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Analysis of Air Quality and Health Risks Among Workers at the Integrated Waste Processing Site

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ABSTRACT

This study analyzes the air quality and associated health risks for workers at the Integrated Waste Processing Site (TPST) BLE in Banyumas Regency, particularly in the incineration area. Measurements using a Low Volume Air Sampler (LVAS), Indoor Air Quality Meter, and Particulate Counter showed that PM2.5 (1,429 µg/m³) and PM10 (1,975 µg/m³) levels far exceeded the limits set by national standards, while CO and CO_2 remained within safe thresholds. The intake value of respirable dust for workers was 0.0076 mg/kg/day, with a Risk Quotient (RQ) of 0.0133, indicating no immediate risk. However, CO_2 showed an RQ of 1.184, exceeding safe thresholds and suggesting potential chronic health effects. Despite most pollutants being within safe limits, workers still reported fatigue symptoms and respiratory complaints. This research highlights the urgent need for improved air pollution control, consistent monitoring, and stronger implementation of occupational safety measures to protect workers' health.

Keywords: Air quality, Air pollution, Respirable dust, TPST BLE, Worker health

1. Introduction

Indoor environmental quality has a significant impact on human well-being and productivity, considering that around 90% of a person's time is spent indoors, both at home and at work (Leech et al., 2002). According to WHO (2020), indoor air pollution (IAP) is responsible for 3.8 million deaths each year. The main sources of IAP come from occupant activities, such as cooking, smoking, use of electronic equipment, and emissions from building materials. Common hazardous pollutants found include carbon monoxide (CO), volatile organic compounds (VOCs), fine particles (PM), and microorganisms (Kumar & Imam, 2013).

Exposure to IAP in the short and long term can cause various serious diseases (Hromadka et al., 2017). The effectiveness of controlling indoor air quality (IAQ) is highly dependent on the recognition of major pollutants, such as NOx, VOC, SO2, O3, CO, PM, and microorganisms (OSHA, 2021). Airborne particulates (PM) are classified by size into PM10, PM2.5, and PM0.1, with smaller particles being more dangerous because they can penetrate the lungs and cause serious health problems (USEPA, 2021). Sources of indoor PM include pollutants from outside as well as activities such as cooking and burning fossil fuels (Brook et al., 2010). Nitrogen dioxide (NO2) is produced from combustion processes, including the use of gas stoves and space heaters. Exposure to NO2 can cause respiratory tract irritation, bronchitis, and lung infections, and in the long term can affect lung function (USEPA, 2021). Sulfur dioxide (SO2) and carbon monoxide (CO) which also come from fuel combustion can have negative impacts on the respiratory and cardiovascular systems. High concentrations of CO can even cause death (Raub et al., 2000).

Workers at the Integrated Waste Processing Site (TPST) in Banyumas Regency are at high risk of experiencing health problems due to direct exposure to hazardous pollutants produced during the waste processing process, especially in the burning area. Therefore, TPST workers are highly likely to experience health problems.

Due to pollution. Some diseases that can arise include irritation of the mucous membranes, nose, and throat, neurotoxic disorders, lung disorders, and decreased concentration (Carrer & Wolkoff, 2018). The health impacts caused depend on the level and duration of exposure, as well as the individual's health condition. Therefore, air pollution control must be carried out without disrupting human activities so that health risks can be minimized (Kornelis, 2016).

The purpose of this study was to determine the air quality in the combustion process area at the Integrated Waste Processing Facility (TPST 3R) in Banyumas Regency. The specific objectives of this study were to measure the amount of intake or the amount of dust or pollutants that entered the lungs of workers and to conduct a comparative evaluation of air quality at the research location based on the established NAB standards.

The benefits of this study are to provide information on the importance of controlling air quality in the workplace, especially in integrated waste processing facilities, to increase worker awareness of the impact of air pollution on health. This study is also expected to be a basis for further, more comprehensive research, thus contributing to an increased understanding of the impact of air pollutant exposure on workers' health and the development of effective prevention and treatment.

2. Material And Methods

2.1 Time and Location of the Study

The study was conducted at the Environmental and Education-Based Final Processing Site (TPA), Dusun I, Wlahar Wetan, Kalibagor District, Banyumas Regency, Central Java and This research was conducted on January 13-18, 2025. Banyumas Environmental and Education-based Final Processing Site (TPST-TPA BLE) is a waste processing facility under the Banyumas Regency Environmental Agency that aims to reduce waste generation through various sustainable methods. Every day, TPST-TPA BLE receives 11-20 dump trucks of waste that are processed through sorting, shredding, composting, maggot cultivation, plastic ore and paving block production, as well as residue processing into Refuse-Derived Fuel (RDF) as an alternative fuel for the cement industry.

One of the main processes at TPST-TPA BLE is the combustion of waste residues using the pyrolysis method with five units of combustion equipment to significantly reduce the volume of waste. In addition, a leachate treatment system is implemented to reduce environmental pollution. The entire operation of TPST-TPA BLE is supported by 99 workers in the Technical Implementation Unit (UPT) who ensure each process runs effectively and sustainably.

Figure 1. Study Location

2.2 Research Type

The type of research conducted uses a quantitative observation method where data is taken directly using a calibrated measuring instrument at the research location. In this study, the samples used were workers and the environment in the combustion process at the BLE TPST, Banyumas Regency. In this study, the samples used were workers and the environment in the combustion process at TPST BLE Banyumas Regency. The sampling technique was carried out using a purposive sampling technique, where samples were selected based on certain criteria that were relevant to the research, namely workers and the environment in the combustion process.

2.2.1 Tools and Materials

a. Low Volume Air Sampler
   LVS-15 from Unedo Science, with adjustable flow rates of 3–15 LPM.
b. Particulate Counter
   DT-96 model from CEM provides real-time particle readings along with temperature and humidity.
c. Indoor Air Quality
   SI-AQ VOC Monitor from SAUERMANN, used to measure VOCs, CO, CO_2, and other gases.
d. Glass Microfiber Filter
   Grade A-E, 4.7 cm, from Zefon International.
e. Analytical Scales
   Type FSR-B from Fujitsu, with 600g capacity.
f. Tweezerz
   Straight taper tweezers from Mechanic.

2.2.2 Working Principle

This study was conducted by capturing dust generated from the combustion process at the BLE TPST-TPA using filters and Low Volume Air Sampler (LVAS) equipment. The captured dust was then analyzed to determine the level of respirable dust, intake value, and health risk ratio.

In addition, air quality measurements around the combustion site were conducted using an Indoor Air Quality and Particulate Counter tool to determine the concentration of airborne particles. The data obtained is compared with the applicable Threshold Value (NAB) to assess the level of pollution, namely the NAB in Minister of Manpower Regulation No. 5 of 2018 and Government Regulation No. 22 of 2021. This analysis is used as a basis for making decisions and recommendations to reduce environmental and health impacts due to the combustion process at TPST-TPA BLE.

3. Results and Discussion

3.1 Combustion Chamber Condition

The combustion room at the Reduce, Reuse, Recycle (3R) Integrated Waste Processing Facility (TPST) in Banyumas Regency is equipped with five combustion engines, but only four units are operating. The combustion process at this facility produces a large flame with thick smoke output that can be seen spreading inside the room. The semi-open building structure with a high roof and adequate ventilation allows smoke to move out, but still creates a work environment filled with combustion particles. Piles of garbage around the combustion engine indicate that the operational process is running continuously, with workers actively involved in waste management. This condition reflects intensive combustion activity and requires regular monitoring to ensure machine efficiency and worker safety in the room.

Combustion

Condition of Combustion Room

Figure 2. BLE Process

3.2 Respirable Dust

Table 1. Respirable Dust Measurement Result

Time	Jan 14	Jan 15	Jan 16	Jan 17	Jan 18
Morning	0,139g	0,139g	0,141g	0,139g	0,141g
Afternoon	0,14g	0,14g	0,14g	0,14g	0,139g

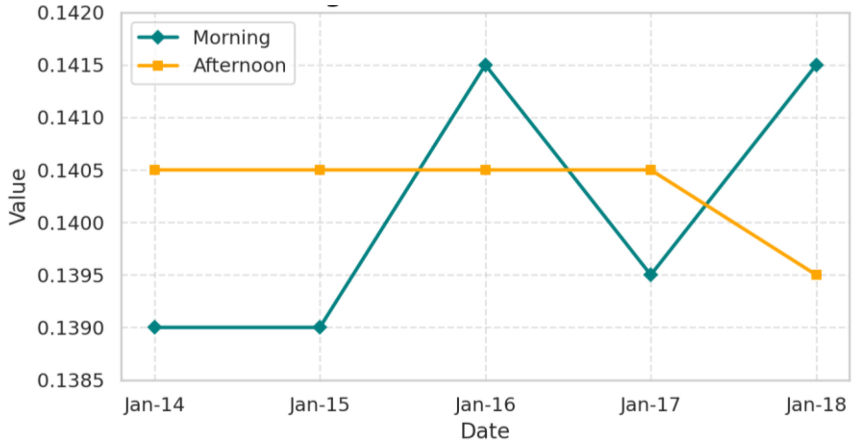

Figure 3. Respirable dust measurement result

The respirable dust measurement results showed an increase in particle mass on the filter after sampling, both in the morning and afternoon. The average filter mass before sampling was 0.138 grams, increasing to 0.140 grams in the morning and 0.141 grams in the afternoon. This increase in particle mass indicates the presence of pollutants in the air, which could pose a risk to workers, thus requiring regular air quality monitoring. After knowing the respirable dust value obtained, then analyze the respirable dust content by TPST BLE Banyumas combustion workers using the following formula:

$$C = \frac{(W2 - W1) - (B2 - B1)}{V} X\ 10^2 mg/m^3$$

In the morning session, the calculated dust level reached 1.67 mg/m³, while in the afternoon it increased to 2.5 mg/m³. The accumulated dust level throughout the measurement period reached 4.17 mg/m³, indicating high dust exposure in the work environment. These results indicate that combustion activities contribute to elevated respirable dust concentrations, which are potentially harmful to workers' health, especially in the long term. The next analysis is to calculate the intake value to determine the exposure to workers. Calculating the intake value of combustion workers using the following equation (I):

$$\frac{CRt_E f_E D_t}{W_b t_{avg}}$$

The following is the intake result of one of the TPST BLE Banyumas combustion workers.

$$I = \frac{4{,}17\ x\ 0{,}83\ x\ 6\ x\ 312\ x\ 3}{97\ x\ 26280}$$

$$I = 0{,}0076 \frac{mg}{kg} /day$$

The maximum respirable dust intake value for combustion workers with an average weight of 97kg and working frequency of 6 hours per day and exposure duration of 3 years is 0.0076 mg/kg/day.

3.3 PM 2.5

Table 2. PM 2.5 Measurement Result

Time	Jan 14	Jan 15	Jan 16	Jan 17	Jan 18
Morning	1171 µg/m³	921 µg/m³	697 µg/m³	798 µg/m³	181 µg/m³
Afternoon	947 µg/m³	1425 µg/m³	1300 µg/m³	881 µg/m³	265 µg/m³

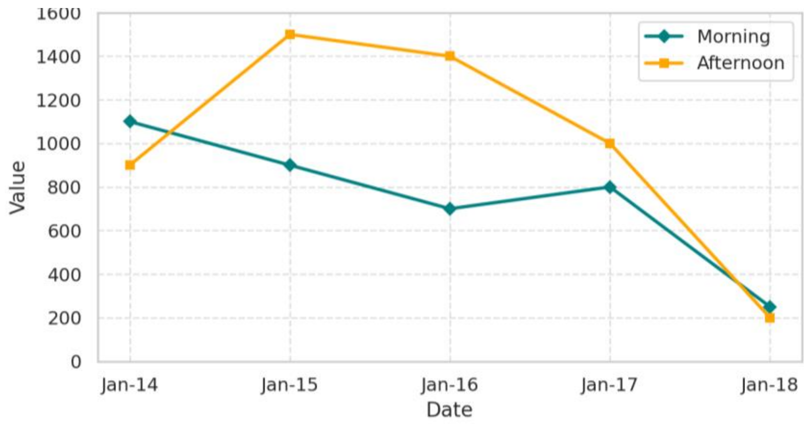

Figure 4 PM 2.5 Measurement Result

The graph shows the trend of PM 2.5 levels in the morning and afternoon from January 14 to 18. Daytime PM 2.5 levels were generally higher than morning levels, with the highest peak on January 15 (1500 μg/m³). Thereafter, PM 2.5 levels decreased gradually until January 18, where morning and afternoon levels were almost equal at the lowest level. When compared to the Threshold Value (NAB) of PM 2.5 based on Government Regulation No. 22 of 2021, which is 55 μg/m³ for daily average, these measurement results far exceed the safe limit. These high concentrations have the potential to adversely affect workers' health.

$$\frac{1{,}425 x\ 0{,}83\ x\ 6\ x\ 312\ x\ 3}{97\ x\ 26280}$$

$$I = 0{,}0026 \frac{mg}{kg} / day$$

With the high concentration of PM 2.5 detected, the next step is to calculate the PM 2.5 intake value to evaluate the potential exposure to workers.

3.4 PM 10

Table 3. PM 10 measurement result

Time	Jan 14	Jan 15	Jan 16	Jan 17	Jan 18
Morning	1171 μg/m³	921 μg/m³	697 μg/m³	798 μg/m³	181 μg/m³
Afternoon	947 μg/m³	1425 μg/m³	1300 μg/m³	881 μg/m³	265 μg/m³

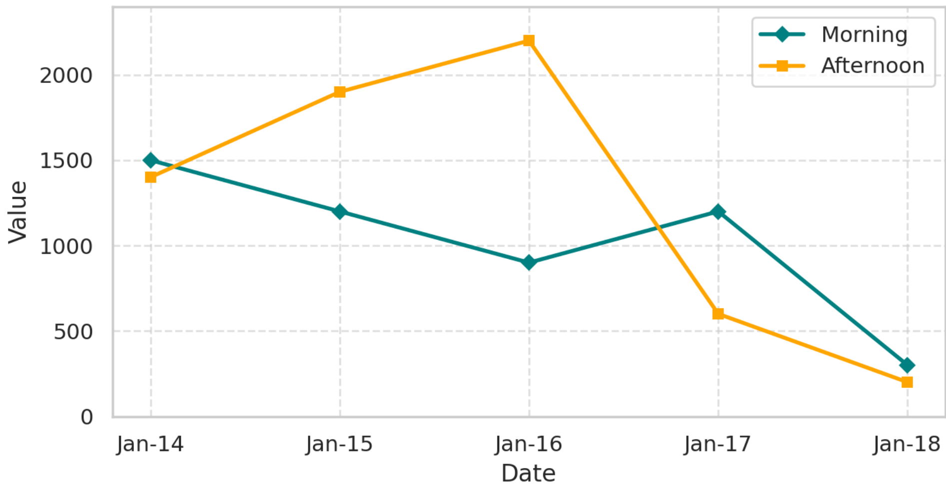

Figure 5. PM 10 Measurement Result

The graph shows the measurement results of PM10 levels in the morning and afternoon from January 14 to 18. In general, PM10 concentrations during the day were higher than in the morning, with the highest peak occurring on January 16 (2100 µg/m³). After that, PM10 levels decreased significantly, especially on January 17 and 18, where morning and afternoon levels were almost the same at the lowest level. When compared to the PM10 Threshold Value (NAB) based on Government Regulation No. 22 of 2021, which is 150 µg/m³ for daily average, these measurement results far exceed the safe limit. These high concentrations have the potential to cause health impacts such as respiratory tract irritation, lung disorders, increased risk of cardiovascular disease, and worsen the condition of people with asthma and chronic obstructive pulmonary disease (COPD). With the high concentration of PM 10 detected, the next step is to calculate the PM 10 intake value to evaluate the potential exposure to workers.

$$I = \frac{2 \times 0{,}83 \times 6 \times 312 \times 3}{97 \times 26280}$$
$$I = 0{,}0037 \frac{mg}{kg} / day$$

The intake value of PM 10 with an average weight of 97kg and the frequency of working for 6 hours per day and the duration of exposure for 3 years is 0.0037 mg/kg/day. 97kg and the frequency of working for 6 hours per day and the duration of exposure for 3 years is 0.0037 mg/kg/day.

3.5 CO₂

Table 4. CO_2 measurement result

Time	Jan 14	Jan 15	Jan 16	Jan 17	Jan 18
Morning	134 ppm	155 ppm	95 ppm	154 ppm	26 ppm
Afternoon	51 ppm	82 ppm	74 ppm	90 ppm	12 ppm

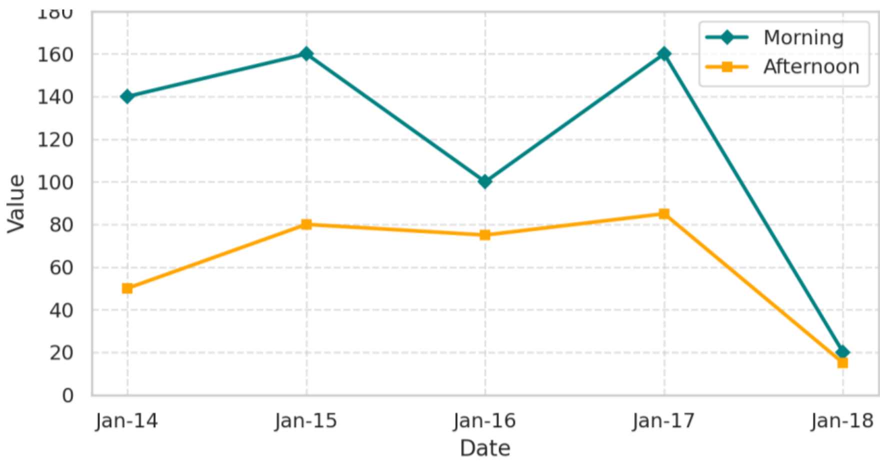

Figure 6. CO_2 measurement result

The graph shows the measurement results of CO_2 levels in the morning and afternoon from January 14 to 18. In general, CO_2 levels in the morning were higher than during the day, with the highest peaks occurring on January 15 and 17 (180 ppm). Meanwhile, CO_2 levels during the day were relatively more stable with a slight increase on January 17 before decreasing significantly on January 18.

Based on Permenaker No. 5/2018, the Threshold Value (NAB) of CO_2 in the workplace is 5000 ppm for an exposure time of 8 hours per day. The measurement results in this graph are still far below the set NAB, so there is no risk to the health of workers under normal conditions. However, while CO_2 levels are still within safe limits, higher than normal concentrations can cause symptoms such as fatigue, headaches and decreased concentration.

Although CO_2 measurement results did not exceed the Threshold Value (NAB), calculations of intake values were still conducted to evaluate the potential exposure to workers.

$$I = \frac{324 \times 0{,}83 \times 6 \times 312 \times 3}{97 \times 26280}$$
$$I = 0{,}592 \frac{mg}{kg} / day$$

The intake value of CO_2 with an average weight of 97kg and working frequency of 6 hours per day and exposure duration of 3 years is 0.592 mg/kg/day.

3.6 CO

Table 5. CO measurement result

Time	Jan 14	Jan 15	Jan 16	Jan 17	Jan 18
Morning	7,7 ppm	2,8 ppm	5,6 ppm	7,9 ppm	0,4 ppm
Afternoon	5,7 ppm	4,6 ppm	4,8 ppm	7,1 ppm	2,7 ppm

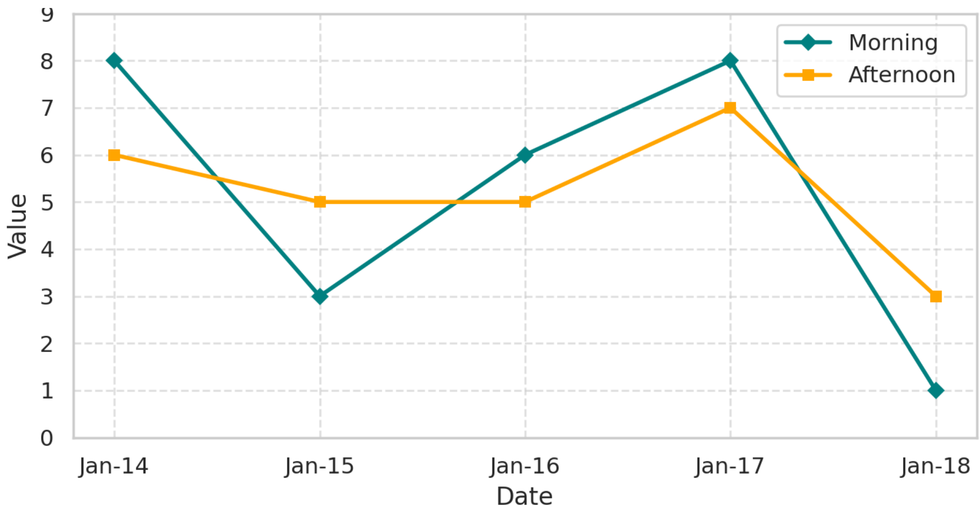

Figure 7. CO measurement result

The graph shows the measurement results of carbon monoxide (CO) levels in the morning and afternoon from January 14 to 18. In general, CO levels fluctuated, with the highest level recorded on January 17 (8 ppm) and the lowest on January 18 in the morning (1 ppm). At the start of the measurement, morning CO levels were higher than afternoon CO levels, but this pattern changed after January 16, where daytime CO levels tended to be higher until they decreased significantly on January 18.

According to Permenaker No. 5 Year 2018, the Threshold Value (NAB) of CO in the workplace is 25 ppm for an exposure time of 8 hours per day. These measurement results show that CO levels are still far below the safe limit, so they do not pose an acute risk to workers under normal conditions. However, even within safe limits, long-term exposure to CO or in poorly ventilated spaces can still cause health problems such as dizziness, nausea, respiratory problems, and decreased oxygen capacity in the blood. Although CO measurement results did not exceed the Threshold Value (NAB), calculations of intake values were still conducted to evaluate the potential exposure to workers.

$$I = \frac{9{,}16 \; x \; 0{,}83 \; x \; 6 \; x \; 312 \; x \; 3}{97 \; x \; 26280}$$

$$I = 0{,}0167 \frac{mg}{kg} /$$

The intake value of PM CO with an average weight of 97kg and working frequency of 6 hours per day and exposure duration of 3 years is 0.0167 mg/kg/day.

3.7 Risk Characterization

The Risk Quotient (RQ) calculation is done by comparing the Intake and Reference (RFC) values. This RQ value is used to determine the level of health risk due to exposure to risk agents.

Table 6. Reference (RFC) values

Respirable Dust	0,57	Pulmonary disorders	NIOSH, 2019
PM 2,5	1,2	Respiratory, cardiovascular disorders	US-EPA
PM 10	1,57	Respiratory tract disorders	US-EPA, 2018
CO2	0,5	Respiratory tract disorders	US-EPA

CO	7,67	Respiratory tract disorders	Tualeka, 2013

The Risk Quotient (RQ) calculation uses the following equation:

$$RQ = \frac{I}{RFC}$$

The following are the results of the Risk Quotient (RQ) calculation of each risk agent.

Table 7. RQ values

Risk Agents	Intake Values	RQ Values	Category
Respirable Dust	0.0076 mg/kg/day	$RQ = \frac{0,0076}{0,57} = 0,0133$	Safe
PM 2.5	0.0026 mg/kg/day	$RQ = \frac{0,0026}{1,2} = 0,00217$	Safe
PM 10	0.0037 mg/kg/day	$RQ = \frac{0,0037}{1,57} = 0,00236$	Safe
CO2	0.592 mg/kg/day	$RQ = \frac{0,592}{0,5} = 1,184$	Risk
CO	0.0167 mg/kg/day	$RQ = \frac{0,0167}{7,67} = 0,00218$	Safe

The calculation results show that the RQ value for respirable dust is 0.0133. This value RQ < 1, which means that exposure to respirable dust is still in the category of no risk or safe to health. The RQ value obtained for PM 2.5 is 0.00217. With RQ < 1, this indicates that the exposure level of PM 2.5 is still in the category of no risk or safe to health. The RQ value for PM 10 is 0.00236. Since RQ < 1, exposure to PM 10 is also categorized as no risk or safe to health. The calculation shows a CO_2 RQ value of 1.184. With an RQ > 1, CO_2 exposure falls into the health risk category, indicating the potential for negative impacts if exposure continues for a long period of time. The RQ value for CO is 0.00218. With RQ < 1, CO exposure is in the category of no risk or safe to health.

Although five of the 4 risk agents are still in the non-risk category, but based on the results of the questionnaire on fatigue, based on the IFRC method with a total sample of 20, complaints such as symptoms of dizziness, difficulty breathing, heavy eyes, forgetfulness, and difficulty concentrating were obtained. Based on observations, the workers at the kiln also have a habit of smoking even when doing work.

4. Conclusion

The air quality analysis at TPST-TPA BLE Banyumas indicates that the combustion process produces high concentrations of airborne pollutants. PM2.5 (1,429 µg/m³) and PM10 (1,975 µg/m³) exceed the permissible limits, while CO and CO_2 remain within safe thresholds. The respirable dust intake value for workers is 0.0076 mg/kg/day. Based on Risk Quotient (RQ) calculations, respirable dust has an RQ of 0.0133, PM2.5 has an RQ of 0.00217, PM10 has an RQ of 0.00236, and CO has an RQ of 0.00218, all of which are categorized as non-risk (RQ < 1). However, CO_2 has an RQ of 1.184 (RQ > 1), indicating a potential health risk if exposure continues over an extended period. Despite most pollutants being within safe limits, some workers still report symptoms such as dizziness, breathing difficulties, and reduced concentration, suggesting possible exposure effects in the work environment

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References

Arba, S., 2019. Concentration of Respirable Dust Particulate Matter (PM2.5) and Health Problems in Communities in Settlements Around PLTU. *Promot J Public Health*, 9(2), 178–184.

Azuma, K., Kagi, N., Yanagi, U. and Osawa, H., 2018. Effects of low-level inhalation exposure to carbon dioxide in indoor environments: A short review on human health and psychomotor performance. *Environment International*, 121(June), 51–56.

Carrer, P. and Wolkoff, P., 2018. Assessment of Indoor Air Quality Problems in Office Like Environments: Role of Occupational Health Services. *International Journal of Environmental Research and Public Health*, 15(4).

Gunaprawira, K.M., Sumeru, S. and Sutandi, T., 2021. Analysis of PM10 and PM2.5 Concentrations in Railway, Bus, City Transportation, New Car, and Old Car Modes of Transportation. *Proceedings of Industrial Research Workshop and National Seminar*, 12, pp.840–845.

Hong, Y., Luepker, R.V., Mittleman, M.A., Peters, A., Siscovick, D., Smith, S.C., Whitsel, L. and Kaufman, J.D., 2010. Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. *Circulation*, 121(21), 2331–2378.

Hromadka, J., Korposh, S., Partridge, M.C., James, S.W., Davis, F., Crump, D. and Tatam, R.P., 2017. Multi-parameter measurements using optical fibre long period gratings for indoor air quality monitoring. *Sensors and Actuators B: Chemical*, 244, 217–225.

Kumar, P. and Imam, B., 2013. Footprints of air pollution and changing environment on the sustainability of built infrastructure. *Science of the Total Environment*, 444, 85–101.

Leech, J.A., Nelson, W.C., Burnett, R.T., Aaron, S. and Raizenne, M.E., 2002. It's about time: A comparison of Canadian and American time-activity patterns. *Journal of Exposure Analysis and Environmental Epidemiology*, 12(6), 427–432.

Ma'rufi, I., 2017. Environmental Health Risk Analysis (Sos, H_2S, NO_2, and TSP due to Motor Vehicle Transportation in Surabaya City). *Media Pharmaceutica Indonesiana*, 1(4), December.

Mukono, H.J., 2000. *Basic Principles of Environmental Health*. Surabaya: Airlangga University Press.

Nurfadillah, A.R. and K, S.B., 2023. Risk Assessment of Total Suspended Particulate Exposure in the Community. *Jambura Health and Sport Journal*, 5(2), 104–113.

Permatasari, Y., 2013. Overview of Air Quality (NOx and Dust), Individual Characteristics and Pulmonary Function Status of Freight Transport Workers (Morning Shift) at Purabaya Terminal Surabaya. Thesis. Surabaya: Airlangga University.

Putranto, A., 2007. Wood Dust Exposure (PM10) and Respiratory Disease Symptoms in Informal Sector Furniture Workers in Pontianak City, West Kalimantan. Thesis. Jakarta: University of Indonesia.

Raub, J.A., Mathieu-Nolf, M., Hampson, N.B. and Thom, S.R., 2000. Carbon monoxide poisoning – A public health perspective. *Toxicology*, 145(1), 1–14.

Sari, M., Santi, D.N. and Chahaya, I., 2013. Analysis of Airborne CO and NO Levels and Complaints of Respiratory Disorders Among Street Vendors in Sangkumpal Bonang Market, Padangsidimpuan City. *Journal of North Sumatra University*.

Sastrawijaya, A.T., 2009. *Environmental Pollution*. Jakarta: Rineka Cipta.

United States Environmental Protection Agency (US-EPA), 2014. Integrated Science Assessment (ISA) for Particulate Matter. [online] Available at: http://www.epa.gov/ncea/isa/ [Accessed 5 December 2014].

WHO, 2020. *Air pollution and child health: Prescribing clean air*. Geneva: World Health Organization.

Zhang, X., Wargocki, P., Lian, Z. and Thyregod, C., 2017. Effects of exposure to carbon dioxide and bioeffluents on perceived air quality, self-assessed acute health symptoms, and cognitive performance. *Indoor Air*, 27(1), 47–64.