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Study of Respiratory Complaints Among Surface Coating Workers Due to Exposure to Particulates and Microbes

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ABSTRACT

Surface coating generates particulates ($PM_{2.5}$ and PM_{10}), especially during sanding and painting. Particulates consist of several organic components, such as nitrates (NH_3), ammonium (NH_4^+), and sulfates, which serve as substrates for microbes (bacteria and fungi) to proliferate. This study aims to analyze the effect of $PM_{2.5}$ and PM_{10} concentrations and the concentrations of bacteria and fungi on respiratory complaints among workers in finishing areas. The independent variables studied are the concentrations of $PM_{2.5}$ and PM_{10}, as well as the concentrations of bacteria and fungi, while the dependent variable is the incidence of respiratory complaints. The statistical test used is binary logistic regression to examine the effects of the independent variables on the dependent variable. The results indicate that simultaneous exposure to PM_{10} and $PM_{2.5}$ significantly affects respiratory complaints. The concentrations of bacteria and fungi also significantly affect respiratory complaints. Previous studies have shown that the size and diameter of particulates and their chemical composition are factors that negatively impact health. On the other hand, the concentrations of bacteria and fungi are positively correlated with particulate concentrations, as the organic substances in particulates allow bacteria and fungi to thrive. Microorganisms grow faster at 22–32°C temperatures and relative humidity between 40–90%. When the relative humidity reaches ≥80%, microbes are more likely to thrive and reproduce.

Keywords: PM_{10}, $PM_{2.5}$, Bacteria, Fungi, Respiratory complaints.

INTRODUCTION

Particulate Matter (PM) or particulates are complex combinations of solid particles and aerosols in the air. Particulates consist of several organic components such as nitrates (NH_3), ammonium (NH_4^+), sulfates (Liu *et al.*, 2023), and fungal spores (Woodson, 2012; Araújo-Martins *et al.*, 2014). Particulates are microscopic solids or liquids suspended in exhaust gases produced during manufacturing processes (Cooper and Alley, 2011). Particulates are common air pollutants found in ambient air. Several epidemiological and toxicological studies have found that fine particulates ($PM_{2.5}$) with a diameter < 2.5 µm are a potential cause of health problems (Thangavel, Park and Lee, 2022). Toxicological research indicates that PM2.5 causes inflammation, increasing the risk of lung injury (Liu *et al.*, 2022). Li et al. (2018) also found that PM2.5 is involved in the molecular pathogenesis of lung cancer and chronic inflammatory respiratory disorders, characterized by increased concentrations of carboxylesterase enzymes in the blood of test animals (Santiasih, Titah and Hermana, 2019). Similar findings by Chen and Hoek (2020) explain that exposure to PM2.5 and PM10 increases the risk of mortality from various causes, including cardiovascular diseases, respiratory diseases, and lung cancer. A significant relationship between PM10 exposure and respiratory diseases in long-term exposure (with a 10-year observation period) includes asthma or chronic obstructive pulmonary disease (COPD) and acute bronchitis/bronchiolitis (Mészáros *et al.*, 2015). Besides organic components such as nitrates (NH3), ammonium (NH_4^+), and sulfates, particulates also consist of volatile organic compounds (VOCs). One source of VOCs is products from bacteria and fungi.

Bacteria release several VOCs into the environment, which are products of microbial metabolism (Almeida *et al.*, 2022). The emitted VOCs are specific to particular species, depending on environmental conditions such as growth media, pH, temperature, incubation time, and interactions with other microorganisms. Bacteria and fungi produce microbial VOCs, generally lipophilic compounds that diffuse quickly through water (Effmert *et al.*, 2012). Indoor air humidity releases hundreds of VOCs from materials inside without microbial content due to relative humidity conditions that cause polar compounds to be quickly adsorbed (Wolkoff, 1998). The type of material and sample location affect microbial growth and mVOC in different building materials under varying relative humidity conditions, ultimately clarifying the impact on indoor wet chemistry. The production of volatile organic compounds from fungi (Fungal VOCs) has been described for all fungal phyla species (Devi *et al.*, 2020; Guo *et al.*, 2021).

In the surface coating process, significant particulate-generating activities are sanding and painting. Abrasive blasting is cleaning or preparing a surface with abrasive materials (which can include sand, coal slag, iron sand, garnet, etc.). Abrasive blasting in surface coating processes is used to roughen the surface of materials in preparation for painting and coating (Santiasih, 2016). Secondary particulates are produced by reactions between ozone and precursor gases from using paint and solvents (Lazaridis *et al.*, 2015). When abrasive blasting in an unconfined space, it is necessary to analyze the potential risks to humans and the environment from toxic materials and particulates generated in this process (Serageldin, 2007).

Painting is a process of decorating or protecting the surface of materials. Paint comprises pigments, solvents or thinners, and dryers (Santiasih, 2016). Typically, painting is done using a spray system. This spraying process generates fine dust or aerosols with a diameter of <1000 nm (Lazaridis *et al.*, 2015; Santiasih and Hermana, 2017). VOCs are volatile organic compounds in various products, including paints and solvents used for surface coating (Jacobson, 2002). Emissions from wet materials like paint are initially dominated by evaporation and later by internal diffusion (Yang *et al.*, 2001, Zhang and Niu, 2003). Previous studies have reported the formation of ultrafine particles during VOC and ozone reactions (Fan et al., 2005), indicating that VOCs can act as precursors. Specifically, coating materials are sources of volatile organic compound (VOC) emissions (Weschler, 2009; Guo *et al.*, 2021). Emissions from wet materials like paint are initially dominated by evaporation and later by internal diffusion (Yang *et al.*, 2001). Previous research also reported the formation of ultrafine particles during VOC and ozone reactions (Fan et al., 2005), suggesting that VOCs can act as precursor gases (Kelly and Fussell, 2012). Therefore, it is essential to discuss the potential exposure of particulates (PM10 and PM2.5) to indoor workers, mainly through inhalation, where particulates (PM10 and PM2.5) and microorganisms act as agents suspended in the air, and workers are the receptors. Although inhalation is not the only route for pollutant exposure to the human body, it warrants serious attention due to the potential health effects on humans.

METHODS

The research was conducted at a furniture company in the finishing area. The raw materials used are wood and plywood. At the same time, the products include kitchen sets, bedroom furniture (beds, cabinets, dressing tables), living room furniture (TV stands, sofas), office furniture (desks, chairs, bookshelves, computer desks), guest room furniture (tables, chairs), and other household accessories. The company's workshop has six sections/rooms: the construction room, finishing room, painting and drying room, administrative room 1, administrative room 2, and storage warehouse, as shown in the layout below.

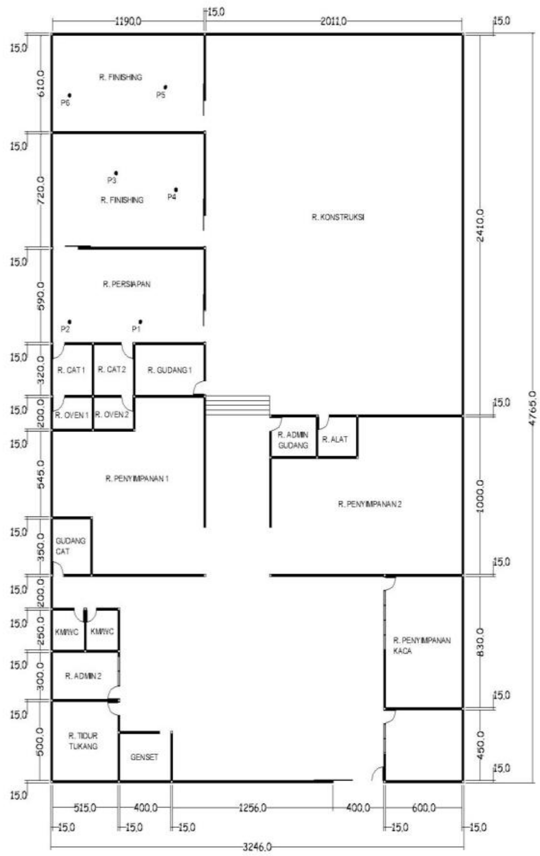

Figure 1. Finishing Room Layout

Cutting/sawing, forming, and assembly processes are carried out in the construction room. Coating processes are performed in the finishing and preparation rooms, and completed products are stored in the storage warehouse. The coating processes in the finishing room include filler application, sanding, and base painting. The finishing room is the focus of this study due to the particulate emissions generated during the coating process. There are two types of production processes in this room: sanding and base painting.

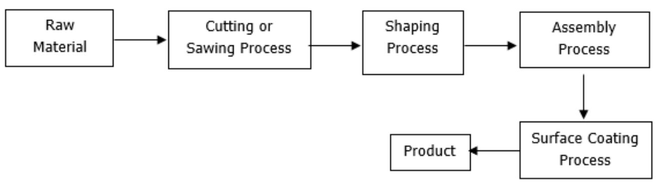

Figure 2. Production Process Flow Diagram in the Finishing Room

The finishing room has three stages of surface coating: preparation, painting, and final stage (drying and storing the finished products).

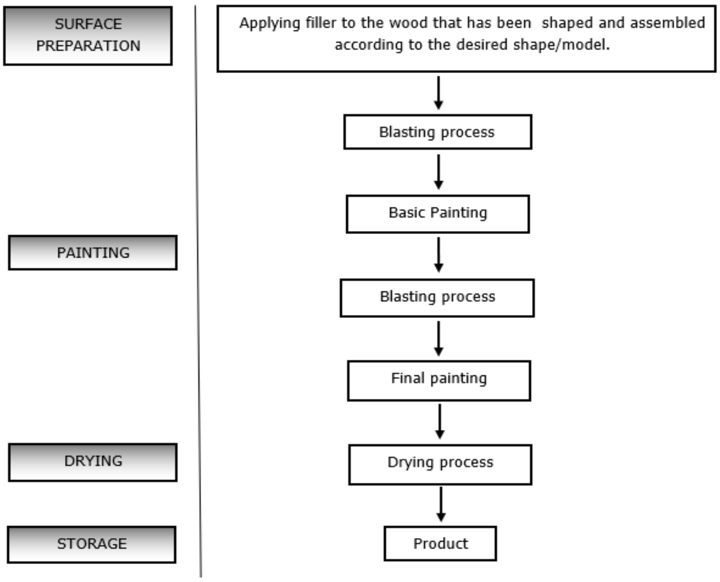

Figure 3. Surface Coating Process Flow Diagram

The stages in the surface coating process are as follows:

A. Preparation Stage
This is the initial step before the wood/raw material is painted. The goal is to fill the wood pores to make the surface smoother. Materials used in this stage include filler and thinner, with a composition of filler to hardener at 4000 grams to 74.4 grams. On average, 8 kg of filler is used per day. After applying the filler, the wood is sanded using progressively finer sandpaper, starting with grit number 180, then 240, and finally 400. Sanding is done twice: once after applying the filler and again after the base painting.

B. Painting Stage
Painting is carried out after the filler application. Generally, painting is done using a spraying system. This process includes two phases: base painting and final painting. The base painting, done in the finishing room, involves the application of a base coat. The final painting is done in a separate room. The composition of the paint layers used for both the base and final painting is the same: stain, hardener, and thinner, with a ratio of stain: thinner: hardener = 1000 mL: 200 mL: 200 mL. The spray gun used is a high volume low pressure (HVLP) type with a transfer efficiency of 65%.

The methods used in this study include:

1. Particulate Measurement
In indoor air, particulate concentrations were sampled during normal production processes (without reduction or addition of raw materials or changes in production time). Sampling for PM10 and PM2.5, as well as microbes (bacteria and fungi), was performed at six points in the finishing room with four repetitions, as shown in Figure 1, using a gas sampler impinger MS 003 GS.

2. Measurement of Bacteria and Fungi Concentrations
Sampling for bacteria and fungi was conducted at six points in the finishing room with four repetitions, as shown in Figure 1, using a gas sampler impinger MS 003 GS. The measured concentrations were of bacteria and fungi in the ambient air. Microorganisms were sampled in indoor air during normal production processes (without reducing or adding raw materials or changes in production time). This sampling was conducted simultaneously with particulate sampling using a High Volume Air Sampler (HVAS). Particulate residues on filter paper were analyzed for microorganism concentrations. The media used for bacterial culture was nutrient agar, while potato dextrose agar was used for fungal growth. The methods for preparing nutrient agar and potato dextrose agar media refer to Rosmania and Yanti (2020). Sample preparation methods, including sterilization, bacterial purification, bacterial rejuvenation, preparation of McFarland 0.5 standard solution, bacterial standard curve creation, bacterial growth curve creation, bacterial suspension preparation, and bacterial count measurement by turbidity, are also based on Rosmania and Yanti (2020). Bacterial and fungal colony counts were analyzed using SNI 9099:2022 for biological factor testing in workplace air (Badan Standardisasi Nasional, 2022).

3. Air Flow Rate Measurement
The airflow rate was measured using a Tenmars TM-402 anemometer. The purpose of measuring the air flow rate is to analyze the air changes per hour (ACH). The standard measurement method refers to SNI 03-6572-2001, which provides guidelines for designing building ventilation and air conditioning systems (Badan Standardisasi Nasional, 2001).

4. Worker Health Data
The study respondents are permanent workers (not contract employees) working in the finishing room. Health data for the workers was obtained from the medical records stored by the company (Table 1).

5. Statistical Analysis
The research variables include particulate concentrations (PM10 and PM2.5), which are represented as variable X1, and microbial concentrations (bacteria and fungi), which are represented as variable X2, concerning the occurrence of health issues among workers (variable Y). The relationship between two variables was tested using the chi-square test, while the effect was tested using binary logistic regression. Statistical analysis was performed using SPSS 21.0 software.

6. Research Assumptions
The assumptions used in the study are:
a) The composition of emission sources is constant during the ambient air sampling period; b) The constituents contained in the particulates do not react with each other; c) Airflow in the finishing room is considered a single airflow with perfectly mixed air (well-mixed room); d) Temperature and relative humidity remain constant during the ambient air sampling period.

RESULTS AND DISCUSSION

The production processes in the finishing room include surface preparation and base painting. The characteristics of this room are as follows: it has an area of 22.66 m², is not fully enclosed (with only partitions separating it from other rooms), and has a height of 10 m.

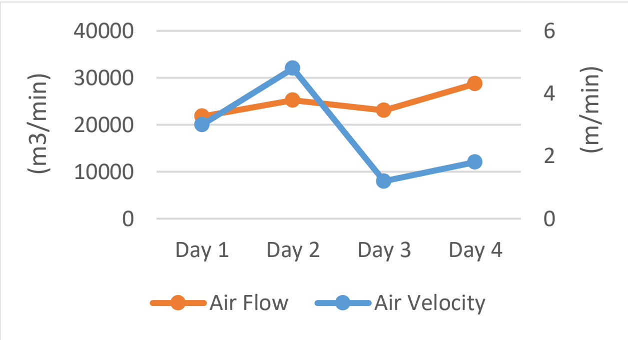

Figure 4. Air Flow Rate and Air Velocity in the Finishing Room

This room lacks filters or blowers and only has openings with a total area of 13.2 m². Given the absence of mechanical ventilation, the airflow in this room is low, as shown in Figure 3. The highest airflow rate was observed on the 4th day, while the lowest was on the 1st. The calculation for air changes per hour (ACH) follows the SNI 03-6572-2001 standard for designing ventilation and air conditioning systems in buildings (2001), which is:

$ACH = \frac{Q}{V} \times 60$ ....(1)

where:

ACH = air changes per hour
Q = air flow rate (m3/minute)
V = room volume (m3)

The calculation results for the lowest air changes per hour on the first day were 5764.3 times per hour. This meets the minimum threshold for air changes per hour, which is at least 6 times per hour, according to SNI 03-6572-2001 (2001). The concentration of PM10 and PM2.5 from day 1 to day 4 at the 6 measurement points is depicted in Figure 4. The concentrations of bacteria and fungi are presented in Figure 5.

Table 1.
Distribution of Respondents by Work Location and Respiratory Health Issues

Work Location	Number of Respondents with Respiratory Issues				Total	
	Yes		No			
	n	%	n	%	n	%
Point 1	6	75.0	2	25.0	8	100.0
Point 2	2	25.0	6	75.0	8	100.0
Point 3	8	100.0	0	0	8	100.0
Point 4	7	87.5	1	12.5	8	100.0
Point 5	7	87.5	1	12.5	8	100.0
oint 6	2	25.0	6	75.0	8	100.0
Total	32	100.0	16	100.0	48	100.0

Figure 4 shows a tendency for the highest concentrations of PM10 and PM2.5 on days one through four to be at point 3. Point 3 is where the base painting occurs, leading to higher particulate exposure than other points. Correlating with the frequency distribution in Table 1, at point 3, 2 people (100%) experienced respiratory issues. The bacterial distribution on the first and second days shows the highest bacterial concentration at point 3, ranging from 56,000 to 70,000 colonies/m³. This aligns with the fact that point 3 is where base painting occurs and correlates with the data in Table 1, where 2 people (100%) had respiratory issues at this point. Secondary particulates from painting activities are very fine, with particle diameters <100 nm, formed through nucleation processes (Lamorena *et al.*, 2007). Atmospheric particle diameters are categorized into four types: nucleation particles (dp < 30 nm), Aitken particles (30 nm < dp < 100 nm), accumulation particles (100 nm < dp < 1 µm), and coarse particles (dp > 1 µm) (Hussein *et al.*, 2005). The Occupational Safety and Health Administration (OSHA) (2023) states that the threshold limit values (TLV) for PM10 are 10 mg/m³ and for PM2.5 are 5 mg/m³. Figure 4 shows that the particulate concentrations during the 4-day measurement period were below the TLV for both PM10 and PM2.5. Chemical composition and particulate size are two parameters of particulates that can be hazardous to health. Studies on short-term exposure with in vitro air pollution sampling have shown relevant toxicological and physicochemical findings (Billet *et al.*, 2007; Abbas *et al.*, 2009). Particulates can contain compounds such as carbon elements, coating materials, metals (e.g., cadmium, nickel, vanadium, copper, and zinc), and polycyclic aromatic hydrocarbons (PAH) (Cheung, Morawska and Ristovski, 2011).

Several researchers have found that VOCs are produced during the painting process. Kura (1998) investigated VOCs and hazardous air pollutants generated from painting. Houang et al. (2001) investigated the control of industrial volatile organic pollutants and the impact of VOCs on health. Malherbe and Mandin (2007) studied VOC emissions during outdoor painting, which increases disease risk. The regression analysis results to determine the influence between PM10 and PM2.5 concentrations on fungal concentrations show the following regression equations:

Bacteria Concentration = $14661\ PM_{10} + 13206$........(2)
Fungi Concentration = $29246\ PM_{10} + 28477$........(3)
Bacteria Concentration = $2265\ PM_{2.5} - 14878$..........(4)
Fungi Concentration = $42531\ PM_{2.5} - 21792$.......(5)

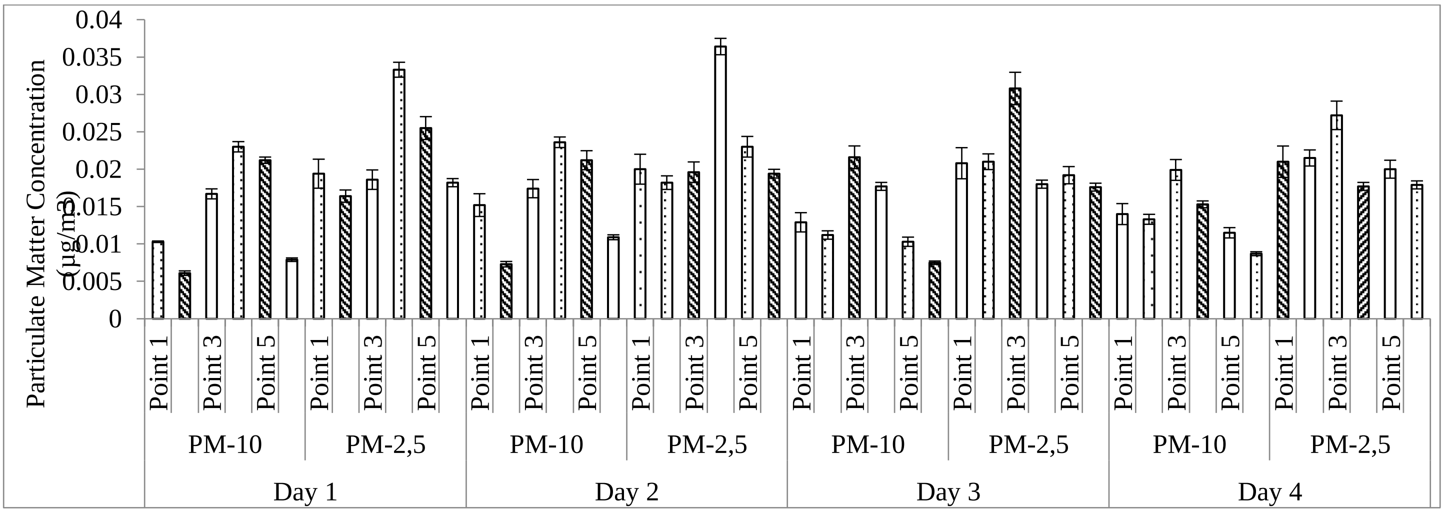

Figure 5. PM_{10} and $PM_{2.5}$ Concentrations in the Finishing Room

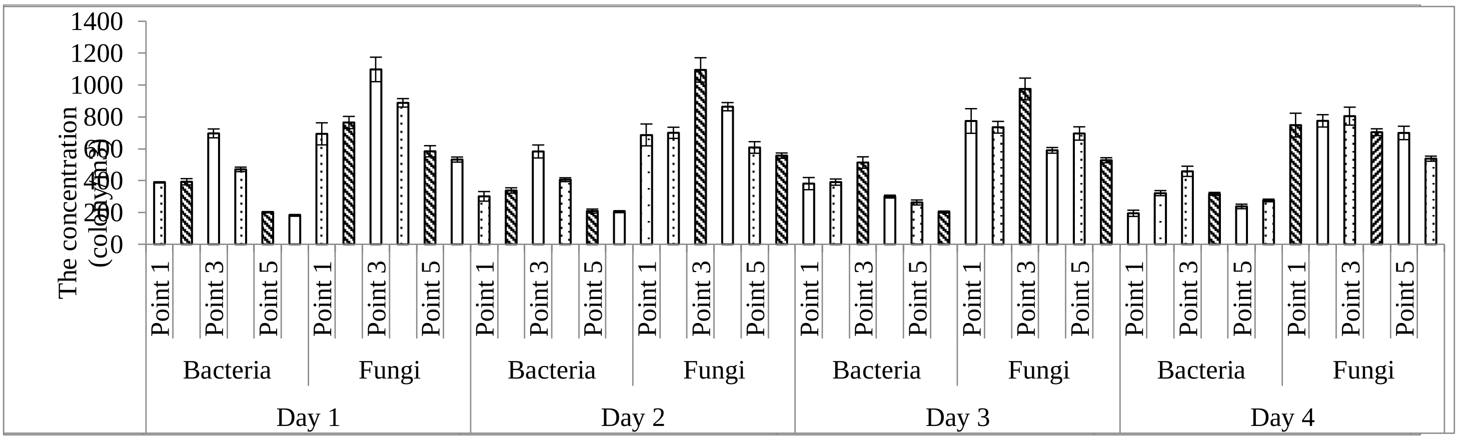

Figure 6. Bacteria and Fungi Concentrations in the Finishing Room

The F test shows a p-value of 0.000 with a 95% significance level, meaning at least one variable x (PM10 or PM2.5) affects the concentration of fungi or bacteria. To see the influence of each variable (PM10 and PM2.5), a T-test was conducted, and the results show that the p-value for PM10 is 0.005 and the p-value for PM2.5 is 0.000 (with a 95% significance level), indicating that PM10 and PM2.5 concentrations affect fungi concentration. The results of the linear regression analysis are consistent with previous studies, which found that Li et al. (2010) observed a positive correlation between the number of microorganisms and the quantity of dust. The more dust deposited, the more microorganisms will appear. Fungi grow more abundantly compared to bacteria in the same sample.

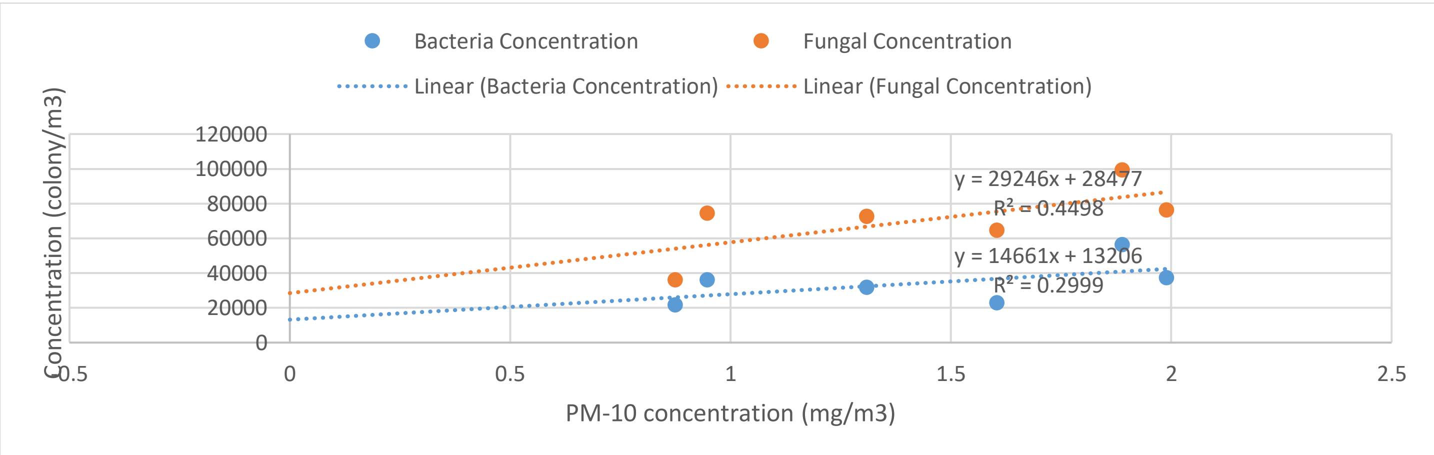

Figure 7. Relationship Between PM10 Concentration (mg/m3) and Bacteria and Fungi Concentrations (colonies/m3)

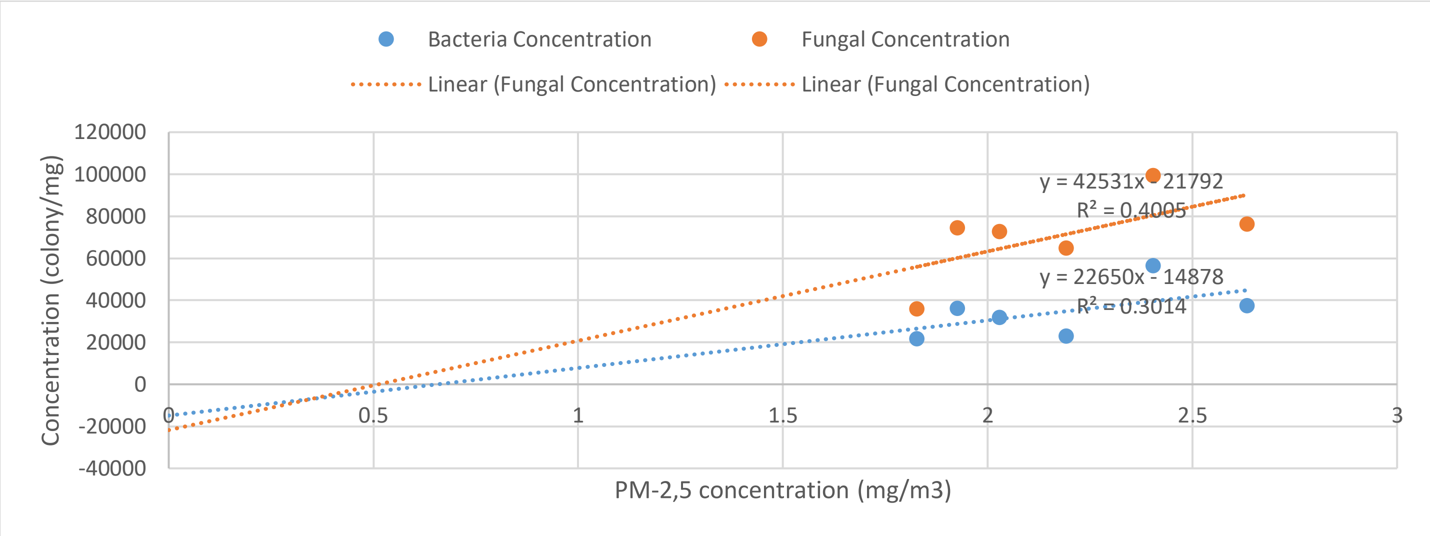

Figure 8. Relationship Between $PM_{2.5}$ Concentration (mg/m^3) and Bacteria and Fungi Concentrations (colonies/m^3)

Based on the measurement results, it was found that the temperature differences at the time of sampling were not significant (ranging from 33.8°C to 34.0°C), so the influence of temperature was ignored, as was relative humidity. Furthermore, understanding the effects of temperature and relative humidity requires a separate experimental study.

The linear regression analysis results show that R2 for fungi > R2 for bacteria, meaning that PM10 and PM2.5 concentrations can explain the fungi concentration better than the bacteria concentration, and other variables included in the error term for fungi are fewer than those for bacteria. The same results were shown in previous studies, where the positive correlation for fungi was more significant compared to bacteria (R for bacteria < R for fungi) (Li et al., 2010).

The binary logistic regression test results show that the p-value for the influence between PM10 and PM2.5 concentrations on health disturbances is 0.000 with a 95% significance level, meaning that PM10 and PM2.5 concentrations significantly affect health disturbances. Meanwhile, the binary logistic regression test results show that the p-value for the influence between bacteria and fungi concentrations on health disturbances is 0.012 with a 95% significance level, indicating that bacteria and fungi concentrations significantly affect health disturbances together. This shows that particulate concentrations (PM10 and PM2.5) and bacteria and fungi concentrations in the air significantly affect health disturbances. Several studies have explained that microorganisms grow faster at temperatures between 22-32°C and relative humidity of 40-90%, and relative humidity above 80% is more conducive to the growth and reproduction of microbes (Li *et al.*, 2010).

Weschler (2009) researched VOCs present in painting materials. Zhang and Niu (2003) found that internal diffusion follows evaporation as the first step in the emission of paint and other wet materials. Ultrafine particles form in reactions between paint products' VOCs and ozone in the surrounding air (Fan *et al.*, 2005). Moreover, this study shows the possibility that VOCs can act as precursor materials. Painting with ozone in the same place produces ultrafine particles (Betha *et al.*, 2011; Hovorka and Braniš, 2011; Quang *et al.*, 2013). Quang et al. (2013) investigated the nucleation process in large buildings. This process produces particles from outside that are brought into the building through high air exchange rates. Betha et al. (2011) studied the formation of ultrafine particles due to the oxidation of VOCs from ozone stimulation.

CONCLUSION

There is particulate exposure (PM10 and PM2.5) to furniture workers in the finishing room, which serves as a workshop for surface coating tasks such as sanding and painting. The emergence of respiratory complaints among workers prompted an investigation into this issue. The combined concentrations of PM10 and PM2.5 exposure significantly influence respiratory disturbances. Similarly, the combined concentrations of bacteria and fungi significantly impact respiratory disturbances. Previous research has indicated that particulate factors affecting health adversely include the size/diameter of particulates and the chemical content within the particulates. The concentration of bacteria and fungi positively correlates with particulate concentration because bacteria and fungi thrive well when organic substances are present in the particulates. Microorganisms grow faster at temperatures of 22-32°C and relative humidity of 40-90%, and conditions become more conducive for microbial growth and reproduction when RH reaches ≥80.

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