Proceedings of the 4th ITB Graduate School Conference
Innovation and Discovery for Sustainability
July 6, 2023

Association between Inhaled Lead Exposure and Blood Lead Levels in Paint Industry Workers

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Abstract. The paint industries which still use lead as an ingredient for pigments and coloring can be considered as the source of lead occupational exposure for the workers where the exposure dominantly occurs through inhalation. Blood lead levels (BLLs or Pb-B) is considered biomarkers of lead exposure. The present study was designed to investigate the association between the concentration of lead in blood (Pb-B) in paint industry workers from Indonesia. A total of 52 paint industry workers aged 25-50 years participated in this study. The inhaled lead concentration was measured in workers' breathing zone using personal sampler pump and analyzed with EDXRF method. Mean inhaled lead exposure was 0.1693 ± 0.1 μg/m^3 and the lowest exposure concentration was in Industry A. Meanwhile, the product finishing process gave the highest inhaled lead concentration, even though it is not significantly higher than other process (p-value = 0.4). Mean blood lead was 4.213 ± 1.6 μg/L; and 17 workers (32.7%) crossed the recommended level of 5 μg/L. There was a positive correlation between the inhaled lead exposure and blood lead levels in Industry A and Industry B (p-value = 0.467 and 0.488 respectively), meanwhile in Industry C the correlation was found to be negative (p-value = 0.021). Aside from the inhaled lead concentration, the usage of the PPE usage at work significantly affects the blood lead levels (p-value = 0.01) where workers who always wear mask at work actually will not absorb lead exposure as much as the measured lead concentration in their breathing zones.

Keywords: *blood lead levels; inhalation; lead; occupational exposure; paint industry*.

1 Introduction

Lead-based paints are still widely produced and sold in developing countries even though most industrialized countries have banned the use and sale of lead-based paints since more than 40 years ago. In Indonesia, there is already SNI 8011-2014 which regulated the maximum level of lead of 600 ppm for the paint industry. By the end of 2021, the standard is also in the process of being reviewed for the reduction to 90 ppm. However, out of 120 paint products circulating in

Indonesian market on 2020, there were 73% of them still containing more than 90 ppm lead, and worse, 39% of them contained more than 10,000 ppm lead [1].

In United States, lead-based paints and lead-contaminated dust are the main sources of exposure of heavy metals in children. Apart from children and the community, lead exposure can occur in occupational environment where the lead-based paints are produced. According to ATSDR [2], most of occupational lead exposure occurs due to inhaling lead-contaminated dust and vapor. Therefore, it can be said that the exposure of lead in occupational environment mainly occurs through inhalation. Several studies have shown the detection of lead in the occupational air, especially in the breathing zone of workers whose jobs related to paint and coloring. Research by Oginawati *et al.* [3] showed that there was 1.241 $\mu g/m^3$ of lead detected in the breathing zone of workers in the informal automobile painting industry in Karasak, Bandung. In addition, Muliyadi *et al.* in [4] also showed that the lead air content in painting section of the autmobile painting industry in Surabaya exceeded the TLV regulated in the Ministry of Manpower Regulation No. 13/2011. Lead was also found in the ambient air in the car body painting section of the automobile painting industry in Semarang [5].

Monitoring the exposure of lead in humans can be done by monitoring the biomarkers. Exposure biomarkers usually involve in measuring a compound in suitable biological samples such as blood, serum, or urine. Lead exposure on humans can be seen from lead concentration in blood (Pb-B), urine (Pb-U), and plasma (Pb-P) [6]. Blood lead level is the most widely used biomarker of lead exposure. Pb-B, especially Pb in red blood cells, represents lead in soft tissue and is widely used to measure the body burden and internal dose of absorbed lead. According to WHO in [7], there is no known threshold or safe limit for lead in human blood. However, according to UCSF Health [8], the normal concentration of Pb-B for adults is < 10 μg/dL. Meanwhile, the level of Pb-B concentration that does not require monitoring is < 5 μg/dL [7] [9] [10]. Based on the described background, it is necessary to monitor the lead exposure in paint industry workers, especially the exposure occurring through inhalation. The monitoring was carried out by measuring the concentration of lead in the workers' breathing zone and the concentration of blood lead levels as the response.

2 Methodology

The study was carried out in three paint factories in three different Indonesian cities. Those factories will be referred Industries A, B, and C. All of the population's workers in the paint industries made up the research subjects. Purposive sampling, a non-probability sampling technique, was used to choose the subjects. Males between the ages of 25 and 50 who had worked in the industry for at least two years and were willing to sign an informed consent form were included in the study. Workers who lived in or close to a landfill or industrial area were excluded. This study included 52 subjects in total.

Interviews and questionnaires were used to gather data in order to learn more about the general population, the traits and customs of the workforce, as well as other details like working hours and duration. In addition, lead air sampling was also carried out in the workers' breathing zone to determine the concentration of lead exposure through the inhalation route. Samples were collected using personal sampling pumps equipped with MCE filter ∅ 25 mm with 0,8 μm of pore size. The air sampling was carried out in 2 – 3 working hours. Then, the concentration of lead captured on the MCE filter was determined in the ratio of the mass units of lead and the unit area of the filter using EDXRF method at the BRIN Radiation Laboratory BATAN Bandung.

The blood sampling is carried out by the medical personnel who is phlebotomy certified. In this study, the blood samples were taken by the personnel from Prodia Clinic Laboratory. Then, at the Prodia Clinic Laboratory, the levels of blood lead were assessed using the ICP-MS method. Through the document 1066/UN6.KEP/EC/2022, the Padjadjaran University Research Ethic Commission had reviewed and approved the procedures involving human research subjects.

The obtained data of lead concentration then is correlated with the blood lead level using statistical method, namely Pearson correlation test, to see how significant the association between the two variables is. Then, the factors that are significantly associated with the exposure biomarkers will also be determined using Kruskal Wallis and Mann Whitney U statistical test. The statistical tests will be carried out using SPSS 22 software with the margin of error (α) equals to 0.05.

3 Results

The study included 52 research participants and was conducted in 3 paint industries spread across 3 different cities. A total of 20 subjects came from Industry A, 12 from Industry B, and 20 from Industry C. The research subjects were between the ages of 25 and 50, with the average age being 34, in accordance with the inclusion criteria. Each subject had an average of 11 years' experience across 2.5 to 29 years in each industry.

3.1 Concentration of Lead in Workers' Breathing Zone

Measurement of inhaled lead concentration was carried out by measuring the concentration of lead captured in the filter installed in the workers' breathing zone during the working hours. The results of lead caught in the filter were obtained through laboratory analysis using EDXRF method. The lead concentration in workers' breathing zone is expressed in µg/m^3 unit. The measurement results of the lead concentration are summarized in Table 4. These values indicate the lead concentration that can potentially be inhaled by the workers if the workers do not use mask PPE while working. There is no reference value for this exposure concentration.

3.2 Comparison of Air Lead Concentration for Each Location

The lead concentration caught in the filter certainly has variations and is affected by several external factors, such as the occupational environment. Thus, the workers' initial workplace can be one of the factors. To see how significant the workplace is affecting the air lead concentration, the Kruskal Wallis test will be carried out. The comparison of lead air level for each industry is shown on Figure 1, while the results of the Kruskal Wallis tests are shown on Table 1 where the mean rank indicates the average rank for each category.

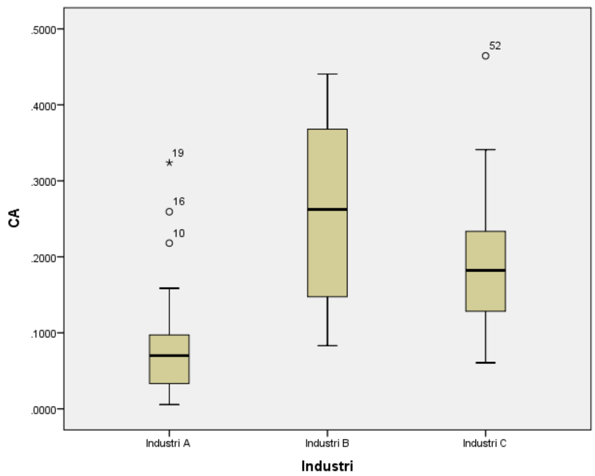


Figure 1 Distribution of HQ values of each subject.

The results in Table 1 show that the p-value is less than 0.05, then the difference of lead air concentrations in at least two industries is significant. To find out in between which industries the difference occurs, the post hoc test using Mann Whitney U test method is conducted. The results of the post hoc test are shown in Table 2.

Table 1 Kruskal Wallis test results for the comparison of lead air concentrations between locations.

Industries	N	Mean Rank	Mean Value (μg/m^3)
A	20	15.30	0.095 ± 0.09
B	12	37.08	0.258 ± 0.1
C	20	31.35	0.195 ± 0.1
p-value (Sig.)			0.000

Table 2 Post hoc test results for lead air comparison.

Factors	Dependent Variable	H_0	p-value (Sig.)
Workplace/industry	Lead air concentration	**μIndustry A = μIndustry B**	**0.000**
		μIndustry A = μIndustry C	**0.000**
		μIndustry B = μIndustry C	0.195

Based on Table 2, it is known that there is a statistically significant difference between the lead air concentration in Industry A and Industry B (p-value = 0.000) and the lead air concentration in Industry A and Industry C (p-value = 0.000). Meanwhile there is no significance difference between the lead air concentration in Industry B and Industry C (p-value = 0.195). Based on the mean rank, it can be concluded that the lead air concentration in Industry A is statistically lower than Industry B and Industry C.

3.3 Differences of Lead Air Concentration for Each Production Process

The paint production process consists of 3 main stages, which are preassembly and premix, pigment milling, and product finishing [11]. In the preassembly and premix stage, the raw materials from the paint will be mixed and then forwarded to grinding unit. Then, at the pigment milling stage, pigment will be mixed in the paint and undergo various adjustments so that the paint can be passed on to the packaging stage. The product finishing stage is filling the paint into the packaging and transferring the paint to a storage container. To see the difference of lead air concentration in between those three stages, the Kruskal Wallis test will be carried out. The difference of lead air concentration in the three working sections is shown in Figure 2, while the Kruskal Wallis test results are shown in Table 3.

Based on the test results on Table 3, it was found that the highest average of lead air concentration was detected in the product finishing section, followed by the pigment milling and QC section, and lastly the lowest average of lead air concentration was detected in the preassembly and premix section. However, the p-value is greater than 0.05, so it was concluded that there was no significant difference in lead air concentration between the three processes.

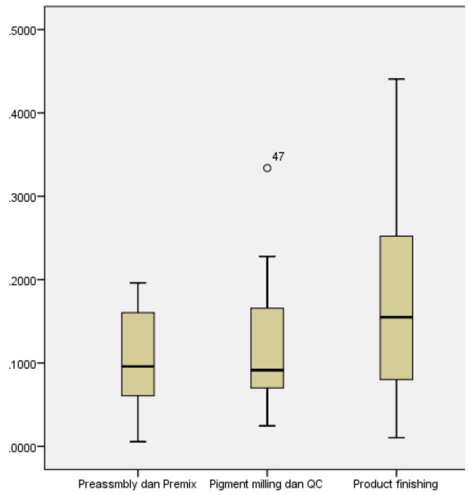


Figure 2 Lead air concentration in each production stage boxplot.

Table 3 Kruskal Wallis test results for the comparison of lead air concentrations between production stages.

Production Stages	N	Mean Rank
Preassembly and premix	6	14.17
Pigment milling and QC	9	16.22
Product finishing	20	19.95
p-value (Sig.)		0,4

3.4 Intake of Inhaled Lead Exposure

The concentration of inhaled lead will be used to determine the daily dose of lead toxicant absorbed by the workers divided with the body weight of the workers. The daily dose is quantified as the intake, which is the exposure that has been normalized with the exposure duration and the subjects' body weight to estimate the dose received or the dose of lead that has been able to exceed the external body barrier [12]. The inhaled lead intake is calculated using Equation 1.

$$Daily\ intake = \frac{CA \times ET \times EF \times ED \times InhR}{BW \times AT} \quad (1)$$

CA is the lead air concentration. ET is the total exposure time each day expressed as the total working hours each day. EF is the frequency of exposure, which is the total working days in a year (1 year = 52 weeks). ED is the exposure duration, which is stated as the period of working (years). AT is the averaging time, which is ED converted into hours. BW is the body weight of the subjects. InhR is the inhalation rate. In this study, the inhalation rate value used is 15.2 m^3/day [13]. The daily intake calculation results for each worker are summarized in Table 4.

3.5 Lead Exposure Biomarker (Pb-B Concentration)

The results of the Pb-B measurements were given in units of g/L, which represent the mass of lead per unit volume of blood that was analyzed using the ICP-MS method. Table 4 lists the findings of the lead exposure biomarker as measured by Pb-B concentrations. The normal Pb-B concentration value for adults is 10 g/L, according to references from UCSF Health in [8]. Adults are allowed to have Pb-B levels no higher than 5 g/L without monitoring [7] [9] [10]. The distribution of Pb-B concentrations for all workers is shown in Figure 3.

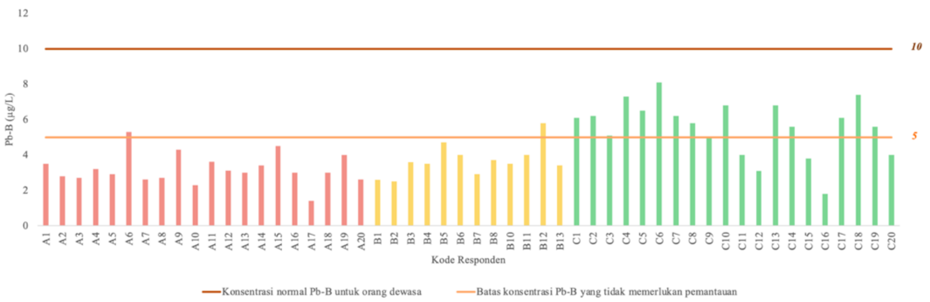


Figure 3 Pb-B concentration distribution for all workers.

According to Figure 3, no workers had Pb-B concentrations that were higher than those of an adult. But only 1 employee from Industry A, 1 employee from Industry B, and 15 employees from Industry C have Pb-B concentrations greater than 5 g/L. Monitoring of blood lead levels is advised even though the values are still within normal bounds.

Table 4 Descriptive summary of exposure and biomarker of inhaled lead.

Parameters	CA (μg/m^3)	Daily Intake (μg/kg-day)	Pb-B (μg/L)
MIN	0.0056	0.000345	1.4
Q1	0.0764	0.004506	3
MEDIAN	0.1520	0.010588	3.75
Q3	0.2408	0.016579	5.6
MAX	0.4646	0.040736	8.1
MEAN	0.1693	0.012368	4.219
STD	0.1	0.01	1.6

3.6 Correlation between Inhaled Lead Intake and Lead Exposure Biomarker

Correlation analysis is needed to determine the relationship between the parameters, which are the dose of inhaled lead received by the workers and the blood lead levels as the exposure biomarkers to make sure that the absorbed lead is from the occupational exposure. Pearson correlation analysis was used to determine the relationship between those two variables. The correlation analysis results are shown in Table 5. The linear regression curve for the relationship between the intake of inhaled lead and the Pb-B concentrations is shown in Figure 4.

Table 5 Correlation between inhaled lead intake and Pb-B concentration.

Correlation	Intake – Pb-B
r (correlation coefficient)	-0.33
p-value (1-tailed)	0.407

The correlation coefficient (r) obtained from the Pearson correlation analysis is negative. This means the correlation between the inhaled lead intake and the Pb-B concentration is not in the same direction, which shows the tendency that the greater intake received by the workers through inhalation, the lower the concentration of Pb-B detected. However, based on its significance, which is greater than 0.05, the correlation between those two variables is not significant.

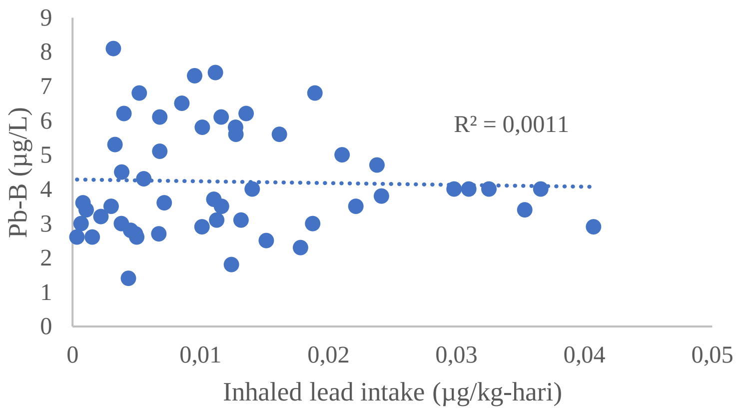


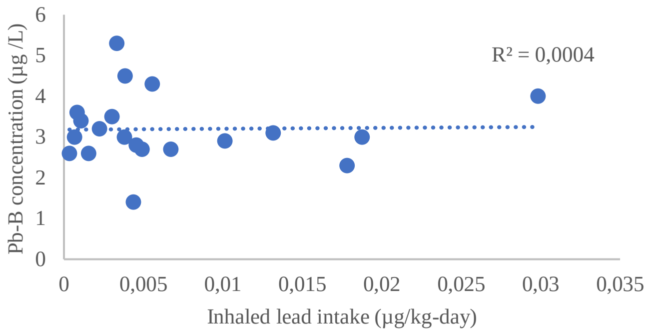
Figure 4 Regression of inhaled lead intake vs Pb-B concentration.

The correlation analysis results were not in accordance with the initial research hypothesis, which is the exposure of lead through inhalation would result in the observed effect in the form of an increase in the Pb-B concentration. However, Pb in the blood has a half-life for about 35 days [14] so that lead can stay and be detected in the blood for a period of 4 – 6 weeks [15]. Thus, the concentration of Pb-B detected is not only influenced by the current exposure of inhaled lead but can also be influenced by the lead exposure within the previous 6 weeks and the lead is accumulated in the blood. Meanwhile, the exposure concentration is the exposure that occurs only within the time span of sampling. In addition, Pb-B is most commonly used to measure lead exposure [6] but is not specific for measuring occupational lead exposure only. Lead exposure can also come from the domestic environment such as leaded-gasoline, cigarettes, or from contaminated drinking water [15]. Then, lead exposure in occupational environment does not only occur through inhalation routes. There are other exposure routes such as dermal and oral that allows absorption of lead into the bloodstream [9]. The intake value obtained also has the potential to provide an overestimate risk due to the concentration measurements are carried out without considering the use of PPE while working. If the workers wear mask while working, the intake will not necessarily be the same as the lead air concentration.

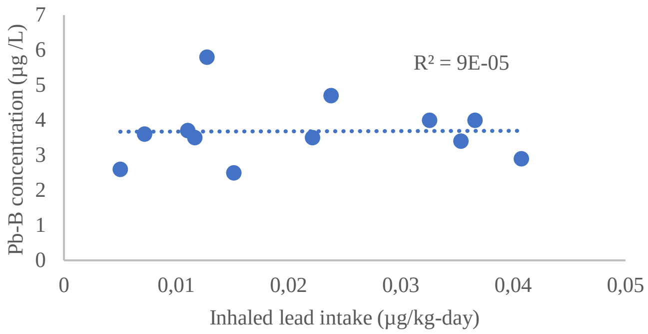
To provide more accurate results, the correlation between the inhaled lead intake and the detected Pb-B concentration will be reviewed for each industry. The comparison was made to review whether in each industry, lead occupational exposure is the main cause that significantly resulted in the increase of Pb-B or were there other significant factors from each industry that had significant effects on the increase in Pb-B concentration. The correlation analysis was also carried out using the Pearson correlation tests. Table 6 summarizes the results of the correlation test between the inhaled lead intake and the Pb-B concentration for each industry and Figure 5 shows the linear regression curve for the correlation between those variables.

Table 6 Correlation between inhaled lead intake and Pb-B concentration for each industry

Industry	Correlation	Intake – Pb-B
A	r (correlation coefficient)	0.02
	p-value (1-tailed)	0.467
B	r (correlation coefficient)	0.009
	p-value (1-tailed)	0.488
C	r (correlation coefficient)	-0.459
	p-value (1-tailed)	0.021



(a)



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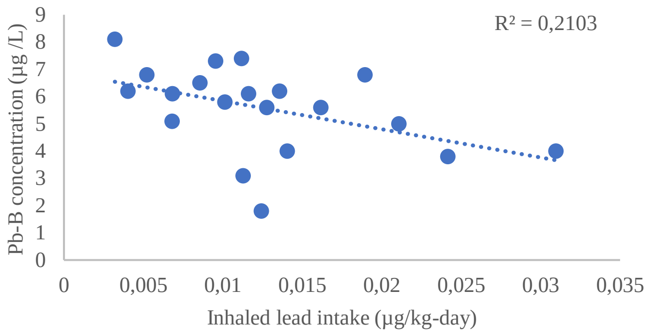

(c)

Figure 5 Regression of inhaled lead intake vs Pb-B concentration for each industry.

Based on the results in Table 6, it is found that the correlation coefficients between the inhaled lead intake and the Pb-B concentration in Industry A and Industry B are positive, which means the correlation of the two variables in both industries is in the same direction or there is a tendency that the Pb-B concentration increases along with the increase in inhaled lead intake. However, the correlation coefficients for Industry A and Industry B are relatively small (close to 0). The p-value for both industries are also less than 0.05 which means that the correlation between those variables is not significant.

Meanwhile in Industry C, the correlation coefficient is negative. The results for Industry C rejected the initial hypothesis of the study. In this case, the cause of the detection of lead in the blood might not be caused by occupational lead exposure through inhalation. Several factors other than inhaled lead exposure also have the potential in affecting the Pb-B concentration. In addition, the limited number of samples can also be one of the inaccuracies factors that occur when the research is conducted.

3.7 Factors Affecting the Lead Exposure Biomarker

As a result of the study's cross-sectional design, the lead exposure biomarker was collected simultaneously with the exposure sample, ensuring that the results of the biomarker analysis accurately reflected the workers' blood's current lead levels. The level of Pb-B that was detected does, however, fluctuate and are affected by other factors.

Working activities, the practice of wearing PPE (masks) while at work, smoking habits, and the type of vehicle used each day are some of the factors that are thought to affect the concentration of Pb-B. The significance of those factors will be determined using statistical analysis, namely Kruskal Wallis and Mann Whitney U test, to determine the significance differences in Pb-B results in certain group of workers divided based on the factors mentioned before. The category of working activities will now be divided into paint production, non-paint production, and logistics. The paint production workers are the workers who are classified as directly exposed subjects, non-paint production workers are those who are classified as indirectly exposed subjects, while the logistics workers are separated because they distribute the products so that they are potentially exposed to leaded gasoline more than others since they spend more time on the road (traffic). Table 7 summarizes the test results of the significance of each factor.

Table 7 Kruskal Wallis and Mann Whitney U Test Results of factors that potentially affect Pb-B concentration.

No	Factors	Categories	N	p-value (Sig.)
1	Working activities	Paint production	35	0.245
		Logistic	10	
		Non-paint production	7	
2	PPE usage	Never	3	**0.01**
		Sometimes	11	
		Always	38	
3	Smoking habit	Smoking	25	0.384
		Non-smoking	27	
4	Daily vehicle used	Opened vehicle (motorcycle, walking, etc.)	46	0.302
		Closed vehicle (car, shuttle bus, etc.)35	6	

The PPE usage factor gave a significance value lower than 0.05, so it can be concluded that the habit of using PPE while working has a significant effect on the Pb-B concentration. To determine in which categories the differences are significant, the post hoc test using Mann Whitney U will be carried out. The results of the Mann Whitney U post hoc test are shown in Table 8.

Table 8 Post hoc test results for the PPE usage factor.

Factors	H_0	p-value (Sig.)
PPE usage	μNever = μSometimes	0.211
	μNever = μAlways	**0.020**
	μSometimes = μAlways	**0.031**

Based on the findings in Table 8, it is known that there was a significant difference in the average Pb-B concentration between the workers who always wear masks while working and the workers who do not (p-value = 0.02) and the workers who only wear masks occasionally (p-value = 0.031). Therefore, it can be concluded that the Pb-B concentration found in workers who always wear masks while working is significantly lower than the Pb-B concentration found in workers who occasionally or never wear masks while working. Santosa et al. [16] reported a similar finding, which the workers who rarely or never wear masks while working are more likely to be exposed to lead than those who always do so.

4 Conclusion

The concentration of lead exposure detected in workers' breathing zone in each industry is in the range of 0.0056 – 0.4646 μg/m^3. The concentration of lead exposure detected in Industry A with the average of 0.0905 ± 0,1 μg/m^3 was significantly lower than Industry B and Industry C. There was no statistically significant difference between the inhaled lead exposure in Industry B and Industry C. The paint producing process with the highest average exposure to airborne lead was the product finishing section, but there was no statistically significance difference among all producing processes (p-value = 0.4).

The concentration of Pb-B detected in all workers was in the range of 1.4 – 8.1 μg/L with the average of 4.213 ± 1.6 μg/L. There are no workers whose Pb-B reaches 10 μg/L. However, there is one worker from Industry A, one worker from Industry B, and 15 workers from Industry C who have Pb-B concentration more than 5 μg/L, so regular monitoring of Pb-B level is suggested to avoid the adverse health effects on workers. A significant factor affecting Pb-B concentration is the use of masks or PPE. The group of workers who always wear mask at work have significantly lower average of Pb-B than those who do not or rarely use masks or PPE at work. In Industry A and Industry B, a positive correlation was found between the inhaled lead intake and the Pb-B concentration. But, in Industry C, the correlation was found to be negative. However, the correlations of those variables are not statistically significant.

Acknowledgement

Authors would like to express the gratitude towards Nexus3 Foundation as the collaborator party in providing and supporting this research and towards International Pollutants Elimination Network (IPEN) who supported and funded this research.

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