environment for a given setting of average display time. Once a peak had been reached, the aerosol level dropped after 5 or 6 data points (or 5 or 6 seconds). A few concentration peaks were found to be over 350 mg/m^3 at times, given a certain value of average display time. These

results did not seem to reflect the definition of average display time. Otherwise, as the average display time got bigger, the longer it would be for a concentration peak to show in the graph relative to the time of aerosol release. It is suggested, however, that the average display time should be chosen to be as small a value as possible.

Figure 7 illustrates the VEM on carbon dioxide gas using the Q-TRAK IAQ Monitor Model 8551. The level of carbon dioxide gas detected by this instrument was between 700 to 1100 ppm each time the gas supply was turned on. There was, however, a delay of 4 or 5 seconds between the time the gas supply was fully opened and the gas level started going up. Similarly, when the supply was closed, the gas level on the bar graph only started to go down after 4 or 5 seconds. The delay could be due to several factors. First, there was a delay in trying to match the time of the first measurement data point with its corresponding video shot and trying to start the bar graph animation together with the video. The other factor was a time gap between the moment when the gas supply was fully opened and the actual release of the gas. Lastly, the overall delay could have been due to instrumentation response delay. These findings revealed that synchronization of video and graph for the Q-TRAK IAQ Monitor Model 8551 was not reached.

Figure 8 illustrates the result of the VEM demonstration performed on a worker cutting a block of stone. There were a few peaks shown on the concentration versus time graph, indicating some degree of high aerosol levels were reached. Each peak corresponded with the video scenes of white clouds of aerosol being visible, due to the stone cutting activity. There were, however, a few times when scenes of such clouds did not at all translate into elevated levels of aerosol. It is suggested that

the breezy condition during the experiment could had influenced the outcome of the VEM. The Personal DataRAM pDR-1200 Monitor was not able to detect much aerosol at occasions when the aerosol cloud was blown away from the stone cutter. As the stone cutting activity was vigorous, it is also suggested that the pDR might not had been too fast to detect the changing amount of aerosols being generated by the work task. Another factor was the positioning of the direct-reading instrument on the stone cutter and how at times it was shielded from capturing the aerosol by the way of the cutter's working posture. This experiment showed that VEM could be used in the analysis of tasks that generate high levels of contaminants, but with certain limitations.

Figures 9 and 10 show the VEM results of the Personal DataRAM pDR-1200 Monitor facing forward and sideways respectively to the source of aerosol. The two figures showed clearly the presence of aerosol eddies around the direct-reading instrument. The VEM results also showed that the instrument had registered concentration readings of aerosol for both orientations of the Personal DataRAM pDR-1200 Monitor. There was, however, no attempt, to compare and quantify which instrument orientation relative to aerosol source which had registered higher levels of aerosol in the air. This experiment showed that the positioning of contaminant source relative to the Personal DataRAM pDR-1200 Monitor inlet had not affected the instrument's ability to register the presence of contaminant.

Figure 11 illustrates the view of the fume cupboard, where experiments had taken place, viewed through the probe lenses of the Elmo SUV-Cam II Micro Video Camera. This picture was taken about 39 in. away from the fume cupboard. The width of the cupboard, measured

47 in. from side to side, was wholly covered in the picture. During the time this demonstration was done, the camera probe, affixed to a hard-hat worn, was about 72 in. from the floor level.

Conclusion

From the experiments conducted for this thesis, several conclusions are made. The VEM system in this thesis was able to be conducted by low cost means. The camera used as part of the VEM system was able to capture the view of a 47-in object from a distance of 39 in. Good synchronization was achieved between the video taken and graph of data collected by the Personal DataRAM pDR-1200 Monitor. However, synchronization was not reached between the video taken and graph of data collected by the Q-TRAK IAQ Monitor Model 8551.

Table 1 – Time Recorded on Personal DataRAM pDR-1200 Monitor Result Printout Compared to Actual Clock Time

Commencement of Recording			Termination of Recording			Data Sets
Displayed Clock Time	Time on First Print-out Reading	Difference (second)	Displayed Clock Time	Time on Last Print-out Reading	Difference (second)	Number of Data Sets
14:32:00	14:31:59	-1	14:33:00	14:32:52	-8	54
14:36:00	14:35:58	-2	14:37:00	14:36:51	-9	54
14:38:00	14:37:58	-2	14:39:00	14:38:51	-9	54
14:41:00	14:40:58	-2	14:42:00	14:41:51	-9	54
14:47:00	14:46:58	-2	14:48:00	14:47:51	-9	54

Table 2 - Time Recorded on Q-TRAK IAQ Monitor Model 8551 Result Printout Compared to Actual Clock Time

Commencement of Recording			Termination of Recording			Data Sets
Displayed Clock Time	Time on First Print-out Reading	Difference (second)	Displayed Clock Time	Time on Last Print-out Reading	Difference (second)	Number of Data Sets
14:26:00	14:25:59	-1	14:27:00	14:26:59	-1	60
14:29:00	14:28:59	-1	14:30:00	14:29:59	-1	60
14:32:00	14:31:59	-1	14:33:00	14:32:59	-1	60

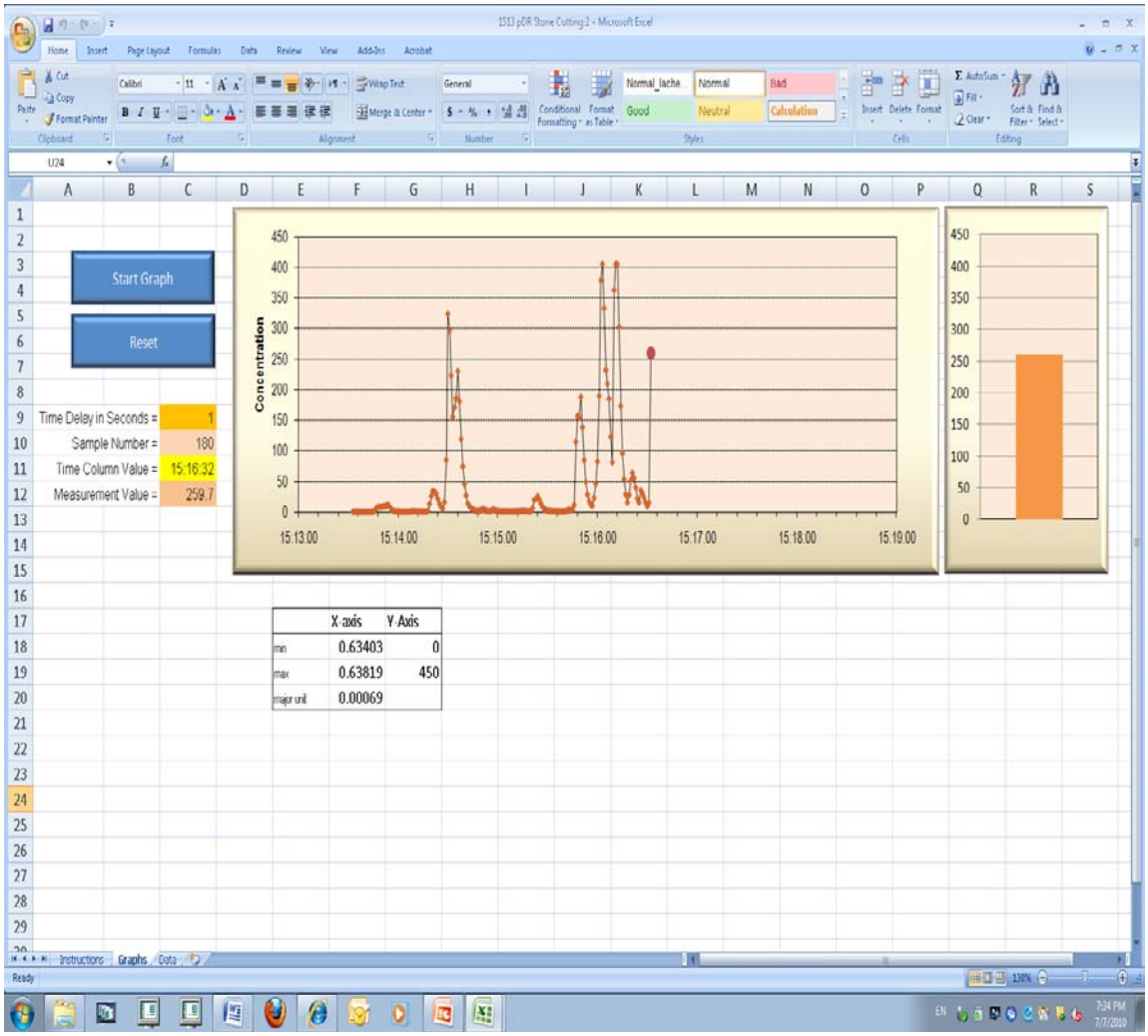

Figure 1 – Example of Typical Animated Graphs Produced by the O'Shaughnessy Spreadsheet Program

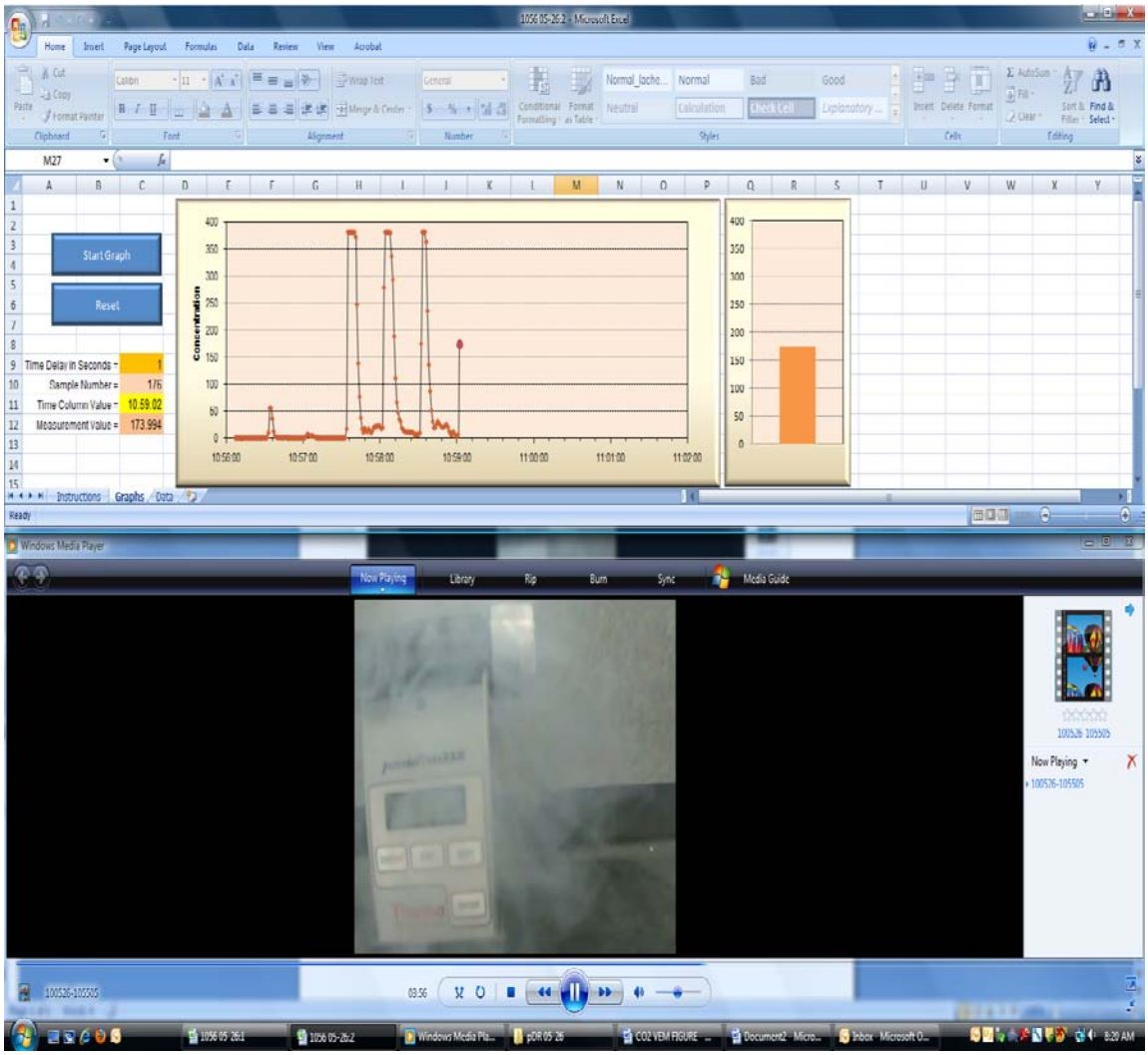

Figure 2 – Result of VEM on Aerosol Produced from Smoke Tube

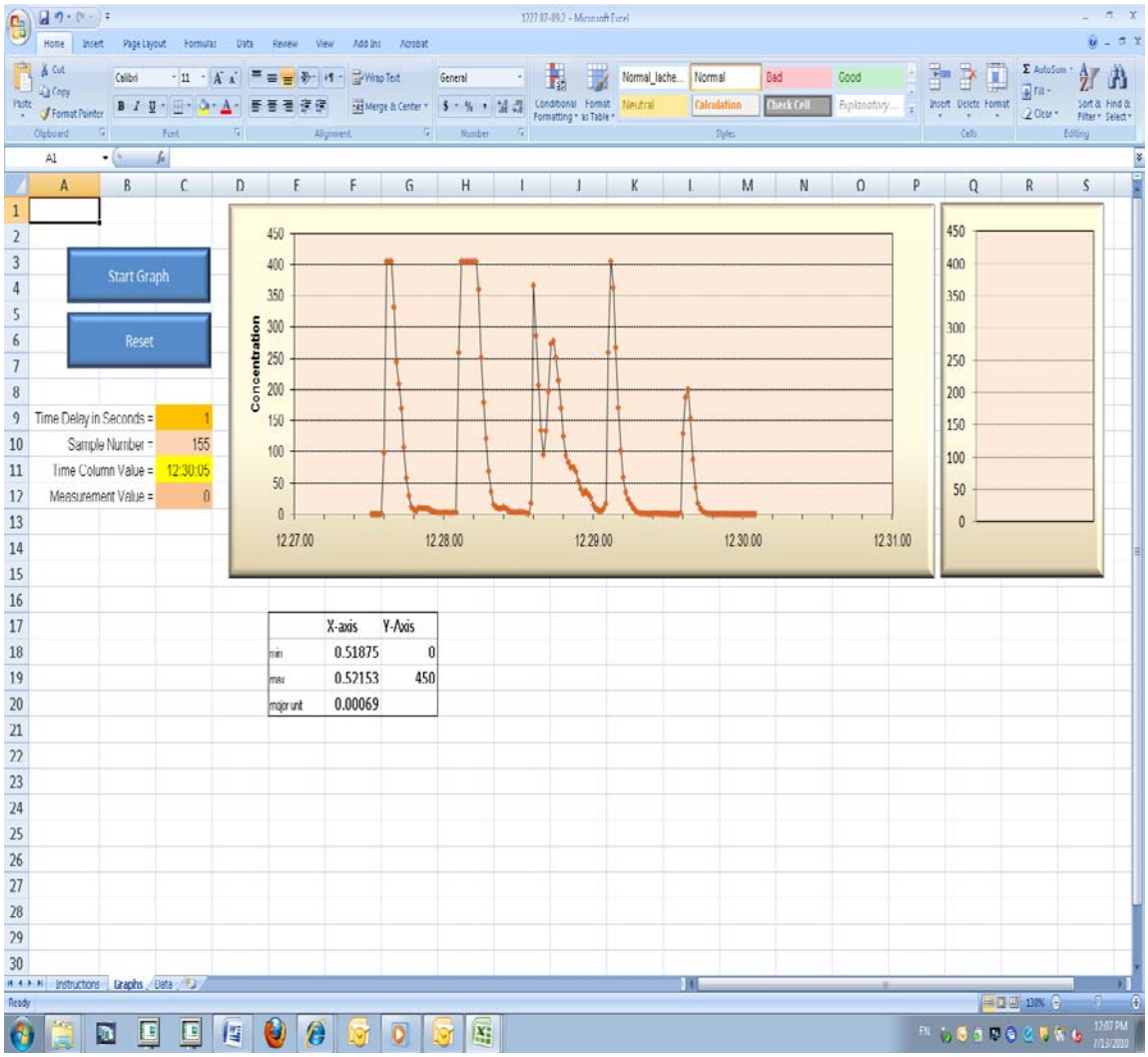

Figure 3 – The Concentration versus Time Graph of Personal DataRAM pDR-1200 Monitor when Averaging Display Time = 1 Second

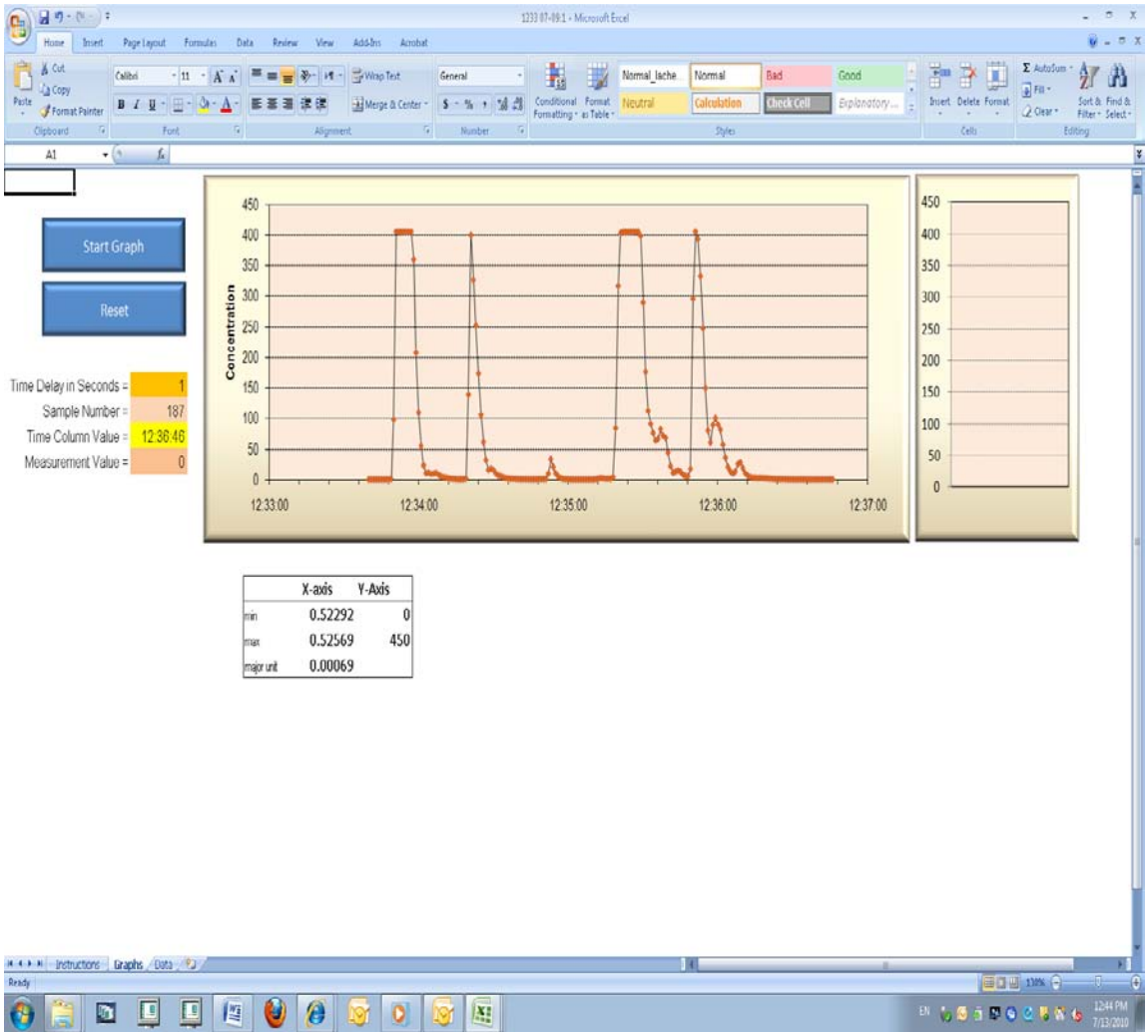

Figure 4 – The Concentration versus Time Graph of Personal DataRAM pDR-1200 Monitor when Averaging Display Time = 5 Seconds

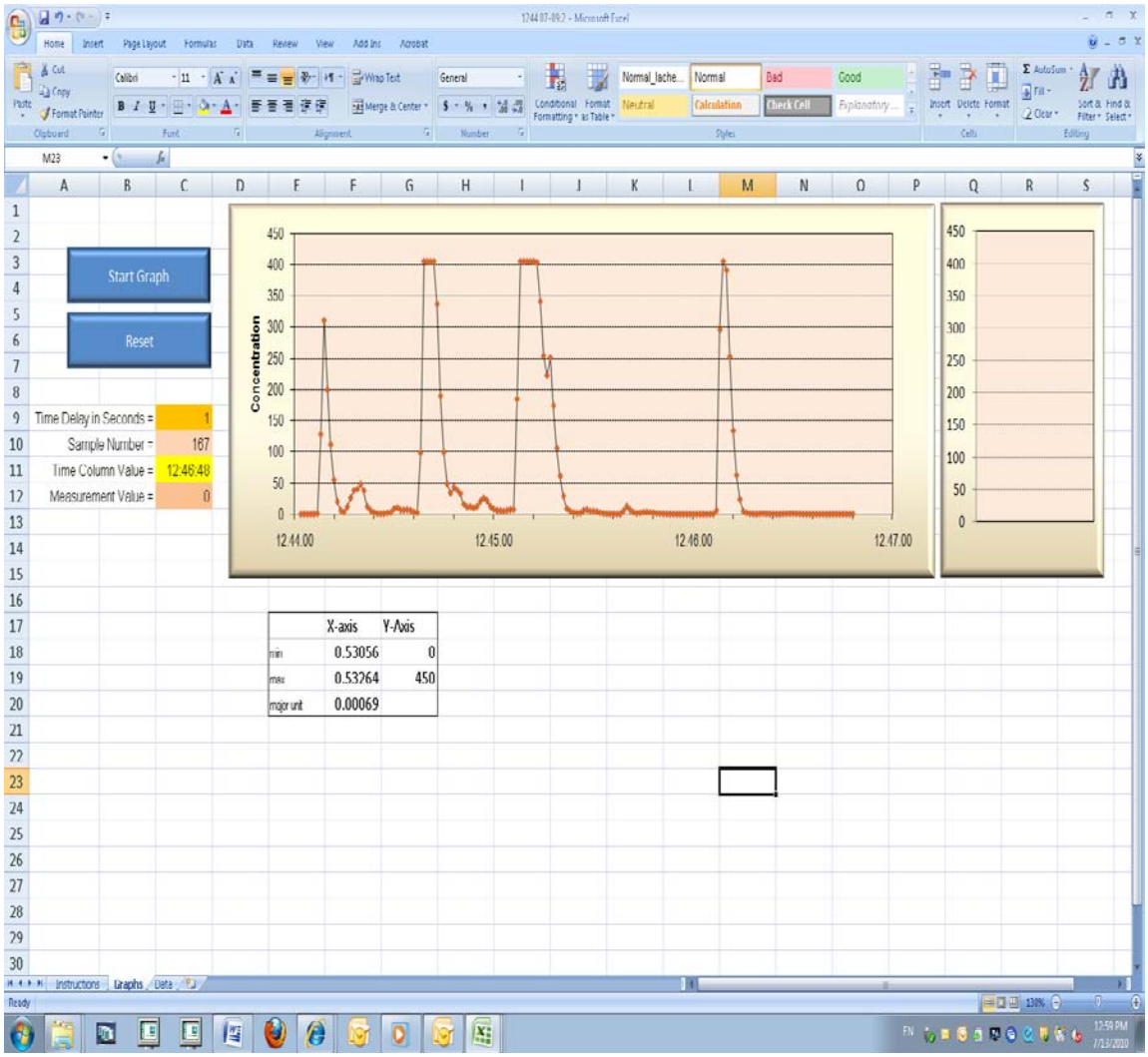

Figure 5 – The Concentration versus Time Graph of Personal DataRAM pDR-1200 Monitor when Averaging Display Time = 10 Seconds

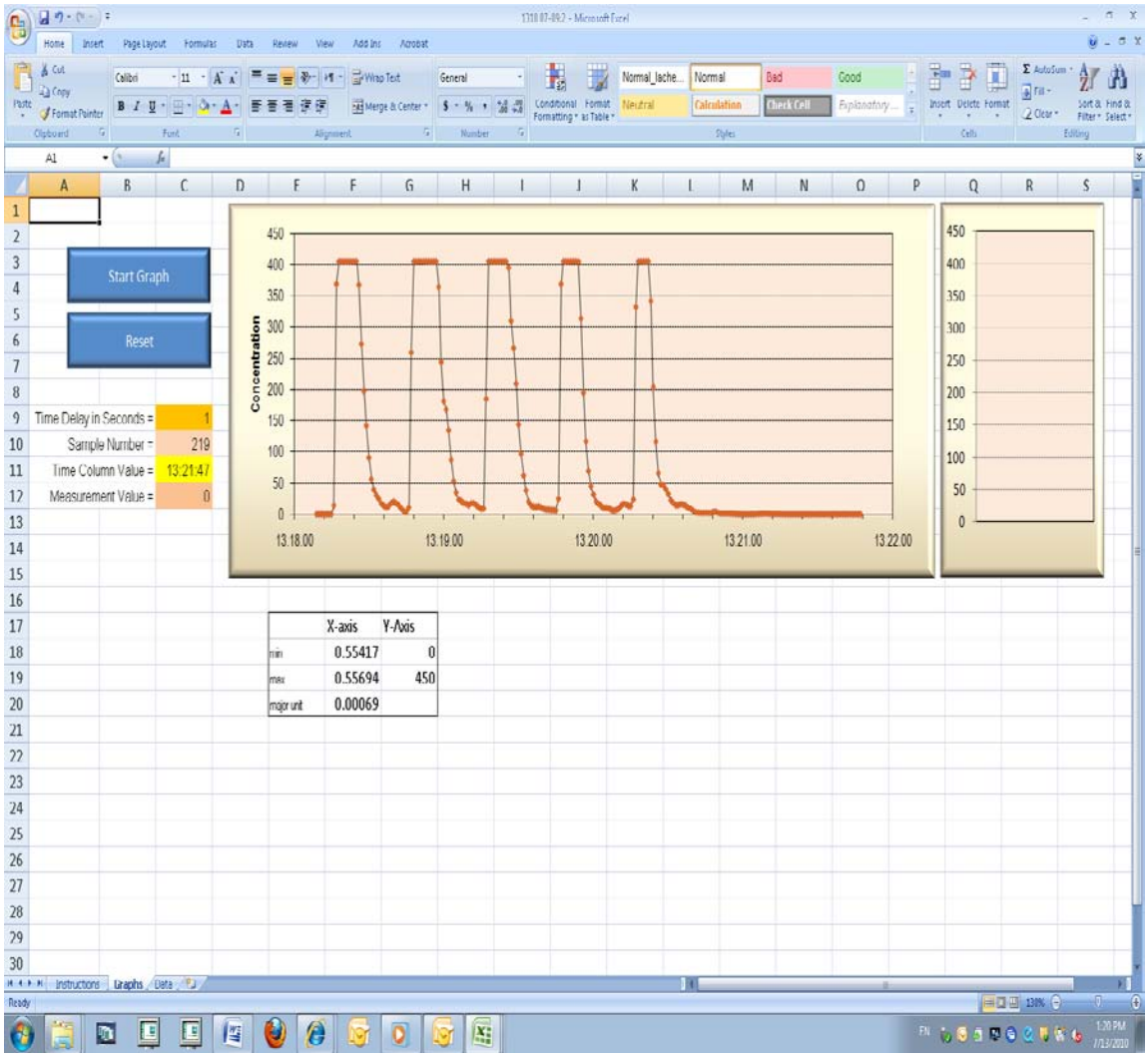

Figure 6 – The Concentration versus Time Graph of Personal DataRAM pDR-1200 Monitor when Averaging Display Time = 30 Seconds

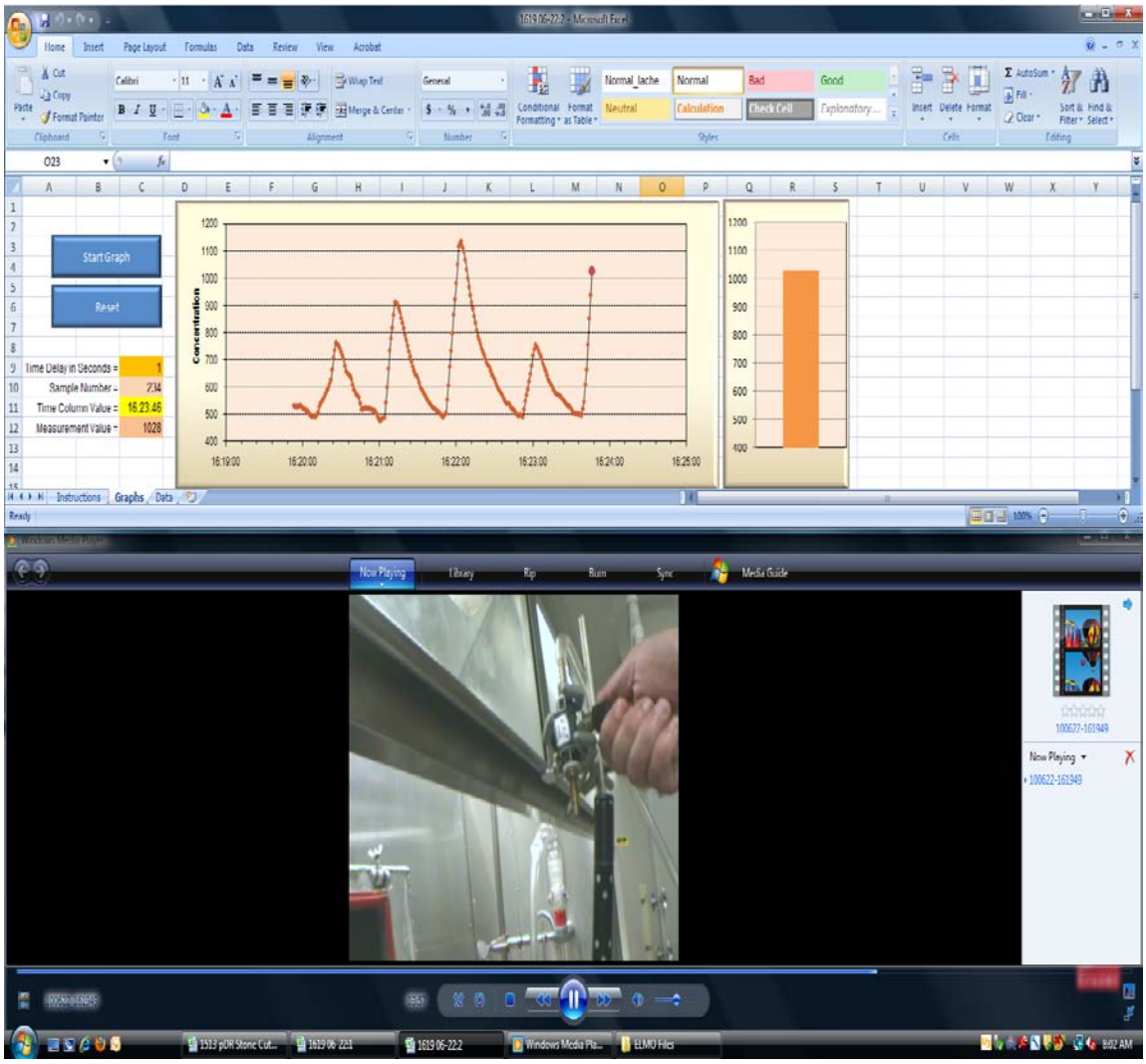

Figure 7 – Result of VEM on Carbon Dioxide Gas

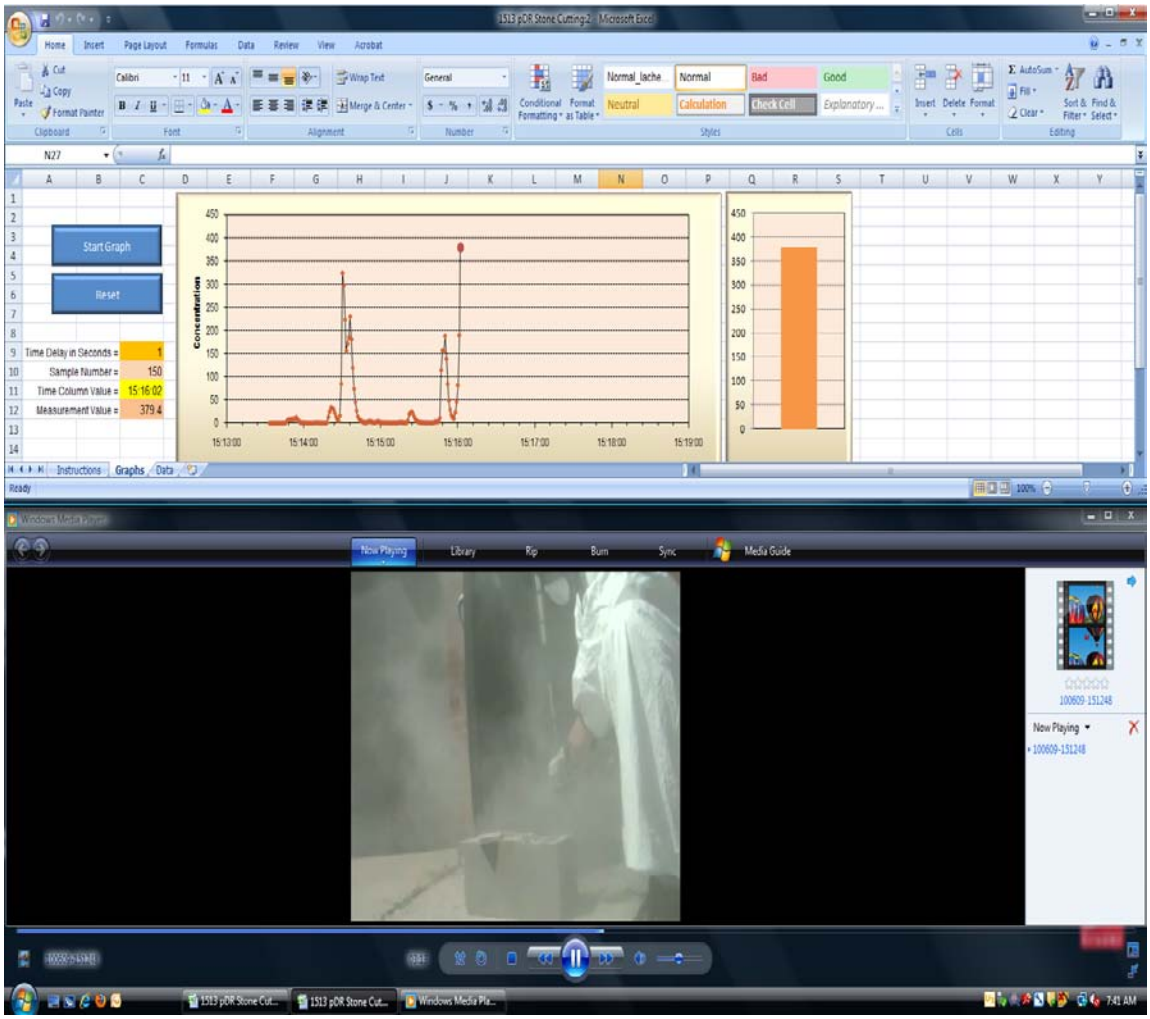

Figure 8 – Result of VEM on Stone Cutting Task

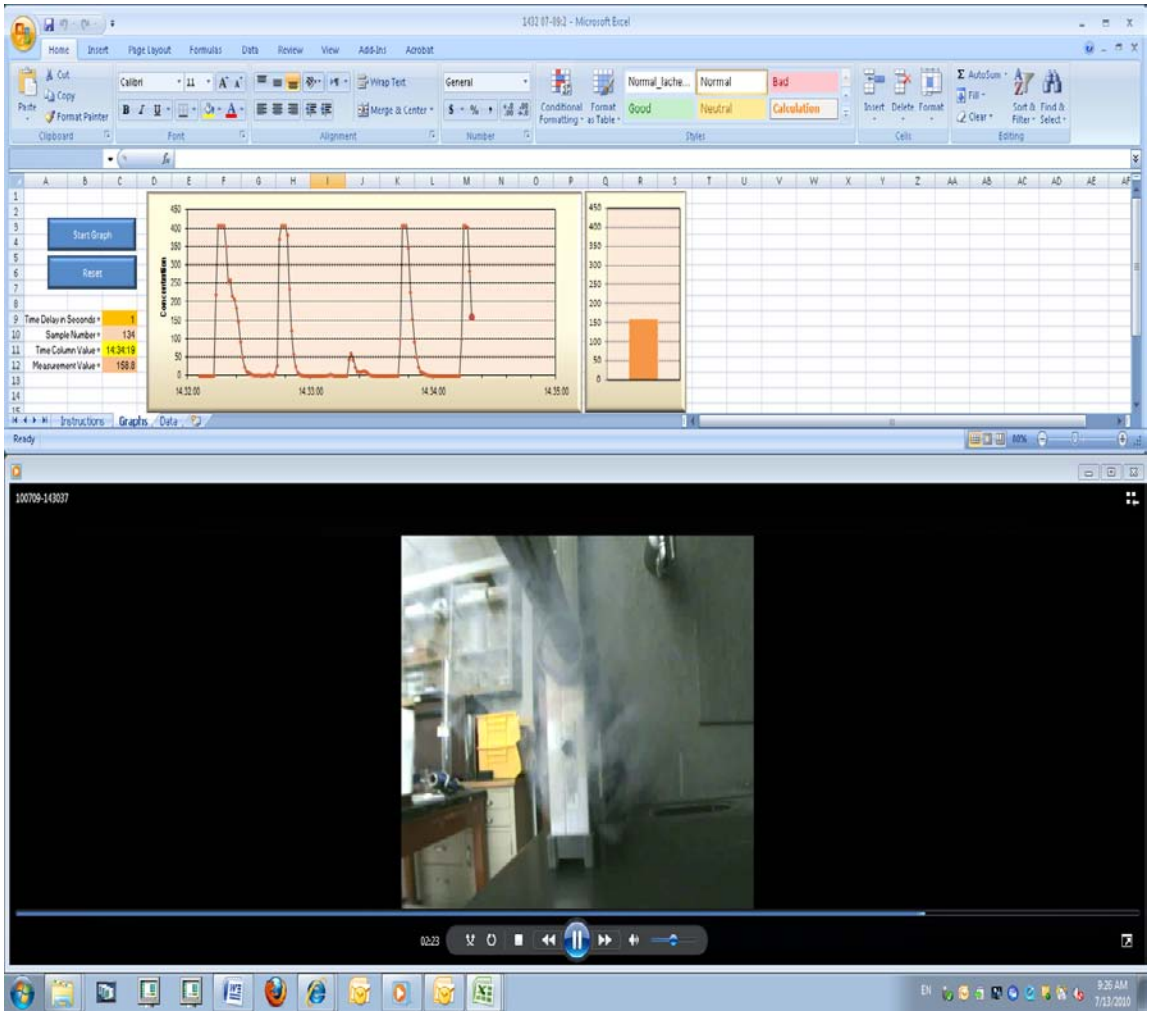

Figure 9 – VEM of Personal DataRAM pDR-1200 Monitor Facing Forward to Source of Aerosol

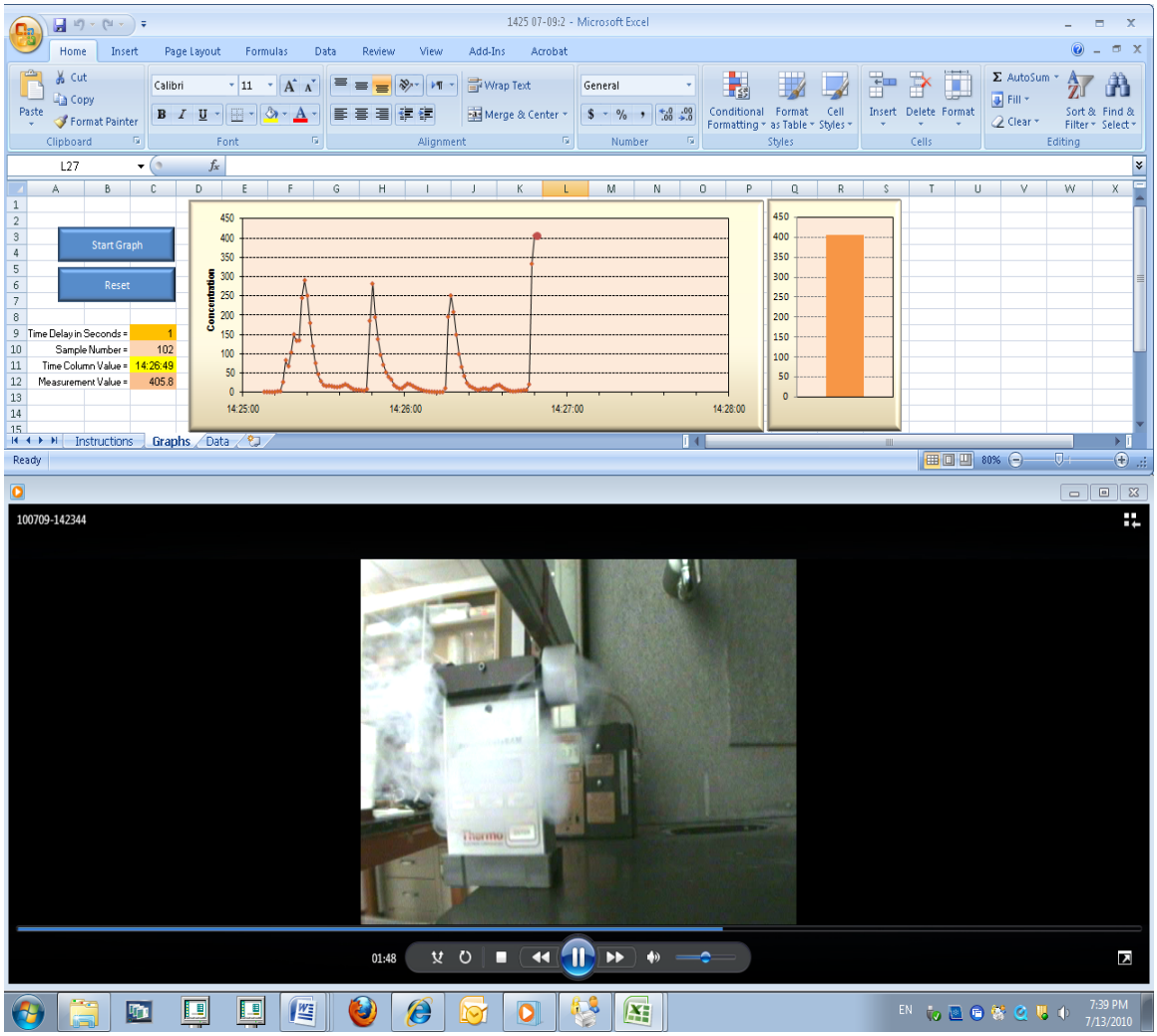

Figure 10 – VEM of Personal DataRAM pDR-1200 Monitor Facing Sideways to Source of Aerosol

Figure 11 – View of Laboratory Fume Cupboard, as Seen Through the Elmo SUV-Cam II Micro Video Camera

CHAPTER 3

USE OF VIDEO EXPOSURE MONITORING IN MALAYSIA

The VEM technique offers opportunities as a tool in the field of industrial hygiene in Malaysia.

For industrial hygienists and safety and health practitioners, the technique could be utilized during health risk assessment on hazardous chemicals use at work. Under the Malaysian Occupational Safety and Health (Use and Standards of Exposure of Chemicals Hazardous to Health) Regulations 2000 (Government of Malaysia, 2000), the employer of a workplace using hazardous chemicals must conduct an assessment before an hazardous chemical is used in his workplace and thereafter a repeat assessment is to be conducted at intervals not more than 5 years. The assessment, to be done by an assessor, is conducted either quantitatively or qualitatively, or a combination of both ways. For the repeat assessment, the assessor could rely on exposure monitoring results and health surveillance reports already conducted. By reviewing the exposure monitoring reports together with the accompanying videos, the assessor would be able in a position to offer better advice on specific work areas or processes where engineering controls could be done or improved, or where work methods could be changed.

VEM would further expand the use of direct reading instruments during workplace inspections and enforcements in Malaysia. All the 13 state branch offices and 2 divisions in the headquarters of the Department of Occupational Safety and Health Malaysia (DOSH) are equipped with various direct reading instruments to measure chemical exposures: these instruments could further be put into better use once the video visualization technique is utilized. Moreover, computers in all state branch offices and divisions in headquarters are equipped with MS Office suites.

However, there remain challenges ahead. As the government encourages the procurement of open source software, such as the Open Office.org, for new computers in place of proprietary ones, it is yet to be known whether spreadsheet programs of such office suites could be customized to be used to generate animated graphs to be combined with video recordings.

Literature review of this technique all point towards its use either towards assessing and controlling workplace or improvement of working methods through the production of training aids. The author is not aware of its widespread use in workplace inspections and enforcements, and in prosecutions against workplace employers and workers due to infringements to occupational safety and health laws. As such, studies could be done to determine whether workplace safety and health inspectorates are able to use this technique to enhance better

compliance to safety and health rules among employers and workers. In Malaysia, in particular, there are issues to be resolved on whether video visualization results obtained during workplace inspections and enforcements are recognized and admissible in the court of law (Government of Malaysia, 1950), especially so as the measurement data and video recordings made are in digital.

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APPENDIX

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Sub Graphit()
'
' Graphing over time Macro
'
' Define sample delay in seconds and the total number of
' measurement to graph
        secs = Sheets("Graphs").Range("C9")
        Datavalues = Sheets("Data").Range("J2")

' Place first values in location corresponding to x and y ranges
        Sheets("data").Cells(5, 6) = Sheets("data").Cells(5, 1)
        Sheets("data").Cells(5, 7) = Sheets("data").Cells(5, 3)

' For loop to cycle through data values
        For r = 5 To Datavalues + 3
' Code to display sample number
        Sheets("Graphs").Range("C10") = Sheets("data").Range("J1")
' Code to display Video Time
        Sheets("Graphs").Range("C11") = Sheets("data").Range("I5")
' Code to display measurement value
        Sheets("Graphs").Range("C12") = Sheets("data").Range("J5")
' The following line is used to update the bar chart
' This changes an indexer used by the VLOOKUP command to get
' the proper time and concentration values for the graph
```

```
        Sheets("data").Range("J1") = r - 3
' The following lines update the moving trendline chart
' It is given an extra value because Excel doesn't graph at the
' same instant that the loop is indexed
        Sheets("data").Cells(r + 1, 6) = Sheets("data").Cells(r + 1, 1)
        Sheets("data").Cells(r + 1, 7) = Sheets("data").Cells(r + 1, 3)
' Code to wait a certain number of seconds between point updates
        Application.Wait Now + secs / 86400
Next r

End Sub
```