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RISK ASSESSMENT OF EXPOSURE TO CARBON MONOXIDE IN A RESIDENTIAL AREA AROUND TOFU MANUFACTURING

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Abstract

Introduction: *The combustion process during the production of tofu leads to the release of Carbon monoxide (CO). This study aimed to analyze the environmental risks of exposure to CO in people residing near the tofu factories in Sidoarjo, Indonesia.* ***Methods:*** *This was an analytic study using a cross-sectional design. Data were obtained from laboratory experiments, interviews, and observations. Five locations of the tofu manufacturing areas as a research location.* ***Results and Discussion:*** *The average CO concentration in five locations was below the quality standard at 54.50 µg/m3. The hazard identification showed CO could have non-carcinogenic health risks. The respondents near the tofu industry inhaled 5.63 µg/kg/day CO in average. Furthermore, at all of the locations, the CO toxic agents in the air have a rate of RQ > 1. This showed that respondents with 55 kg body weight could be exposed to CO for 8 hours/day or for 312 days/year. As a result, the exposure to CO is unsafe or likely to result in non-carcinogenic effects on the residents in the next 30 years.* ***Conclusion:*** *CO concentration in all tofu manufacturing areas was below the quality standard and could cause health problems. Residents around the factory are advised to avoid exhaust gas emissions from tofu factories by providing an air exhaust system. The residents also can reduce the exposure by using a mask when outdoor activity.*

INTRODUCTION

Air is an important factor for all living things. Physical or chemical material or substance that contaminates the air causes air pollution which is undetectable by humans until it reaches a certain amount. Air pollution is the consequences from daily activities that carried out by humans in the world.

Furthermore, manufacture is one of the major sources of gas waste (1) which is composed of carbon monoxide, carbon dioxide, carbon disulfide, hydrogen sulfide, hydrogen chloride, nitrogen oxides, vitriol fog, fluoride, chlorine, lead, mercury, beryllium, soot, and industrial dust. These gases are generated during the process of fuel combustion and industrial production. When flowing to the atmosphere, they contaminate the air, making it harmful to human health (2-3). Qualitative and quantitative studies have also shown a correlation between pollutant emission from fuel combustion production and air quality (4).

The Sidoarjo District Environment and Sanitation Service and the Director General of Waste, Hazardous, Toxic and Waste Management of the Indonesian Ministry of Environment, inspected one of the tofu factories in Klagen Hamlet RT 1 RW 4, Tropodo village, Krian, Sidoarjo. The results of the inspection showed that aluminum foil and plastics were used as fuel for the tofu production. Carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NOx), Furan, and Dioxin are hazardous gases that burnt wastes yield. In this case, CO is a dangerous air pollutant as a result of industrial combustion. It may result in negative effects on animals, for example hormonal system changes, fetal growth changes, decreased reproductive capacity, and immune system suppression.

The CO concentration above 800 ppm indoors may endanger human's health because it causes tissue hypoxia which symptoms include weakness, nausea, vomiting, vertigo, and death. As a result of CO poisoning, tissue hypoxia reduces the ability of hemoglobin (Hb) to bond with O_2 because CO stronger to bond Hb compared to oxygen. Therefore, it reacts easily with blood to form carboxyhemoglobin (COHb) which can disrupt blood to transport oxygen. Burnt waste can produce CO (which is colorless, odorless, and tasteless) that is hardly detected. Temperatures are directly proportional to the CO concentration, i.e., higher temperature leading to a higher CO concentration.

According to the Occupational Safety and Health Administration (OSHA), the CO threshold-limit value (TLV) is 500 ppm. A TLV above 800 ppm indicates a lack of fresh air and low air mixture in the area (5). Furthermore, the National Institute for Occupational Safety and Health (NIOSH) sets a safe indoor CO concentration for humans not to exceed 1,000 ppm. (3, 6-7). A study on the influence of carbon-dioxide concentration on human well-being and the intensity of mental work concluded that CO concentration in the air was less advantageous for mental health compared to 600 ppm concentration. Human well-being including the capacity to concentrate continuously declined when subjects spent 2 to 3 hours indoor with a CO concentration of 3000 ppm or in the air with a higher CO_2 concentration (8).

Another study showed that when CO gases were transported into the lungs, they diffused to the blood circulation and blocked the entry of oxygen (O_2). It is likely to occur as CO gas is metabolically poisonous, reacts metabolically in the blood, and combines with hemoglobin to form carboxyhemoglobin (COHb). The carboxyhemoglobin bond is much more stable compared to the bond between oxygen and blood (oxyhemoglobin). As a result, CO bonds the blood more easily and disrupts the transport of oxygen in the blood (9).

Risk assessment is a systematic method or technique for analyzing risks in various fields such as environmental health, toxicology, industrial hygiene, occupational safety, environmental effects, weather forecasting, epidemiology, and social behavior (10). Besides, it is an analysis that uses information about toxic substances at a particular location to estimate health risks of exposure to these substances in communities. Using the information, they can make decisions and take actions to protect their health.

In this study, risk assessment means characterizing potentially detrimental effects of exposure to environmental hazards on human's health. Scientists and government collaborate to run the assessment to predict an increase in health risks due to the exposure to toxic substances. Furthermore, it aims to assist decision-makers and stakeholders (legislators and regulators, industry, and other stakeholders) with a scientific framework for solving environmental and health problems (10).

Environmental health risk assessment is essential for risk management and pollution control to protect populations from hazardous materials (11). Besides, it is an approach for calculating or predicting public health risks, identifying uncertainty factors, tracking specific exposures, and accounting for the inherent agent characteristics and the characteristics of specific targets (12). Risk assessment is performed in some stages of hazard identification, namely dose-response assessment, exposure assessment, and risk characterization (10,13). An excessive level of carbon monoxide can cause local public health problems. This study is notable to understand the risks and discover ways of risk exposure reduction. Therefore, it aimed to analyze the effect of exposure to carbon monoxide (CO) on the residents around the tofu manufacturing areas.

METHODS

This study was a cross-sectional design where observations and measurements of variables were carried out simultaneously at the same period. Data were obtained from laboratory experiments, interviews, and observations. Regarding the research location, this study took place in a residential area near the tofu manufacturing areas in Tropodo village, Krian, Sidoarjo. The research was carried out by collecting air samples and measuring air quality, checking results, calculating environmental risk, and preparing a report.

First, air sampling was carried out at a 10-meter distance from the pollution source in three locations. It was performed pointing the direction of the wind with an air sampler impinger for one hour. After the air sampling, air quality was measured to determine the pollution level. In this case, a pollution exposure assessment was used to determine the dose of toxic materials per person.

There are some stages of risk assessment as follows:

Hazard identification. The first stage in the health risk analysis was a hazard identification. This technique used to determine danger, recognize types of hazards, potential exposure to danger, how far exposure occurs, the frequency and duration of exposure, and its effects. In the identification stage, data were collected and evaluated to produce the desired values.

Dose-response assessment. Dose-response assessment was performed to determine the relationship between doses or levels of chemical exposure and its adverse effects on human health. This stage was used to determine if the toxic agents caused adverse health effects on the population at risk.

Exposure assessment. It was carried out by calculating the amount of hazardous materials that entered the body through inhalation. Intake is how many times an individual is exposed per kilogram of body weight per day and a lifetime basis. A lifetime exposure used was the standard exposure duration (Dt) of 30 years, which is the typical estimated time for non-carcinogenic effects to be manifested in humans (14). The standard inhalation rate (R) used was 0.83 m^3/hour for adults aged 21 to 61 years and weighing 55 kg for Asian adults (15). The researchers used an environmental health risk assessment to determine the dose of toxic agents using the following formula.

$$I = \frac{C \times R \times te \times fe \times Dt}{Wb \times tavg}$$

Description:

I	=	intake, mg/kg × days
C	=	the concentration of toxic agents, µg/m^3 for air, mg/L for drinking water, mg/kg for food
R	=	intake or consumption rate, 0.83 m^3/hour for adult inhalation, L/day for drinking water, g/day for food
te	=	Time of exposure, hours/day
fe	=	Frequency of exposure, day/year
Dt	=	Duration of exposure, years (real-time or projected, thirty years for residential default values)
Wb	=	Weight, kg
tavg	=	meantime period (Dt×365 days/year for non-carcinogens, 70 years×365 days/year for carcinogens)

Risk characterization. The calculation combines the values obtained in the dose-response and intake or exposure assessment. The level of non-carcinogenic health risks was obtained by dividing the daily intake attributable to inhalation with a dose-response value known as the Reference Concentration (RfC).

Risk management. Risk management was selected to minimize the impact of exposure to hazardous materials on workers' health by changing the exposure factor. This factor ensured that the amount of intake that enters the body is smaller or at least the same as the reference dose. The calculation is presented as follows:

Safe concentration

$$Safe\ C = \frac{RfC \times Wb \times tavg}{R \times te \times fe \times Dt}$$

Time and duration of safe exposure

$$Time\ and\ duration\ of\ safe\ exposure = \frac{RfC \times Wb \times tavg}{C \times R \times fe \times Dt}$$

Frequency of safe exposure

$$Frequency\ of\ safe\ exposure = \frac{RfC \times Wb \times tavg}{R \times te \times te \times Dt}$$

RESULTS

CO Concentration in Tofu Manufacturing Areas, Tropodo Village, Krian

CO is a product of combustion and air pollution. Most of the CO was formed due to incomplete combustion of the carbon materials as fuel. The primary data from air sampling indicated different CO concentration, as shown in Table 1. The average CO concentration in the areas was 54.50 μg/m^3.

Table 1. Measurement Results of CO Concentrations in settlements around the tofu industry in Tropodo Village, Krian

Measurement Location	CO Concentration (μg/m^3)
Location 1	60.56
Location 2	30.28
Location 3	60.56
Location 4	90.84
Location 5	30.28
Average	54.50

Exposure Risk Assessment

Risks to the populations exist between uncertainty and certainty (0 < risk <1).

Hazard Identification

Based on the observations, one tofu factory was located in every five houses in a densely populated area. The measurement data showed that the CO concentration in the five tofu manufacturing areas in Tropodo village, Krian, was below quality standards. Also, everyday exposure to CO will result in respiratory problems. Many tofu factories have produced CO sources in the residential area.

Dose-Response Assessment

CO is a compound that is not a carcinogenic substance. CO dose analysis in this study used the reference dose standard (RfC).

Exposure Assessment

Meanwhile, the CO concentration was the concentration measured at each measured location near the tofu manufacturing areas as shown in Table 1. Furthermore, the exposure duration was obtained based on the calculation of the combustion duration of tofu production at 8 hours/day and 48 hours/week for six working days/week. The results of the exposure assessment are explained in Table 2.

Table 2. Calculation of CO Intake Risk in the Tofu Industry Settlement of Tropodo Village, Krian.

Location	CO Concentration (μg/m^3)	CO Intake (μg/kg/day)
Location 1	60.56	6.25
Location 2	30.28	3.13
Location 3	60.56	6.25
Location 4	90.84	9.37
Location 5	30.28	3.13
Average	54.50	5.63

Table 2 shows the most extensive CO intake was 9.37 μg/kg/day, while the lowest was 3.13 μg/kg/day.

The average CO intake was 5.63 μg/kg/day, which is not the same as the actual received by the individuals. The definite intake received may be smaller or larger compared to the CO concentration that enters the body.

Risk Characterization

The calculation of RQ (Risk Quotient) is presented in Table 3 that the CO toxic agents in the air at all measured locations had a value of RQ > 1. This implies that the residents weighing 55 kg and getting exposed to CO for 8 hours/day or 312 days/year inhaled unsafe air which has non-carcinogenic effects in the next 30 years.

Table 3. The RQ (Risk Quotient) Calculation Results in the Tofu Industrial Settlement of Tropodo Village, Krian.

Location	CO	
	RQ (Risk Quotient)	RQ Criteria
Location 1	312.48	Not safe
Location 2	156.24	Not safe
Location 3	312.48	Not safe
Location 4	468.72	Not safe
Location 5	156.24	Not safe

Safe CO Concentration

From the calculation above the maximum acceptable CO concentration is 0.194 mg/m^3 for 30-year exposure by an assumption that the frequency of yearly and daily exposures is at 312 days per year and 8 hours per day, respectively.

Safe Exposure Time and Duration

In the tofu manufacturing areas, the average concentrations of CO, NO_2, and SO_2 were 54.5 μg/m^3, 12.96 μg/m^3, and 3.26 μg/m^3, respectively. The exposure time to that CO concentration was 0.028 hours. In other words, a person weighing 55 kg and getting exposed to CO will be safe for the next 30 years if the daily exposure time is 0.028 hours/day or about 1.68 minutes. Meanwhile, person weighing 55 kg and getting exposed to dust daily for 8 hours at a CO concentration of 54.5 μg/m^3 will be safe if they have exposure duration of 0.11 year (1 month).

Safe Exposure Frequency

When an individual weighing 55 kg is exposed to a CO concentration of 54.5 μg/m^3 for 8 hours daily, safe exposure frequency for the next 30 years is one day/year. Firstly, they should reduce CO concentration and exposure duration to 0.194 mg/kg/day and 1 month, respectively. Secondly, they should implement quality standard regulations for exhaust gas emissions in the air and optimizing equipment performance to control emissions. Besides, they should provide a dissemination of quality standards for exhaust gas emissions and install occupational health and safety equipment at manufacturing locations.

DISCUSSION

The implementation of environmental health risk assessment begins with identifying common environmental problems and involving parties obliged to determine environmental health threats. According to the Government Regulation No. 22 Year 2021 about the Implementation of Environmental Protection and Management, it was observed that none of the results of CO concentration at five measured locations in Table 1 exceeded the quality standard (16). Furthermore, environmental assessment aims to provide complete information to policymakers, especially the government for formulating policies (17).

Based on Decree of the Ministry of Health of Republic Indonesia No. 876/MENKES/SK/VIII/2001 regarding Technical Code for Environmental Health Impact Assessment, environmental assessment is described as an approach method to examine the magnitude of potential hazard risks. This assessment is usually related to ecological problems in the present or in the past. In the 2011 Guidelines of the Director General of Disease Control and Environmental Health

Indonesian Ministry of Health for Environmental Health Risk Assessment, the International Program on Chemical Safety (IPCS) Risk Assessment Terminology defines environmental assessment as a process of estimating human health hazards. The methods used include determining uncertainty aspects, discovering distinct exposures, and considering characteristics of inherent agents and specific targets. It is worth noting that the implementation of risk assessment provides information of hazard identification, distinguish between factors affecting the environment and hazards to human health and environmental sustainability, analyze current risks, and estimate changes due to exposure to hazard risks. The results can be used as references to formulate preventive measures (18). CO concentration in the residential area was below the standard, but it did not mean that it was safe for human.

There are some stages for conducting risk assessment, namely hazard identification, dose-response assessment, exposure assessment, risk characterization, and risk management. In the hazard identification, exposure metrics are predicted in multiple tiers with various levels of complexity and uncertainty which are applied in the epidemiological evaluation to figure out the advantage of more refined exposure metrics (19). The carboxyhemoglobin bond is much more stable compared to the bond between oxygen and blood (oxyhemoglobin). As a result, the blood easily bonds CO and are unable to carry oxygen (16,18). People diagnosed with diseases such as lung disease and heart disease will get worse when exposed to low CO concentration due to the bond between Hb and CO.

The daily CO exposure metrics are essential to support the prediction of health impacts for future epidemiological evaluation. For a fine-scale model of exposure, an individual exposure assessment that the research employed accounts for differences of daily exposures to CO. Employing this fine-scale model of exposure for the epidemiological evaluation depends on various aspects such as the research designs and the distributions of exposure.

Exposure assessment is a contact assessment to identify the pathway of exposure to toxic agents and calculate the intake level in the population at risk (20). CO produced by industrial chimneys will spread through the wind to the residential area where the community can breathe the polluted air. CO sources in the area were not only from one place but several places. The tofu factories are operated for 8 hours every day and generate CO that will accumulate in the body. Continuous exposure to CO will cause respiratory problems. A previous study showed a correlation between CO pollution and respiratory diseases (21). The average annual prevalence of respiratory diseases in the experimental group who breathed air pollution was 57.17%. Meanwhile, the prevalence (41.10%) was substantially lower in the control group. Another study found the prevalence of bronchitis and bronchiolitis was 12.50% and 20.00% in the control and experimental groups, respectively.

Additionally, the prevalence of tracheitis and other lung diseases was 0.96% and 3.88% in the control and experimental groups. Some other respiratory diseases, such as other nose and paranasal sinuses with code J30-J31 and J33- J34, and influenza with code J10-J11, were not reported in the control group (4).

The intake calculation requires toxic agent concentration in certain environmental media, anthropometric characteristics such as body weight, inhalation rate or consumption patterns, and activities in contact with toxic agents (22). The higher CO concentration in ambient air, the more risk the worker experiencing pain (5). Exposure to CO was combined for 22, 24, or 48 hours to illustrate usual daily exposure. In measuring the level of CO exposure, some studies have been previously carried out using the sensor-based method and colorimetric dosimeter, respectively (23).

Risk characterization determines whether the population is at risk of the toxic agent entering the body as seen from the RQ (Risk Quotient) (24). CO exposure in the tofu manufacturing areas has a RQ value > 1. Risk Management requires CO exposure control. The maximum durations of CO exposure should be at 8 hours/ day, 1 month, and 30 years. Risk communication is a follow-up step in the implementation of the environmental health risk assessment. It can provide the processes of risk characterization and alternatives of management to the local village head. Meanwhile, the risk management could minimize toxic agent exposure through exhaust gas emission control. The results of the measurement could determine hazards, develop strategies for enhanced control, and appraise the effectiveness of controls (25).

Above all, the present research does not check exhaust gas in the tofu manufacturing areas. It is necessary to identification of exposure from source. And it can reduce CO concentration from source so that can reduce duration of exposure to the residents.

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CONCLUSION

This study concluded that the CO concentration in the residential areas near the tofu manufacturing areas was below the quality standard, would possibly cause health problems. Therefore, it is necessary for the residents to reduce the time and frequency of exposure. The residents also can reduce the exposure by using a mask.

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