Assessing Long-Term Oil Mist Exposures for Workers in a Fastener Manufacturing Industry Using the Bayesian Decision Analysis Technique

Hsin-I Hsu¹, Mei-Ru Chen², Shih-Min Wang³, Wong-Yi Chen¹, Ya-Fen Wang⁴, Li-Hao Young³, Yih-Shiaw Huang⁵, Chung Sik Yoon⁶, Perng-Jy Tsai¹,³*

¹ Department of Environmental and Occupational Health, Medical College, National Cheng Kung University, 138, Sheng-Li Road, Tainan 70428, Taiwan
² Department of Occupational Safety and Health, Chung Hwa University of Medical Technology, 89 Wenhwa 1st St., Rende Shiang, Tainan 71703, Taiwan
³ Department of Occupational Safety and Health, College of Public Health, China Medical University, 91, Hsueh-Shih Road, Taichung 40402, Taiwan
⁴ Department of Bioenvironmental Engineering, Chung Yuan Christian University, 200, Chung Pei Road, Chung-Li 320, Taiwan
⁵ The Industrial Safety and Health Association of the Republic of China, F. 6, 10, Sec. 6, Roosevelt Road, Taipei 116, Taiwan
⁶ Institute of Health and Environment, School of Public Health, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 151-742, Korea

ABSTRACT

Collecting multiple and long-term samples is necessary to accurately describe the exposure profile of a similar exposure group (SEG), but only a few industries can afford to do this because of the costs and manpower needed. In the present study, measured oil mist concentrations ($C_m$, $n = 11$) were randomly collected on eleven days during one year (serving as the likelihood distribution in Bayesian decision analysis (BDA)), and daily fastener production rates ($Pr$, $n = 250$) were used as a surrogate for predicting the yearlong oil mist exposure concentrations ($C_p$) (serving as the prior distribution in BDA). The resulting BDA posterior distributions were used to assess the long-term oil mist exposures to threading workers in a fastener manufacturing industry. The feasibility of the proposed methodology was finally examined with reference to the effects of the sample size of the $C_m$. The results show that threading workers experienced more severe thoracic and respirable oil mist exposure than exposure to the inhalable fraction. Using $Pr$ as a surrogate was adequate to explain ~92% of the variations in $C_m$. By combining $C_p$ and $C_m$, our results suggest that the BDA technique adopted in this work was effective in predicting workers’ long-term exposure. By judging the consistency of the resulting posterior exposure ratings, this study suggests that the proposed methodology could be feasible, even when the sample size of $C_m$ is set as low as 3.

Keywords: Oil mist; Exposure assessment; Bayesian decision analysis; Predictive model.

INTRODUCTION

In 2010, there were 1,233 fastener manufacturing industries employed with ~37,000 workers in Taiwan according to the governmental statistics. The annual production rate was ~1,280,000 tons/year accounting for ~14% world production. Manufacturing fasteners involves seven processes, including the wire drawing, forming, threading, cleaning, heat treatment, surface treatment, and packaging and shipping. Mineral oil-based metal working fluids (MWFs) are involved in the forming, threading, heat treatment for cooling, lubricating, and corrosion inhibition purposes, and hence might result in the exposures of workers to oil mists (Thornburg and Leith, 2000; Michalek et al., 2003). Among these workplaces, the threading was found with the highest exposure level (Chen et al., 2007).

Epidemiological and animal studies have indicated that oil mist exposures might result in the laryngeal cancer (Russi et al., 1997), asthma (Robertson et al., 1988), bronchial hyper-responsiveness (Kennedy et al., 1999), lipoid pneumonia (Cullen et al., 1981), lung cancer (Kazerouni et al., 2000), and many other respiratory illnesses (Jarvholm et al., 1982; Massin et al., 1996). These suggest that oil mist exposures to different regions of the respiratory tract might lead to different health effects (Heyder et al., 1986). Currently, an 8-h time-weighted-average occupational

*Corresponding author. Tel.: +886-4-22053366 ext. 6000; Fax: +886-4-22030418. E-mail address: pjtsai100@mail.cmu.edu.tw
exposure limit (OEL-TWA) of 5 mg/m³ for oil mist (mineral) is currently adopted by the US Occupational Safety and Health Administration (OSHA), UK Health and Safety Executive (HSE), American Conference of Governmental Industrial Hygienists (ACGIH), and Taiwan government, with the exception of The Japan Society for Occupational Health (JSOH) adopting a lower exposure limit of 3 mg/m³ (Chen et al., 2007). In 1997, National Institute for Occupational Safety and Health (NIOSH) proposed an OEL-TWA of 0.4 mg/m³ for thoracic oil mist exposures (NIOSH, 1997). Kennedy et al. found that, while workers were exposed to oil mists with aerodynamic diameter less than 9.8 μm with exposure levels greater than 0.20 mg/m³, the occurrence of cross-shift decrements in FEV₁ was statistically significant (Kennedy et al., 1989).

Currently, the comprehensive sampling strategy has been adopted by many researchers in the occupational health field (Liedel et al., 1997; Bullock and Ignacio, 2006). Therefore, collecting multiple and long-term samples are needed in order to properly describe the exposure profile for a similar exposure group (SEG). However, many research works have been conducted only for a short period of time (Shih et al., 2008; Choosong et al., 2010; Geiss et al., 2010; Wang et al., 2011), or even on a cross-sectional basis (Shih et al., 2009; Chen et al., 2010; Wang et al., 2010; Wang et al., 2010; Colbeck et al., 2011; Hwang et al., 2011) because of the cost and manpower concerns. To date, the Bayesian decision analysis (BDA) technique has been adopted by many researchers in determining the exposure profile for an SEG based on a small amount of sampling data (Ramachandran et al., 2003). In addition, the technique has also been used for different purposes, including historical exposure data reconstruction (Ramachandran, 2001; Sottas et al., 2009; Chen et al., 2012), reconfirmations of exposure factors (Sottas et al., 2009), and exposure management (Hewett et al., 2006). The use of BDA technique requires the estimation of both the prior and likelihood exposure distributions for the targeted SEG. Then, the posterior exposure distribution can be obtained to describe its exposure profile (Hewett et al., 2006). In principle, the limited measured concentrations can be used to estimate the likelihood exposure distribution. For the estimation of the prior exposure distribution, many methodologies have been used by industrial hygienists, including the expert system (Ramachandran, 2001; Wild et al., 2002; Ramachandran et al., 2003; Chen et al., 2012), numerical model (Vadali et al., 2009; Chen et al., 2012), surrogate exposure method (Hewett et al., 2006; Chen et al., 2012). Here, the use of the expert system might lead to an inaccurate estimation in the posterior distribution due to the inherent huge variations among involved experts (Ramachandran, 2001; Ramachandran et al., 2003; Wild et al., 2002). On the other hand, many environmental and workforce information (i.e., boundary conditions) are needed if the numerical model was adopted (Sottas et al., 2009). But for the surrogate method, it requires the effectiveness of the involved surrogate in predicting the exposures of interest.

In the present study, the BDA technique was adopted to determine the oil mist exposure profile for threading workers. The fastener production rate (Pr) was used as a surrogate method for predicting oil mist exposure levels (Cp) by relating the recorded Pr to the measured oil mist exposure levels (Cm). By combining Cm (i.e., the likelihood exposure distribution) with Cp (i.e., the prior exposure distribution), the posterior exposure distribution was obtained and used to describe the exposure profile of the threading workers. Finally, the feasibility of the proposed methodology was examined by reference to the effect of the sample size of Cm on the consistency of the resultant posterior distributions.

METHODS

Sampling Strategies and Sample Analyses

The whole study was conducted on threading workers whom has been recognized with the highest oil mist exposure in fastener manufacturing industries (Chen et al., 2007). To simulate insufficient personal exposure samples in the occupational hygiene practice, one threading worker was randomly selected to conduct personal sampling on one day randomly selected from each of the eleven months during one year. The IOM personal inhalable aerosol sampler (SKC Inc., Eighty-four, PA, USA) was used to measure the exposure concentration of oil mist with a sampling flow rate of ~2.0 L/min and the sampling time of ~8 h. One static sample, by mounting an IOM personal inhalable aerosol sampler on a mannequin with a rotating stand (to simulate the orientation averaged situation), was collected from the threading workplace at the end of the Chinese New Year festival to estimate the background concentration of the workplace.

In our study, we found the viscosity of the involved MWF for the threading process was much greater (183.7 cSt at 40°C). Based on a study conducted by Simpson, oil mist samples lost less than 5% of their weight while the viscosity of the involved mineral oils were greater than 18 cSt (at 40°C) (Simpson, 2003). Therefore, the gravimetric analysis was used to determine concentrations of oil mist for all collected samples by using an electronic balance (Sartorius, Model RC210P, Goettingen, Germany), since the loss of mass due to the evaporation could be negligible (Health and Safety Executive, 1997; Simpson, 2003). To reduce errors associated with moisture adsorption, all filters (before and after field samplings) were conditioned by placing them in a desiccator overnight prior to weighing.

Determining Measured Oil Mist Exposure Concentrations

In the present study, the oil mist concentration obtained using the IOM personal inhalable aerosol sampler represents the measured personal inhalable oil mist concentration (Cinh-m). In order to determine its corresponding health-related oil mist exposure concentrations, particle size segregating sampling were conducted simultaneously on the four of the eleven workers whom were selected for conducting personal inhalable aerosol samplings. A modified Marple 8-stage cascade impactor (m-Marple) with a sampling flow rate of ~2.0 L/min and the sampling time of ~8 h was used for conducting particle size segregating
samples. The sampler consists an inlet foam stage (O = 30 mm, depth = 12.5 mm, 10 pores per inch, with a 50% cut-off aerodynamic diameter (d_{50%}) of 27 µm), eight impaction stages (with d_{50%,8} of 21.3, 14.8, 9.8, 6.0, 3.5, 1.55, 0.96, and 0.52 µm, respectively), and a back-up filter. The inlet of the m-Marple has been proven with aerosol aspiration efficiencies of unity for particles with aerodynamic diameter less than 56 µm (Wu, 2002). A 34-mm PVC filter was used as the collection medium (pore size 5.0 µm, Omega Inc., Chelmsford, MA, USA).

In this study, the log-probability plot was used to estimate the mass median aerodynamic diameter (MMAD) for a particle size segregating sample and its corresponding geometric standard deviation (GSD) was estimated by d_{4%}/d_{50%} (or d_{50%}/d_{16%}). Since the m-Marple has been proven with aerosol aspiration efficiencies of unity for particles with aerodynamic diameter less than 56 µm (Wu, 2002), the resultant estimated oil mist particle size distribution can be regarded as the "true total" size distribution of mists exposed to workers. Therefore, the above data was directly used to estimate inhalable, thoracic, and respirable oil mist exposure concentrations for threading workers by using the conventions promulgated by the ACGIH, ISO and CEN (CEN, 1992; ISO, 1992; ACGIH, 1993–1994). Beside C_{inh-m}, its corresponding thoracic (C_{tho-m}) and respirable (C_{res-m}) oil mist exposure concentrations were determined based on the above estimated thoracic and respirable fractions by reference to the inhalable fraction.

**Predicting Oil Mist Exposure Concentrations and Establishing Historical Oil Mist Exposure data**

In this study, the daily fastener production rate (Pr) was also recorded during the eleven sampling days. Since the workplace is located near the center of the whole manufacturing plant, the effect of the outside wind speeds on that of inside could be negligible. Since both sampling days and workers were randomly selected, no bias effect associated with their variations on the measured oil mist concentrations could then be expected. Therefore, it is reasonable to assume that the fastener production rate could be the only main factor affecting workers’ exposure levels. A simple linear regression analysis was used to examine the relationship between the recorded Pr and measured workers’ exposure concentrations (including C_{inh-m}, C_{tho-m} and C_{res-m}). The resultant regression equations were used to further predict the long-term oil mist exposure concentrations (including C_{inh-p}, C_{tho-p}, and C_{res-p}) of workers based on the 250 Pr records collected from 250 working days during the sampling year. All these predicted oil mist exposure concentrations were served as a basis for establishing the historical exposure data bank.

**Bayesian Decision Analysis**

For Bayesian decision analyses, the measured workers’ exposure concentrations (including C_{inh-m}, C_{tho-m}, and C_{res-m}) and the predicted long-term oil mist exposure concentrations (including C_{inh-p}, C_{tho-p}, and C_{res-p}) were used respectively for establishing the likelihood and prior exposure distributions in order to estimate the posterior exposure distributions of workers. The software of the IH Data AnalystV1.0.1 (Exposure Assessment Solutions, Inc., Morgantown, West Virginia, USA) was used for conducting BDA. In this study, the exposure ratings were classified into five categories: ER1 ≤ 0.250OEL, 0.250OEL < ER2 ≤ 0.500OEL, 0.500OEL ≤ ER3 ≤ 1.00E, 1.00E < ER4 ≤ 10OEL, and ER5 > 10OEL, respectively. The values of 5 mg/m³, 0.4 mg/m³, and 0.2 mg/m³ were chosen as OELs for C_{inh}, C_{tho}, and C_{res}, respectively.

**Examining the Feasibility of the Proposed Methodology**

It is known that the sample size of predicted concentrations (i.e., n = 250) were much greater than that of measured concentrations (i.e., n = 11). If there is no change in prior distributions, and the only change was the sample size of the measured concentrations, then the variations in the resultant posterior distribution can be regarded as the effect solely arising from the change in likelihood distributions. In this study, the sample sizes ranging from 3 to 10 were randomly selected from the 11 collected C_{inh-m} to establish the corresponding likelihood exposure distributions, and the consistency in the resultant posterior distributions were used to examine the feasibility of the proposed methodology for assessing workers’ oil mist exposure profiles.

**RESULTS AND DISCUSSION**

**Measured Exposure Concentrations**

As shown in Table 1, C_{inh-m} (GM = 1.95 mg/m³, GSD = 1.5, n = 11) was lower than the OEL adopted by OSHA, ACGIH, HSE, and Taiwan government ( = 5 mg/m³) and that adopted by JSOH (= 3 mg/m³). Nevertheless, the level was much higher than that for tunnel construction workers (= 0.070–1.4 mg/m³) (Bakke et al., 2000), overall ship engine maintenance workers (= 0.24 mg/m³) (Svendsen and Hilt, 1997; Svendsen and Borresen, 1999), steel millers (= 0.27–1.6 mg/m³) (Monarca et al., 1984), and ferry engine maintenance workers (= 0.45 mg/m³) (Svendsen and Hilt, 1997), with the exception for both cable manufacturing workers (= 2.25 mg/m³) (Ronneberg and Skyberg, 1988), and car-making workers (= 2.6 mg/m³) (Ameille et al., 1995). Fig. 1(a) shows likelihood distribution for C_{inh-m}. It can be seen that the dominant probabilities were at ER3 and ER4 with values of 79.0% and 21.0%, respectively. Apparently, the above results indicate that C_{inh-m} has 100% certainty in the resultant posterior distributions were used to establish the corresponding likelihood exposure distributions, and the consistency in the resultant posterior distributions were used to examine the feasibility of the proposed methodology for assessing workers’ oil mist exposure profiles.

**Table 1.** Geometric mean oil mist concentrations (GMs) of the measured and predicted inhalable (C_{inh-m}, C_{inh-p}), thoracic (C_{tho-m}, C_{tho-p}) and respirable (C_{res-m}, C_{res-p}) fractions and their corresponding geometric standard deviations (GSDs) for the treading workers (n = 11, n = 250)

<table>
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<th>Types of exposure</th>
<th>GM</th>
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<td>C_{inh-m}</td>
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<tr>
<td>C_{tho-m}</td>
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<td>1.50</td>
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<tr>
<td>C_{res-m}</td>
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<td></td>
</tr>
<tr>
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</tr>
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</tr>
<tr>
<td>C_{res-p}</td>
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probability higher than action level (0.5 OEL), 21.0% probability exceed OEL. The above results clearly indicate that \( C_{\text{inh-m}} \) should not be ignored.

Fig. 2 shows the measured oil mist particle size distributions were in a bimodal form. The coarse mode (MMAD = 8.96 μm; GSD = 1.57) oil mists could be mainly generated by the mechanical force (i.e., the impaction of MWF inside the threading machine). We used an infrared thermometer (Raytec PM40, measurable range = −18°C–870°C) to measure the temperature at the inner surface of the threading gear, and found that the temperature was ~70°C. Therefore, the fine mode oil mists (MMAD = 0.50 μm; GSD = 1.65) could be formed via the evaporation and condensation of MWFs during the manufacturing process. The above results were quite consistent with that found in a clutch manufacturing plant (i.e., MMADs for the fine and coarse modes were 0.1–1.0 μm and > 8 μm, respectively) (Chan et al., 1990), and that found by Chen et al. in a threading workplace (i.e., MMADs of 0.501 μm and 9.20 μm for the fine and coarse mode, respectively) (Chen et al., 2007).

In this study, the obtained oil mist particle size distribution data was used to determine the fractions of \( C_{\text{inh}}, C_{\text{tho}} \) and \( C_{\text{res}} \) by using the conventions promulgated by the ACGIH, ISO and CEN (CEN, 1992; ISO, 1992; ACGIH, 1993–1994). Results show the fractions of \( C_{\text{inh}}, C_{\text{tho}} \) and \( C_{\text{res}} \) were 85.7%, 70.2% and 62.4%, respectively. The above fractions were used to further convert \( C_{\text{inh-m}} \) to \( C_{\text{tho-m}} \) and \( C_{\text{res-m}} \), respectively. For \( C_{\text{tho-m}} \), its concentration (GM = 1.52 mg/m³, GSD = 1.5, n = 11; Table 1) was higher than the level proposed by the NIOSH (0.4 mg/m³). Fig. 1(b) shows the likelihood distribution for \( C_{\text{tho-m}} \). It can be seen that its probabilities for ER4 and ER5 were 83.8% and 16.2%, respectively. For \( C_{\text{res-m}} \), its concentration (GM = 1.29 mg/m³, GSD = 1.5, n = 11; Table 1) was even much higher than the level known for causing “increased risk of pulmonary injury” (= 0.2 mg/m³) (Kennedy et al., 1989). Therefore, it is not surprising to see that its probabilities for ER4 and ER5 were 20.5% and 79.5%, respectively (Fig. 1(c)). The above results apparently suggest exposure oil mist concentrations in both thoracic and respirable fractions for threading workers were much more severe than the exposure concentrations of the inhalable fraction. However, it should be noted that the above inference was made simply based on the limited data collected during the sampling year. It might be inadequate to describe workers’ long-term oil mist exposure scenarios.

**Predicted Exposure Concentrations**

Fig. 3 shows the establishment of predicting models for predicting oil mist exposure concentrations of \( C_{\text{inh-p}}, C_{\text{tho-p}} \) and \( C_{\text{res-p}} \) by relating \( Pr \) to its corresponding \( C_{\text{inh-m}}, C_{\text{tho-m}} \) and \( C_{\text{res-m}} \). The resultant predicting models can be described as follows:

\[
\frac{dc}{d\log_{10}(dae)}, \text{mg/m}^3, \text{μm}
\]

\[
\begin{array}{ccccccc}
\hline
\text{dae,μm} & 0.13 & 0.52 & 0.98 & 3.5 & 6 & 9.8 & 14.8 & 21.3 & 27 \\
\text{dc/dlog}_{10}(dae), \text{mg/m}^3, \text{μm} & \text{I} & \text{I} & \text{I} & \text{I} & \text{I} & \text{I} & \text{I} & \text{I} & \text{I} \\
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\end{array}
\]

Fig. 2. Measured particle size distribution of oil mists exposed to the selected threading workers respirable (\( C_{\text{res}} \)) oil mist concentrations.
Fig. 3. Relationship between the predicted oil mist exposure concentrations, (a) $C_{inh-p}$, (b) $C_{tho-p}$ and (c) $C_{res-p}$ and their corresponding fastener production rates ($Pr$).

(a) $C_{inh-p}$

$C_{inh-p} = 1.42 Pr + 0.267$  
$R^2 = 0.921; n = 12$  

(b) $C_{tho-p}$

$C_{tho-p} = 0.99 Pr + 0.187$  
$R^2 = 0.92; n = 12$  

(c) $C_{res-p}$

$C_{res-p} = 0.94 Pr + 0.177$  
$R^2 = 0.921; n = 12$

The obtained three positive regression coefficients were statistically significant ($p = 0.0001$) indicating that the three oil mist exposure concentrations increased as $Pr$ increased. The resultant $R^2$ was 0.921 which further confirm the feasibility of our previous assumption (i.e., $Pr$ was the only main factor affecting oil mist exposure concentrations). In addition, the intercept for the $C_{inh-p}$ model was 0.267 mg/m$^3$ which was quite comparable to the measured background value (i.e., the sample collected during the Chinese New Year Festival; $= 0.200$ mg/m$^3$). The above result further
confirms that the resultant predicting model could effectively predict the exposures of threading workers. According to our field observation, the working environment of the studied threading process was considered quite stable. Therefore, variations of workers’ exposures due to environmental fluctuations were considered to be negligible. However, it should be noted that part of year-round daily Pr records (range = 0.087–4.44 ton/d; n = 250) fell outside the range of Pr (range = 0.0–2.70 ton/d; n = 12) used to establish the three predicting models. Therefore, extrapolations were used in predicting the corresponding oil mist exposure concentrations.

Table 1 also shows the three predicted exposure concentrations of Cinh-p, Ctho-p, and Cres-p. For Cinh-p (GM = 1.99 mg/m³, GSD = 1.62, n = 250), the resultant prior distribution suggests that main probabilities fell to ER3 and ER4 (= 84.3% and 15.4%, respectively; Fig. 4(a)). The similar pattern can also be seen in the likelihood distribution resultant from Cinh-p (i.e., probabilities for ER3 and ER4 were 79.0% and 21.0%, respectively; Fig. 1(a)). For Ctho-p (GM = 1.40 mg/m³, GSD = 1.62, n = 250; Table 1), the dominant probabilities in the prior distribution were at ER4 and ER5 (= 90.0% and 9.7%, respectively; Fig. 4(b)), which can also be seen in the likelihood distribution (= 83.8% and 16.2%, respectively; Fig. 1(b)). For Cres-p (GM = 1.32 mg/m³, GSD = 1.62, n = 250; Table 1), we found that the resultant prior distribution (Fig. 4(c)) and likelihood distribution (Fig. 1(c)) shared the same trend with the highest two decision probabilities also fell to ER4 and ER5 (21.6% and 78.1% for prior, and 20.5% and 79.5% for likelihood, respectively). Here, it should be noted that the inference made by the prior distributions were based on the predicted exposures using the predicting models and Pr records. Obviously, directly using these inferences to assess workers’ exposure profiles could be inappropriate. On the other hand, the consistency in both prior and likelihood distributions suggest the resultant posterior would be more feasible to assess workers’ long-term oil mist exposures (Sottas et al., 2009).

### Assessing the Long-term Oil Mist Exposure Profile for Threading Workers

Fig. 5 shows the posterior distributions for assessing threading workers’ long-term oil mist exposure profiles of Cinh, Ctho, and Cres, respectively. For Cinh (Fig. 5(a)), the probabilities respectively for ER3 and ER4 were 95.4% and 4.6% indicating that Cinh should not be ignored since 95.4% of Cinh could be greater than action level(0.5 OEL). For Ctho (Fig. 5(b)), the resultant posterior probabilities at ER4 and ER5 were 98.0% and 2.0%, respectively. For Cres (Fig. 5(c)), the resultant posterior probabilities at ER4 and ER5 were 6.6% and 93.4%, respectively. The above two results suggest threading workers were indeed exposed to oil mists more severely in both the thoracic and respirable fractions than that of the inhalable fraction. Therefore, appropriate control measures should be taken by the fastener manufacturing industry, particularly for the abatement of both the thoracic and respirable oil mist fractions (such as the installation of a local exhaust ventilation system for each threading machine).

![Fig. 4. The established prior distributions for the predicted (a) inhalable (Cinh-p), (b) thoracic (Ctho-p) and (c) respirable (Cres-p) oil mist concentrations.](image)

![Fig. 5. The resultant posterior distributions for the (a) inhalable (Cinh), (b) thoracic (Ctho) and (c) respirable (Cres) oil mist concentrations.](image)
Effects of the Measured Sample Size on Oil Mist Exposure Assessment

To understand the effect of the sample size of measured exposures on the posterior distributions, 3 to 10 personal sampling results were randomly selected from the 11 measured results to re-establish the likelihood exposure distributions. In the present study, only the results obtained from C_{inh-m} were presented for the illustration purpose.

It is known that the sample size of predicted concentrations (i.e., n = 250) were much greater than that of measured concentrations (i.e., n = 11). Therefore if 3 to 10 measured concentrations were randomly selected from the 11 measured results, then the variations in the resultant posterior distribution can be regarded as the effect solely arising from the intrinsic differences in the selected sample size of measured oil mist samples. Table 2 compares the exposure ratings of each likelihood exposure distribution for C_{inh-m} with sample sizes ranging from 3 to 11 and its resultant corresponding posterior distribution. For likelihood exposure distributions, the mean probability and its standard deviation for ER3 and ER4 were 64.9% (10.23%) and 27.8% (11.7%), respectively. For the resultant posterior exposure distributions, the values were 92.4% (3.88%) and 7.56% (3.88%), respectively. Obviously, the mean probabilities obtained from likelihood distributions were somewhat different from that of posterior distributions. The above results suggest that the sample size of the measured exposures did affect the variations of its likelihood exposure ratings. In additions, the standard deviations of the resultant likelihood exposure distributions (for both ER3 and ER4) were greater than the corresponding values of the posterior exposure distributions. In addition, the probabilities of ER3 and ER4 for the likelihood exposure distributions were somewhat different from the corresponding values obtained from the posterior exposure distributions. The above results further suggest that directly using measured exposures will result great variation on the resultant exposure ratings. On the other hand, the use of BDA technique would be helpful for industries to describe exposure profile particularly when insufficient exposure samples were available.

CONCLUSIONS

Oil mists measured from the threading workplace were found with a particle size distribution in a bimodal form. The fractions of C_{inh}, C_{tho} and C_{res} with respect to the total oil mist concentration were 85.7%, 70.2% and 62.4%, respectively. For threading workers, they experienced more severe C_{tho} and C_{res} oil mist exposures than that of the C_{inh}. It is suggested that fastener manufacturing industry should take the necessary control measures, such as local exhaust ventilation system and personal protective equipment, in order to reduce workers’ thoracic and respirable oil mist exposures. The sample size of the measured exposures did affect the variations of its likelihood exposure ratings. However, the use of BDA would result in the decrease in the variations of the corresponding exposure ratings obtained from the posterior exposure distributions. It is concluded that, while Pr was used as a surrogate for predicting C_{pr}, the use of BDA technique would be beneficial to predict workers’ long-term exposures even the sample size of the measured exposures was as low as 3.

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Table 2. Variations in values on ER3 and ER4 for the likelihood and posterior distributions of C_{inh} for different sample sizes (n = 3–11) were adopted for the likelihood distribution.
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