The modelling of particulate matter concentration using mass balance model in surface coating activities at finishing room of shipbuilding process

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Abstract. The surface coating process of shipbuilding produces pollutants in the form of particulate matter (PM$_{10}$ and PM$_{2.5}$), potentially generating environmental pollution and respiratory problems in workers. The concentration of indoor particulate matter (PM) can be predicted using mass balance model. This study aims to prove that mass balance can be employed to estimate the concentration of PM. Mass balance is calculated from the concentration of pollutants, inserted into indoor, indoor emission rate, airflow rate and pollutant removal rate. The model estimation results show that PM$_{10}$ concentrations on the first day, second day, third day and fourth day were 1.22 mg/m$^3$, 1.52 mg/m$^3$, 1.84 mg/m$^3$ and 1.80 mg/m$^3$. While the PM$_{2.5}$ concentration on the first day, second day, third day and fourth day was 2.67 mg/m$^3$, 3.03 mg/m$^3$, 2.99 mg/m$^3$ and 3.15 mg/m$^3$. The RMSE values on day 1 to day 4 for PM$_{10}$ were 0.679412, 0.565597, 0.682349, 0.546626, while for PM$_{2.5}$ are 0.755513, 0.980255, 0.975141 and 1.108106. Giving evidence that mass balance model was reliable that proved by the lower value of RMSE which is generally less than one. It proves that the concentration of PM (PM$_{10}$ dan PM$_{2.5}$) is close to actual value of PM concentration from measurement results.

1. Introduction
The surface coating is one of the production activities of shipyard companies in East Java. The process carried out in the finishing room includes the activities of giving fillers (putty), rubbing (blasting) and basic painting. The process of painting executes with a spray gun is more dangerous than paintbrushes due to the small particles can be released into the environment. The application of spray painting operation generates the ultrafine particles (Santiasih and Hermana 2017) that discharge to the environment and then fly in the air, thus it can contaminate the environment and endanger the human health (He et al. 2019). Spray paints convert substances into aerosols and/or particulate matter (PM), which is a group of ultrafine particles in the form of liquid and/or solid substances. PMs are obtained from spraying mechanisms, nebulization and bubble producing (Santiasih, Titah, and Hermana 2020). Particulate matter with a small size (ultrafine PM) will be easily inhaled during inhalation exposure, thus it is potential exposure especially to the respiratory system. The empirical relationship between exposure to particulate matter with enzymatic effects on mammals (Santiasih et al. 2019) and advanced effects on the respiratory system, cardiovascular system and particulate concentrations in ambient air has been conducted by a previous study (USEPA 1997).
Spray painting method in the surface coating process which has a low transfer efficiency, thereby releasing more aerosols into the air (overspray) compared to aerosols that attach to the work plane (Figure 1). The process of surface coating produces pollutants, namely secondary PM with a very small size (ultrafine PM). Secondary particles are generated as a result of chemical reactions from precursors substances of volatile organic compounds (VOC) such as sulphate, nitrate, Sulphur dioxide, nitrogen dioxide and ammonia (Lazaridis et al. 2015a). Volatile organic compounds (VOCs) from painting solvents are one of the most important sources of pollutant outputs for the shipbuilding and ship repair industry (Celebi and Vardar 2008a). Impacts caused by PM are exposure to smoke or fog, contamination of buildings and other materials, corrosion and material damage and also initiate local weather changes. Besides, particulates also cause interference with humans, animals and plant growth. Some scientist has investigated health impact of PM in the respiratory system, cardiovascular system, and cellular effect (Franck et al. 2011; Karottki et al. 2014; Orona et al. 2014).

Indoor air quality (IAQ) is currently attracting the attention of many experts, especially environmental engineers and industrial hygienists because the importance of the indoor environment is related to indoor exposure to workers. The exposure of indoor PM has to obtain serious attention, considering that humans spend most of their time (80%) indoors whether in homes, offices, vehicles, workplaces, laboratories (Myers and Maynard 2005). Cooper dan Alley (2011) investigated that the concentration of indoor air pollutants can be predicted using a simple mathematical model, with the key variables being the emission rate and ventilation rate, such as the mass balance model. In a typical indoor air mass balance model, the assumption is generally formulated that the indoor air is well-mixed (Wadden and Scheff 1983). The mass balance equation is based theoretically on the physical law of mass conservation, to calculate the particle concentrations in indoor regarding all parameters such as particle outdoor concentration that inserted into indoor, initial indoor concentration, indoor emission rate, sink removal and also considering indoor airflow rate (Cooper and Alley 2011).

It is essential to investigate the estimation of indoor PM (PM10 and PM2.5) using the mass balance model, to examine the reliability of the mass balance model in predicting the concentration of indoor PM. The results of this study can be an alternative method to determine the concentration of indoor PM if a direct measurement is difficult or not possible to be carried out.

2. Material and Methods

2.1. The Measurement of Particulate Matters (PM)

PM2.5 and PM10 measurements were conducted using a High-Volume Air Sampler (HVAS) in the breathing zone in height from the floor to represent inhaled PMs. The PM air sampling in ambient air (indoor) was carried out when the production process was running normally (no reduction or addition of raw materials, and production time). A sampling of PM10 and PM2.5 was conducted at 6 points (P) in the finishing room (Figure 2) with 4 repetitions. The measured PM10 and PM2.5 concentrations were in ambient air indoors, and outdoors.
2.2. The Measurements of Air Flow and Air Velocity
The airflow rate and air velocity were measured at 6 points (P) in the finishing room (Figure 2) by the repetition of 4 times measurement, using the wet bulb globe temperature (WBGT) instrument Questtemp Heat stress monitor model 32.

Figure 2. The Layout of Finishing Room.

2.3. The Modelling Concentration of Particulate Matters using the Mass Balance Model
The concentration of indoor air contaminants was predicted using simple mathematical models such as mass balance, with the key variables being the rate of emissions and the rate of ventilation. In some buildings, the airflow rate was very simple, so it could be assumed that the building had a single airflow rate and the also contained perfectly mixed air. The mass balance equation was based theoretically on the physical law of mass conservation, to calculate the particle concentrations in indoor regarding all parameters such as particle outdoor concentration that inserted into indoor, initial indoor concentration, indoor emission rate, sink removal and also considering indoor airflow rate (Cooper and Alley 2011).

\[
\frac{V dC_i}{dt} = QC_0 + S - QC_i - kC_iV
\]  

Where:
- \( V \) = room volume, m\(^3\)
- \( C_i \) = concentration of indoor pollutants, \( \mu g/m^3 \)
- \( C_0 \) = the concentration of pollutants in the outside air, \( \mu g/m^3 \)
- \( Q \) = ventilation rate, m\(^3\)/hour
- \( S \) = rate of emission source in the room, \( \mu g/hour \)
- \( k \) = the constant of removal rate (assumed beforehand), hour\(^{-1}\)
Thus, Equation 1 could be written as:

\[
\frac{dC_i}{dt} + \left(\frac{Q}{V} + k\right)C_i = \frac{Q}{V} C_0 + \frac{S}{V}
\]

The value of \((\frac{Q}{V} + k)\) was a time characteristic or time constant for this system and was given the symbol \(\tau\). The general solution for Equation 1 was:

\[
C_i = \left\{C_0 - \tau \left(\frac{Q}{V} C_0 + \frac{S}{V}\right)\right\} \exp\left[-t/\tau\right] + \tau \left(\frac{Q}{V} C_0 + \frac{S}{V}\right)
\]

(2)

Where \(C_0\) was the initial concentration in the room at time 0. The \(\frac{Q}{V}\) value included the air exchange rate (hour\(^{-1}\)) or could be interpreted as the room volume of the air exchange per hour. The solution for the steady-state case from Equation 2 was:

\[
C_{i_{\text{ss}}} = \tau \left(\frac{Q}{V} C_0 + \frac{S}{V}\right)
\]

(3)

Based on Equation 3, the mass balance model for indoor air quality was:

\[
C_{i_{\text{ss}}} = \left(\frac{Q}{V} C_0 + \frac{S}{V}\right) \exp\left[-\frac{t}{\tau}\right]
\]

(4)

or

\[
C_{i_{\text{ss}}} = \left(\frac{AC_0 + S/V}{A + k}\right)
\]

Where \(A = \frac{Q}{V}\) air exchange in each hour (Cooper dan Alley, 2002).

Nevers (1995) examined the indoor air quality model that formulated more realistic and more complex

**Figure 3.** The Flow Chart of Model Constructed with Well-Mixed of Indoor Air (Shair and Heitner 1974).
Figure 3 illustrated that there was a building with air infiltration, ventilation with treatment, and recirculation air with separate treatment. Thus, it could be assumed that the building had perfectly mixed air. This model could be compared with real building conditions, where there were many rooms with simultaneous airflow from one room to another, and had different emission rates and concentrations in several rooms.

The material balance equation for the room in Figure 3 was:

\[
\frac{dC_i}{dt} = \frac{Q_2C_0 + Q_3C_0 (1-\eta_1) + Q_4C_i (1- \eta_2)}{V} - \frac{(Q_2+Q_4+Q_5)C_i + S - R}{V} \]

Where:
- \( \eta_1 \) dan \( \eta_2 \) = removal efficiency of each filter (%)  
- \( Q \) = air flow rate (m\(^3\)/s)  
- \( R \) = pollutant removal rate (μg/s)  
- \( S \) = emission rate (μg/s)  
- \( C_0 \) = outdoor concentration (μg/m\(^3\))  
- \( C_i \) = indoor concentration (μg/m\(^3\))  
- \( t \) = time (s)  
- \( V \) = room volume (m\(^3\))

Figure 3 showed that the filter conducted was a wide-ranging purpose, meaning that this filter could be used not only for one pollutant but also could remove several pollutants.

Nevers (1995) investigated the mass balance model was a simple fixed box model that was applied to buildings with well-mixed of internal air conditions with only one inlet and one outlet, in this case, infiltration and exfiltration. In other words, it illustrated that the airflow into and out of buildings through windows, wall openings and roofs that were driven by wind and/or temperature differences inside and outside the room were not considered. Thus, the treated air (makeup water), recirculated air and air through exhaust were assumed to be zero for this simple box model.

The mass balance of pollutants under steady-state conditions with some of the assumptions was explained as follows:

Outflow pollutant = inbound pollutant flow + emission generated in the room - excluded pollutants. Thus, if this condition was explained in the form of an equation, it could be:

\[
Q_2C_i = Q_1C_0 + S - R \]

Since the changes in temperature and humidity of the air that passed through this structure were ignored, the values of \( Q_2 \) and \( Q_1 \) were approximately equal, so the equation could be simplified to:

\[
C_i = C_0 + \frac{S - R}{Q} \]

2.4. The Estimation of Particulate Matter Emission Rate in Surface Coating Process

Particulate emissions were calculated in three basic stages of surface coating, namely the preparation stage, the painting stage and the equipment cleaning stage (Table 1). Table 1 explained some typical emissions produced at each stage (NPI 1999b).

In the process of surface coating, a significant activity producing PM was the process of rubbing and painting. Generally, the painting process was executed by a spray system. This spraying process produced fine and ultrafine dust or aerosols (NPI 1999a).
Table 1. The Raw Materials Used and Emissions Generated in the Surface Coating Process.

| Process Stages | Raw Material Used | Emissions Generated (According to the List on the NPI) |
|----------------|-------------------|------------------------------------------------------|
| Preparation and Scouring | Sandpaper, solvent, detergent, acid and caustic soda. | Particulates, including lead and other metals, sludge (paint), liquid waste. |
| Painting | Paint, lacquer, varnish, primers. | Individual and total organic compounds in coatings and thinners. |
| Equipment Cleaning | Solvents and thinners | Individual and total organic compounds in coatings and thinners, liquid waste. |

Source: (NPI 1999a, 1999b)

The estimation of many materials from coatings that evaporated in the air during the polishing process was conservatively around to 10% of polishing and painting (NPI 1999a) using the following Equation 8.

\[
PM = A \times OpHrs \times SA \times Po
\]  

Where:

- \( PM \) = the particulate emission rate originating from the scrubbing process (kg/hour)
- \( A \) = the activity rate of scrubbing material usage (kg/hour)
- \( OpHrs \) = total hours of the scrubbing process (hour/day)
- \( SA \) = the percentage of solid ingredients on the scrubbing material.
- \( Po \) = the percentage of PM emitted during the scrubbing process.

Table 2. The Emission Factors of PM10 and PM2.5.

| Surface       | PM Emission Factors, kg/kg sand | PM10  | PM2.5  |
|---------------|---------------------------------|-------|-------|
| Precleaned    |                                 | 0.0099| 0.0018|
| Painted       |                                 | 0.022 | 0.0011|
| Oxidized      |                                 | 0.0074| 0.0011|
| Average       |                                 | 0.013 | 0.013 |

Source: USEPA (1997)

The emission factors of PM emitted from abrasive materials according to USEPA AP-42 (1999) were 0.0099 kg/kg for PM10 and 0.0018 kg/kg for PM2.5.

Whereas the typical density and the percentage of solid ingredients used in coatings were as follows in Table 3.
Table 3. The Typical and Percentage of Solid Density in Surface Coating.

| Type of Coating | Density kg/L | Solids (% in Volume) |
|-----------------|--------------|----------------------|
| Enamel, air dry | 0.91         | 9.1                  |
| Enamel, baking  | 1.09         | 9.1                  |
| Acrylic enamel  | 1.07         | 9.1                  |
| Alkyd enamel    | 0.96         | 9.1                  |
| Primer surfer  | 1.13         | 9.1                  |
| Primer, epoxy   | 1.26         | 10.5                 |
| Varnish, baking | 0.79         | 6.6                  |
| Lacquer, spraying | 0.95   | 7.9                  |
| Vinyl roller   | 0.92         | 7.7                  |
| Polyurethane   | 1.10         | 9.2                  |
| Stain          | 0.88         | 7.3                  |
| Sealer         | 0.84         | 7.0                  |
| Magnet wire, enamel | 0.94 | 7.8                  |
| Paper coating  | 0.92         | 7.7                  |
| Fabric coating | 0.92         | 7.7                  |

Source: USEPA, 1995

The equation applied to estimate the emission rate of PM\textsubscript{10} dan PM\textsubscript{2.5} was as follows in Equation 9.

\[
PM = \rho_n \times S_T \times S_A \times Po
\]  

(9)

Where:
\(\rho_n\) = mixture density.
\(S_T\) = maximum spray gun rate (L/hour).
\(S_A\) = the percentage of solid ingredients on the coating layer.
\(Po\) = the percentage of PM\textsubscript{10} or PM\textsubscript{2.5} during the painting process.

2.5. The Validation of the Mass Balance Model

The performance of the mass balance model was evaluated using the Root Mean Square Error (RMSE), by comparing the concentration of PM measurements with the estimated concentrations using the mass balance model. An evaluation of the model performance was carried out to assess the accuracy of the relative predictions of the model with the results of observations, giving the meaning that a low RMSE closed to real value (Ait-Amir, Pougnet, and El Hami 2015). RMSE values indicated the level of error from the modelling results compared with observation results. The error level of a model was low if it had a total RMSE value closed to zero. Featherstone et al. (1997) examined that the RMSE used to measure the deviation between random variables with some standard or accepted value.

\[
RMSE = \sqrt{\frac{\sum (x_i - a_i)^2}{N}}
\]  

(10)

Where \(x_i\) was a random variable of N data set, and \(a_i\) was the accepted value. This criterion in Equation 10 measured the mean square error committed in the test data. In other words, a low MSE value meant that the predicted values are close to the real values (Ait-Amir et al. 2015).
3. Results and Discussion

The process of the surface coating produced pollutants, namely secondary PM with a very small in size (ultrafine PM) (Lazaridis et al. 2015a). In the finishing room, there were three stages of the process of coating (surface coating), namely the stage of preparation (surface preparation), the stage of painting (painting) and the final stage (drying and storage of finished products). In general, the process can be explained in Figure 4.

![Surface Coating Process Diagram](image)

**Figure 4.** The Flow Diagram of Surface Coating Process.

### 3.1. Measurement of Particulate Matter Concentration

The Measurement of particulate concentrations was carried out at 6 points in the finishing room (Figure 2) with 4 repetitions. USEPA (2004) investigated that the mass balance estimation method was suitable for estimating the emissions from sources that produced evaporated pollutants, assuming 100% of the solvent was released into the air through evaporation.

![PM Concentration Graph](image)

**Figure 5.** The PM$_{10}$ Concentration of PM Measurements. Data presented in mean and standard deviation.

Figure 5 illustrates the largest of PM$_{10}$ mass concentration was point 4 in day 2 of $3.64 \pm 0.06$ mg/m$^3$. The largest mass concentration of PM$_{2.5}$ was also in point 4 in day 2 of $2.36 \pm 0.06$ mg/m$^3$ (Figure 6). Point 3 and point 4 were the area of basic painting. Painting activities generated fine PM that was
produced secondary PM by a chemical reaction between volatile organic compound (VOC) and ozone and ambient air (Celebi and Vardar 2008b; Lazaridis et al. 2015b).

The process sequence of the surface coating after the basic painting was blasting/scrubbing that was carried out at area point 3 and 4 as well. The scrubbing process produced coarse PM. The coarse PM had a significant influence on the mass PM, unlike fine PM that had no effects on the mass PM (Kelly and Fussell 2012). Giving evidence why point 3 and 4 illustrated the largest mass-PM both PM10 and PM2.5.

3.2. The Measurement of Air Flow and Air Velocity
The surface coating process carried out in the finishing room was surface preparation and basic painting. The room had an area of 22.66 m², not completely closed because it was only given a dividing partition with another room, with a height of 5.4 m. There was no filter or blower in this room, only employed openings of 13.2 m². Given the absence of mechanical ventilation in this room, the airflow was low, as listed in Figure 7.

Figure 6. The PM2.5 Concentration of PM Measurements.
Data presented in mean and standard deviation.

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Figure 7. The Airflow and Air Velocity of Measurement.
Data presented in Mean of Each Day Measurements.

Figure 7 illustrates the air velocity was very low because there were only some fans in the large room. While the airflow was high enough, thus it fulfilled the Standard Nasional Indonesia (SNI 2001) threshold value, that the minimum value of Air Change per Hour (ACH) was 6.
3.3. The Estimation of Emission Rate in Surface Coating Process

The surface coating process included three stages as described in Figure 4, thus, the emission rate was determined in every each of these stages.

3.3.1. The Estimation Emission Rate in The Surface Preparation.

The preparation stage (surface preparation) was the initial stage before the wood/raw material was painted. The purpose of this step was to close the wooden pores to make them appeared smoother. The materials applied at this stage were fillers and thinners. After giving the filler (putty), the wood was then scrubbed using sequential sandpaper starting from number 180, number 240 and finally number 400. Scrubbing in the process of surface coating aimed to roughen the material surface as preparation for painting and coating (Lee, 2009). The scrubbing process was conducted 2 times. The first scrubbing was executed after giving filler (putty) and the second scrubbing was carried out after basic painting. The emission rate resulting from the scrubbing process could be calculated using Equation 8. According to USEPA (1997), S_A values for primary surfaces and the emission factors of PM that were released during surface preparation referred to Table 2 (USEPA 1995).

![Figure 8. Particulate Matter Emission Rate on Surface Coating.](image)

The emissions rate resulting from the scrubbing activity illustrated in Table 4.

| Surface Coating Activity | Emission Rate (mg/hour) |
|--------------------------|-------------------------|
|                          | PM_{10}                 | PM_{2.5}               |
| Scrubbing                |                         |                        |
| First scrubbing          | 16,41.10^2              | 2,98.10^2              |
| Second scrubbing         | 36,47.10^2              | 1,82.10^2              |
| Painting                 |                         |                        |
| Basic painting           | 36,47.10^2              | 1,82.10^2              |
| Total                    | 5325,29                 | 487,24                 |

3.3.2. The Estimation of Emission Rate in The Painting Process.

The painting process was carried out by spraying using a spray gun. This process included basic painting and final painting. The painting process executed in the finishing room was basic painting. Whereas the final painting was conducted in a separate room. The composition of the paint layer applied in the basic painting process was colouring (stain), hardener and thinner. While the spray gun used was a high-volume low pressure (HVLP) type with a transfer efficiency of 65%. The particulate emission rate that results from the painting process according to Equation 9. The mixture density of the painting solution was 1,1247 kg/m^3 and the maximum spray gun rate was 2.4 L/ hour. USEPA (1995) examined that S_A value for epoxy primers referred to Table 3. According to USEPA (1995), the Po value for PM_{10} was 0.069 and 0.0134 for PM_{2.5}. Thus, the emission rate from the base painting activity for PM_{10} was 37.29 mg/hour,
while for PM$_{2.5}$ was 7.24 mg/hour (Figure 8). The total emission rate generated in the coating process (surface coating) in the finishing room shows in Table 4.

3.4. The Mass Balance Model

In the finishing room, there was no exhaust fan. It was assumed there was no pollutant removal process in the finishing room ($R = 0$), thus, Equation 7 for the estimated PM$_{2.5}$ concentration on the first day became:

$$C_{PM} = C_0 + \frac{\delta}{Q}$$

(11)

Table 5. The Estimation of PM Concentration.

| Days   | Concentration $C_0$ (mg/m$^3$) | Concentration Estimation Results (mg/m$^3$) |
|--------|-------------------------------|--------------------------------------------|
|        | PM$_{10}$ Out1 Out2 | PM$_{2.5}$ Out1 Out2 | PM$_{10}$ Out1 Out2 | PM$_{2.5}$ Out1 Out2 |
| First  | 0.61 0.61 | 1.03 1.03 | 1.64 1.64 | 2.67 2.67 |
| Second | 0.67 0.85 | 1.21 1.21 | 1.82 1.82 | 3.03 3.03 |
| Third  | 0.79 1.05 | 1.25 1.25 | 1.74 1.74 | 2.99 2.99 |
| Fourth | 0.80 1.00 | 1.40 1.40 | 1.75 1.75 | 3.15 3.15 |

Out1 = outdoor 1; Out2 = outdoor 2

Cooper and Alley (2002) investigated that the concentration of indoor air contaminants could be predicted using a simple mathematical model, with the key variables being the emission rate and ventilation rate. The concentration of PM$_{10}$ and PM$_{2.5}$ was estimated for 4 days as illustrated in Table 5. The results show that the estimated PM$_{10}$ and PM$_{2.5}$ concentrations had the accuracy of up to 10$^{-5}$ (for example, the estimated PM$_{2.5}$ results on the first day was 2.670373). However, considering the accuracy of the measuring instrument just only reached 10$^{-3}$ (two digits after the decimal point), the results were depicted two digits after the decimal point. Regarded on the estimated concentration of PM$_{10}$ and PM$_{2.5}$ on 4 days of sampling, it could be calculated the estimated concentration of PM$_{10}$ and PM$_{2.5}$ that left in the room after the work process was finished (after 7 hours of work) using Equation 7. There was no air treated through the filter ($R = 0$), no air recirculated ($Q_3 = 0$) and there was no exhaust fan ($Q_4$ and $Q_5 = 0$), thus, the equation was only influenced by infiltrated air into the room. So, Equation 7 modified as followed in Equation 12.

$$\frac{dC_i}{dt} = Q_1 C_0 - Q_2 C_i\quad (\frac{c_o - c_i}{(c_o - c_i)}\text{inhal})$$

(12)

The estimation of PM concentration was determined using Equation 12, and the results were depicted in Table 6.
Table 6. The Estimation of PM Concentration that was Left Behind in the Finishing Room.

| Day   | Concentration $C_0$ (mg/m$^3$) | Concentration Estimation Results left (mg/m$^3$) |
|-------|-------------------------------|-----------------------------------------------|
|       | PM$_{10}$ | PM$_{2.5}$ | PM$_{10}$ | PM$_{2.5}$ |
| Out1  | Out2     | Out1       | Out2         |
| First | 0.61     | 0.61       | 1.03        | 1.64       |
| Second| 0.67     | 0.85       | 1.21        | 1.82       |
| Third | 0.79     | 1.05       | 1.25        | 1.74       |
| Fourth| 0.80     | 1.00       | 1.40        | 1.75       |

Even if the estimation of PM concentration were left behind in the room as though the same every day, so as if there was no PM$_{10}$ and PM$_{2.5}$ were out of the room. However, there was a small portion of PM$_{10}$ and PM$_{2.5}$ concentration that flew out of the room, more or less under $\frac{1}{100}$ mg/m$^3$. It related to adjusts of the accuracy of the measuring instrument.

3.5. Model Validation with Root Mean Square Error (RMSE)

The root meant square error (RMSE) (Equation 10) was employed to measure the deviation between the random variable with some standard or accepted value. Sivacoumar (2001) examined the error rate of a model was proven to be low if the RMSE value close to zero (Figure 9). The intended random variable was the result of the estimated calculation of PM$_{10}$ and PM$_{2.5}$ concentrations in the room and the accepted value referred to the PM measurement.

![Figure 9. The Root Mean Square Error of PM Concentration.](image)

The RMSE value shows that the bias (error) between PM measurement and the estimated results of PM concentrations was small (close to zero). It meant that the model estimation of PM concentration was close to the actual value (the PM measurement). Giving evidence that the mass balance model was reliable to estimate PM$_{10}$ and PM$_{2.5}$ concentrations.

4. Conclusion

The application of spray-painting operation generates the paint mist that releases to the environment and then flies in the air; thus, it can pollute the environment and endanger human health. Volatile organic compounds (VOCs) from painting solvents are one of the most important sources of pollutant outputs for the shipbuilding and ship repair industry. The concentration of particulates (PM$_{10}$ and PM$_{2.5}$) in the room can be estimated using the mass balance model. The mass balance model is a simple mathematical model that can be used to estimate particulates (PM$_{10}$ and PM$_{2.5}$) in the room. This is evidenced by the value of the root mean square error (RMSE) is small (close to zero), so it can be concluded that the error (error)
from the estimated results of particulate concentrations (PM$_{10}$ and PM$_{2.5}$) to the results of small measurements or estimated values close to the actual value (value of measurement results).

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