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Risk Analysis of CO and CO_2 Exposure Before and After Practicum

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ABSTRACT

Abstract. Laboratory air quality is an important factor affecting the health of laboratory users. The Chemistry Department of FMIPA UNSRI consist of biochemistry, analytical chemistry, physical chemistry, organic chemistry, and inorganic chemistry laboratories. This study aimed to evaluate the potential hazards caused by exposure to carbon monoxide (CO) and carbon dioxide (CO2) among the laboratory users in the Chemistry Study Program at FMIPA UNSRI. This study was an observational study using the Environmental Health Risk Analysis (EHRA) method. Measurements were taken before and after the practicum. The study was conducted in 5 laboratories within the Chemistry Study Program at FMIPA UNSRI. The concentrations of CO and CO2 showed that the conditions after the practicum were higher than before the practicum, CO reached 2.07 ppm and CO2 reached 631.69 ppm with the risk quotient (RQ) for both CO and CO2 both showing RQ > 1. Based on the EHRA calculation, it shows that the accumulation of CO and CO2 gases after the practicum suggest that continuous exposure for 8 hours per day over 5 consecutive days may have adverse health effects on laboratory users, including lecturers, students and analysts at FMIPA environment. Therefore, it is recommended to implement risk management, monitoring and use Personal Protective Equipment (PPE) whenever entering the laboratory.

Keywords: Carbon Dioxide, Carbon Monoxide, Laboratory Users, Environmental Health Risk Analysis

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INTRODUCTION

Indoor pollutants are an important occupational health concern. As the number and concentration of pollutants increases, indoor air quality deteriorates (1). Indoor air pollution arises from human activities involving exposure to particulate matter, gases, and other pollutants originating from vehicles, combustion processes, heating, and chemical reactions that are carried into the indoor environment through air or dust infiltration. A portion of these pollutants is transported by airflow, while another portion remains suspended in the indoor air, ultimately contributing to the degradation of overall indoor air quality (2) In addition, the decline in indoor air quality within laboratory environments is often indicated by elevated concentrations of gases such as carbon dioxide (CO_2) and carbon monoxide (CO).

Air is a determinant of workers' health. The presence of pollutants in laboratory spaces causes a deterioration of indoor air quality. The U.S. Environmental Protection Agency (EPA) has noted that indoor pollutant concentrations can exceed outdoor levels; recent field studies in university and laboratory settings have confirmed elevated indoor concentrations of CO_2 and particulate matter associated with occupancy and inadequate ventilation (3). Previous studies have shown an association between declining indoor air quality and adverse human health outcomes, leading to various physical and psychological disorders. The severity of these effects depends on the level and duration of exposure to airborne gases and pollutants, which have been linked to acute and chronic respiratory diseases, adverse pregnancy outcomes, stroke, cardiovascular disorders, lung cancer, and hypertension (4)

Laboratories are a fundamental component of higher education institutions, playing a vital role in supporting practical training, research, and community service activities for both students and faculty. A laboratory is a specialized environment for carrying out experimental tasks, measurements, testing, and the application of theoretical knowledge, involving three main elements: equipment, materials, and users (5). Working in a laboratory naturally involves risks and potential hazards across multiple domains, including physical, chemical, biological, ergonomic, and psychosocial aspects. These multidimensional risks can lead to occupational injuries, exposure to dangerous reagents or pathogens, musculoskeletal disorders, and stress or fatigue among laboratory personnel (6). Several potential hazards may arise within laboratory settings, one of which is a decline in indoor air quality. As laboratory activities increase, such as chemical handling, experimental procedures, and the presence of multiple occupants, concentrations of indoor pollutants also rise. These pollutants accumulate and become trapped within the laboratory environment, raising the risk of exposure and adverse health outcomes (7–9). Poor indoor air quality can adversely affect health, reduce worker productivity, and contribute to the development of occupational diseases as well as workplace accidents (10,11).

Laboratory staff are at risk of exposure to CO and CO_2 due to direct inhalation during their activities within the laboratory. Increased concentrations of CO and CO_2 in the lab space create an unsafe environment for workers, which over time may accumulate in the respiratory system and adversely affect their health (1,12) Higher education institutions typically operate various laboratory facilities, including those within the Faculty of Mathematics and Natural Sciences (FMIPA) at Sriwijaya University, located on the Indralaya Campus. The chemistry laboratory serves as an essential facility not only within FMIPA but also for the broader academic community of Sriwijaya University. Each study program is equipped with laboratories distributed across different locations within the faculty. The chemistry laboratory plays a crucial role, particularly for students, by supporting learning activities and final-year research. In recent years, the number of studies conducted in the chemistry laboratory has increased, largely due to the availability of comprehensive equipment, materials, and standardized procedures. These resources enable students to perform a wide range of activities, including practical coursework and research projects.

Indoor air quality within the chemistry laboratory is a critical factor influencing the health of laboratory users. Therefore, it is necessary to assess the risk associated with the accumulation of gas exposure in the lab in order to prevent health disorders and occupational diseases among lab users (13,14). Based on the aforementioned background, the researcher intends to conduct a study entitled 'Risk Analysis of CO and CO_2 Exposure Before and After Practicum'. Assessing the risk levels of CO and CO_2 exposure is expected to support monitoring and evaluation of indoor air quality to ensure that it meets safety requirements. This study aims to promote a laboratory environment that is safe and comfortable, thereby preventing health problems and work-related illnesses among laboratory users.

METHOD

The study was conducted in September 2024. This research employed an Environmental Health Risk Assessment (EHRA) approach to estimate the magnitude of risk associated with gas exposure among laboratory users, including students, lecturers, and laboratory analysts in the Chemistry Department, Faculty of Mathematics and Natural Sciences, Universitas Sriwijaya. The EHRA applied in this study was based on projected exposure durations ranging from year 1 to year 30, enabling an evaluation of potential risks or impacts resulting from long-term accumulation of CO and CO_2 within the laboratory environment.

The study took place in five laboratories in the Chemistry Department, namely Analytical Chemistry, Physical Chemistry, Biochemistry, Organic Chemistry, and Inorganic Chemistry. Measurements were conducted twice, before practicum activities and after practicum activities, with each session lasting 60 minutes. Air sampling was performed using direct measurement, meaning that air samples were examined on site without the need for laboratory analysis. The concentrations of Carbon Monoxide (CO) and Carbon Dioxide (CO_2) were measured using an Aeroqual Gas Monitor from Kanomax USA. The scope of the EHRA used in this research is presented in Figure 1:

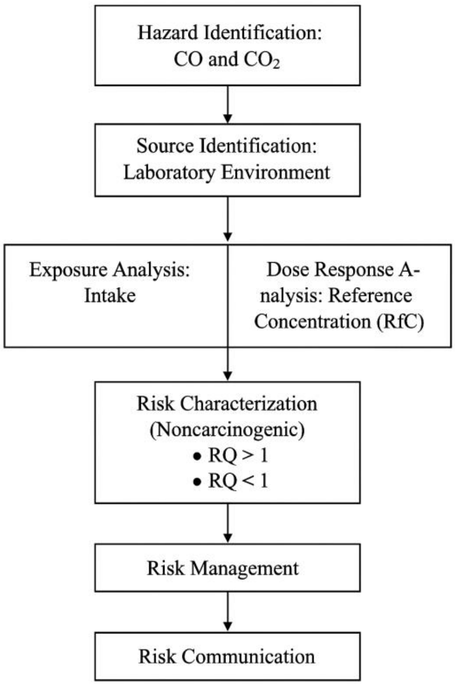

Figure 1. Scope of Research

The scope of the Environmental Health Risk Assessment begins with hazard identification, which in this study focuses on CO and CO_2 as pollutant gases. The next step is source identification, which refers to activities carried out inside the laboratory that generate these pollutants. Data collection consisted of both primary and secondary data. Primary data included body weight measurements of laboratory personnel and the measured concentrations of CO and CO_2 exposure. Secondary data consisted of reference dose values (RfC) for CO and CO_2 as well as inhalation rates obtained from the US EPA Default Exposure Factors. Following data collection, the daily intake received by laboratory users was calculated, after which the pollutant risk level (RQ) was determined. If the RQ value is greater than 1, risk management and risk communication steps are subsequently required (15,16). According to the USEPA guideline (2009), the data and information required to calculate indoor CO and CO_2 intake can be obtained using the following equation:

$$Cair - adj = \frac{\mathrm{C\ x\ ET\ x\ EF\ x\ ED}}{\mathrm{AT}}$$

Cair-adj	:	Adjusted air concentration (mg/m^3)
C	:	Concentration of the risk agent. Units include mg/m^3 for air, mg/L for drinking water, mg/Kg for food
ET	:	Exposure Time, in hours/day
EF	:	Exposure Frequency, in days/year
ED	:	Exposure Duration in years, based on real time data or projected residential default values up to thirty years
AT	:	Averaging Time. For noncarcinogenic risk, AT = ED x 365 days/year, using a projection from year one to year thirty

RESULTS AND DISCUSSIONS

Hazard identification was carried out by measuring the concentrations of CO and CO_2 before and after practicum sessions in five laboratories within the Chemistry Study Program of the Faculty of Mathematics and Natural Sciences, Universitas Sriwijaya. The results are presented in Table 1:

Table 1. Concentrations of CO and CO_2 Before and After Practicum Activities

Laboratory Name	CO Concentration (ppm)		CO_2 Concentration (ppm)	
	Before	After	Before	After
Biochemistry	0,8732	1,7464	541,7898	565,6841
Physical Chemistry	0,3493	2,1830	583,4659	748,5034
Inorganic Chemistry	0,4366	3,1436	577,3534	660,1500
Organic Chemistry	0,8732	2,0084	549,0136	583,4659
Analytical Chemistry	0,6986	1,3098	565,6841	600,6920
Mean	0,6462	2,0783	563,4614	631,6991

The measurement results of CO and CO_2 concentrations at the five sampling points show that the mean CO concentration before practicum activities was 0,6462 ppm, and this value increased to 2,0783 ppm after practicum sessions, based on a measurement duration of sixty minutes. For CO_2, the mean concentration before practicum activities was 563,4614 ppm and increased to 631,6991 ppm afterward. The highest post practicum CO concentration was found in the Inorganic Chemistry Laboratory with a value of 3,1436 ppm, while the lowest was recorded in the Analytical Chemistry Laboratory with a value of 1,3098 ppm. The highest post practicum CO_2 concentration was observed in the Physical Chemistry Laboratory at 748,5034 ppm, and the lowest was measured in the Biochemistry Laboratory at 565.6841 ppm. Overall, the concentrations of CO and CO_2 both before and after practicum activities remained below the permissible limits set by Peraturan Menteri Kesehatan Republik Indonesia Number 2 of 2023, which specifies permissible limits of less than 9 ppm for CO and less than 1000 ppm for CO_2 .

The Reference Concentration (RfC) values used in this study refer to Peraturan Menteri Kesehatan Republik Indonesia Number 2 of 2023, which specifies air quality standards of 9 ppm for CO and 1000 ppm for CO_2 . The conversion of these values into milligrams per cubic meter was carried out as follows.

1. Conversion of RfC Value for CO (mg/m^3)
   $$RfC = \frac{\text{RfC (ppm) x Molecular Weight of CO}}{24{,}45} = \frac{\text{9 ppm x 28 gram/mol}}{24{,}45} = 10{,}310 \text{ mg/m}^3$$
2. Conversion of RfC Value for CO_2 (mg/m^3)
   $$RfC = \frac{\text{RfC (ppm) x Molecular Weight of CO2}}{24{,}45} = \frac{\text{1000 ppm x 44 gram/mol}}{24{,}45} = 1799{,}591 \text{ mg/m}^3$$

Based on these calculations, the Reference Concentration (RfC) for CO is 10.310 milligrams per cubic meter, while the RfC for CO_2 is 1799.591 milligrams per cubic meter. To conduct a risk analysis, the availability of key data is required, including concentration values and reference values. If these data are insufficient, the following considerations must be used:

Table 2. Modified Default Exposure Factors (US-EPA)

Hazard Identification	Exposure Route	Daily Intake (mg/ m^3)	Exposure Frequency	Exposure Duration
CO dan CO_2 in the laboratory	Inhalation	CO = 10,5205 CO_2 = 5354,9589	240 days/year	Projected from year 5 to year 30

These exposure parameters were utilized to estimate the potential health risks associated with chronic inhalation of carbon monoxide (CO) and carbon dioxide (CO_2) among laboratory staff.

CONCLUSION

Hazard Identification

The first stage of the risk assessment involves hazard identification, specifically the gaseous pollutants carbon monoxide (CO) and carbon dioxide (CO_2). Subsequently, the sources of these pollutants are determined, which in this context are the laboratory activities carried out within indoor spaces. CO and CO_2 are both colorless, odorless, and tasteless gases, typically generated by incomplete combustion processes. In a laboratory setting, such emissions may arise from the use of equipment—such as hot plates, furnaces, and other heating devices—that do not achieve full combustion (17). Several practical activities conducted in the chemistry department laboratory can act as sources of gaseous pollutants. These include the use of hot plates for heating, ovens for drying, and furnaces for combustion processes, as well as solution mixing for chemical reactions that release heat. Additionally, the operation of laboratory equipment such as rotary evaporators and autoclaves may contribute to emissions resulting from incomplete combustion. Collectively, these activities can lead to the generation of colorless, odorless, and tasteless gases such as carbon monoxide (CO) and carbon dioxide (CO_2), which pose inhalation risks to laboratory personnel if proper ventilation and safety measures are not in place (18). An increase in laboratory activities, including both practical sessions and research experiments, leads to the accumulation of airborne residues, which become trapped within the laboratory environment (19). The concentrations of carbon monoxide (CO) (20) and carbon dioxide (CO_2) (21) in the laboratory environment primarily pose a risk of exposure through inhalation. Secondary routes of exposure may include dermal contact and accidental ingestion (8,22). The severity of a gas's effects depends on its concentration in the air and its solubility, which determines how much of the gas is absorbed upon inhalation (23). The accumulation of gases over time, particularly at high concentrations, can lead to various adverse health effects, including impaired pulmonary function, reduced cardiac performance, and even reproductive disorders (4,7,24). Acute respiratory conditions may manifest as allergies, mild irritation, or inflammation of the airways, while chronic exposure can result in long-term respiratory diseases such as chronic bronchitis, emphysema, structural lung abnormalities, and, in severe cases, complete respiratory failure. The severity and onset of these conditions are largely dependent on the intensity and duration of pollutant exposure (25,26).

Carbon monoxide (CO) in the air is rapidly absorbed into the body through respiration, entering the bloodstream, heart, muscles, and the inhalation pathways toward the lungs. CO is primarily eliminated from the body via the lungs during exhalation; however, there is a delay in its removal, with the minimum clearance taking up to 24 hours (27). The toxic effects of CO are exacerbated by its strong binding affinity to hemoglobin in the blood. Hemoglobin normally functions to transport oxygen from the lungs to tissues throughout the body and to carry carbon dioxide back to the lungs for exhalation (28). CO has a higher affinity for hemoglobin than oxygen, leading to the formation of carboxyhemoglobin (COHb), which reduces the blood's oxygen-carrying capacity. This hypoxic condition can trigger the onset of various diseases (29,30).

Exposure and Dose–Response Analysis

Exposure assessment was conducted by calculating the intake of the risk agent, namely carbon monoxide (CO), in the laboratory environment, using risk estimates projected over a period of 5 to 30 years while considering the activity patterns of the respondents. The study included five laboratory staff members who work daily in the laboratory and are therefore at risk of exposure to CO and CO_2 . The Environmental Health Risk Assessment (EHRA) applied in this study was calculated using the formula provided in the USEPA guidelines (2009), which does not rely on individual characteristics such as body weight, age, or gender. Body weight was not incorporated because EHRA is intended to assess the environmental risk of exposure within a specific setting; including body weight would yield results that vary for each individual.

The duration of exposure was determined based on the number of hours respondents spent at the research site each day. The average working time was 8 hours per day, from 08:00 to 16:00. Exposure frequency was calculated as the total number of days per year minus the days when respondents were absent from the laboratory, resulting in an average of 240 days per year for each respondent. The inhalation rate used was the standard value for adults, 0.83 m³/hour. An example of the intake calculation per laboratory, projected over 5 to 30 years, is provided as follows:

$$Cair - adj = \frac{\text{Cair x (ETx EFx ED)}}{\text{ED x } 365\frac{\text{days}}{\text{year}}}$$

1. Carbon Monoxide (CO) intake after practicum

$$Cair - adj = \frac{2\ \frac{\text{mg}}{\text{m}^3} \text{ x } 8\,\frac{\text{hours}}{\text{day}} \text{ x } 240\frac{\text{days}}{\text{year}} \text{x } 5 \text{ years}}{5 \text{ years x } 365\frac{\text{days}}{\text{year}}} = 10{,}5205 \text{ mg/m}^3$$

2. Carbon Dioxide (CO_2) intake after practicum

$$Cair - adj = \frac{1018\ \frac{mg}{m^3} \text{ x } 8\ \frac{hours}{day} \text{ x } 240 \frac{days}{year} \text{x } 5 \text{ years}}{5 \text{ years x } 365 \frac{days}{year}} = 5354{,}9589 \text{ mg/m}^3$$

Table 3. Laboratory Intake Values (30-year Projection)

No	Laboratory Name	Exposure Duration (5-30 years)	Intake CO (mg/m3)		Intake CO_2 (mg/m3)	
			Before	**After**	**Before**	**After**
1	Biochemistry	5-30	5.2603	10.5205	5128.7671	5354.9589
2	Physical Chemistry	5-30	2.1041	13.1507	5523.2877	7085.589
3	Inorganic Chemistry	5-30	2.6301	18.9370	5465.4247	6249.2055
4	Organic Chemistry	5-30	5.2603	12.0986	5197.1507	5523.2877
5	Analytical Chemistry	5-30	4.2082	7.8904	5354.9589	5686.3562

Table 3 indicates that the intake of CO and CO_2 exposure exhibits consistent values across all projections from the 5th to the 30th year. This suggests that the cumulative intake of the risk agent remains constant, even from the first year of laboratory work, provided that exposure to the gases occurs for 8 hours per day and exceeds the threshold limits established by Peraturan Menteri Kesehatan Republik Indonesia No. 2 of 2023. These findings are consistent with previous research demonstrating that health effects are dependent on the duration of exposure; the longer an individual is exposed to a hazardous agent, the greater the potential adverse effect on health (31). In addition to exposure duration, the severity of health outcomes is also influenced by the intensity of exposure (32). This observation aligns with a study conducted on parking attendants in Medan, Indonesia, which found that attendants with a work duration of ≥5 years experienced a 75% reduction in lung capacity (7).

Risk Characterization

Exposure to carbon monoxide (CO) and carbon dioxide (CO_2) occurs primarily through inhalation during respiration. The main step in the Environmental Health Risk Assessment (EHRA) is risk characterization, which includes the evaluation of the Non-Carcinogenic Risk Quotient (RQ) to determine whether exposure to CO and CO_2 poses a potential health risk. The RQ value is calculated by dividing the measured intake (Table 3) by the reference dose (RfC) for laboratory users. An RQ value of less than 1 indicates that the exposure is unlikely to pose a health risk, whereas an RQ value greater than 1 indicates a potential health risk to laboratory personnel (16). The following section presents the calculated RQ values for CO and CO_2 exposure across five laboratory settings:

Table 4. Risk Quotient (RQ) of CO and CO_2 Exposure in Five Laboratories

Laboratory Name	CO Exposure			CO_2 Exposure		
	RfC (mg/kg/day)	RQ		RfC (mg/kg/day)	RQ	
		Before	After		Before	After
Biochemistry	10.31	0.51	1.02	1799.591	2.85	2.98
Physical Chemistry	10.31	0.20	1.28	1799.591	3.07	3.94
Inorganic Chemistry	10.31	0.26	1.84	1799.591	3.04	3.47

Laboratory Name	CO Exposure			CO_2 Exposure		
	RfC (mg/kg/day)	RQ		RfC (mg/kg/day)	RQ	
		Before	After		Before	After
Organic Chemistry	10.31	0.51	1.17	1799.591	2.89	3.07
Analytical Chemistry	10.31	0.41	0.77	1799.591	2.98	3.16

Based on the EHRA calculations presented in Table 4, the RQ values were less than one prior to laboratory practical activities and greater than one after conducting the practical sessions. This indicates that practical activities conducted in the chemistry department laboratories, such as reacting chemicals, heating solutions, operating heat-generating equipment, and other routine procedures, contribute significantly to the increase of CO and CO2 concentrations in the laboratory environment. The accumulation of gases and other airborne particles increases proportionally with the intensity and frequency of laboratory activities, resulting in higher overall concentrations. The health risk evaluated in this study is non-carcinogenic, as CO and CO2 do not have implications for cancer development. Risk projections were extended up to 30 years (lifetime) according to US-EPA guidelines.

The results show that post-practical RQ values exceed one in all laboratories, indicating a non-carcinogenic health risk that must be mitigated for laboratory personnel. The intake of CO and CO2, according to EHRA calculations, has exceeded the daily exposure reference doses considered safe. This implies that being present in the laboratory for eight hours per day over five consecutive days may result in adverse health effects for laboratory staff.

Risk management and risk communication are essential steps when the calculated risk indicates an unsafe condition, that is, RQ greater than one. Risk management strategies to minimize the risk (RQ) include setting safe limits for concentration, exposure duration, and frequency. Based on the calculations, the safe concentration limits for laboratory users, assuming a constant exposure time of eight hours per day (480 minutes), are as follows: CO concentration below 1.96 mg/m^3 and CO2 concentration below 342,11 mg/m^3.

According to the health risk analysis in this study, the RQ values for both CO and CO2 have already exceeded the safe limits. Although severe acute symptoms have not yet been observed, chronic exposure may increase the risk of headaches, fatigue, and respiratory disorders among at-risk groups, such as laboratory personnel. Therefore, the research team will conduct risk communication with faculty decision-makers regarding the EHRA results to reduce pollutant sources and regularly monitor indoor air quality. Preventive and control measures following OHSAS 18001:2007 guidelines include:

1. Elimination: Removing the hazard source. Completely eliminating pollutants in the laboratory is challenging; however, airborne concentrations can be reduced by calculating safe limits, exposure durations, and frequencies that are acceptable for laboratory personnel.
2. Substitution: Replacing methods, equipment, or chemicals with safer alternatives. For example, performing chemical reactions in a fume hood allows vapors generated during the reaction to be directly exhausted by the blower, preventing accumulation in the laboratory.

3. Engineering Controls: Implementing technical solutions such as green open spaces around the laboratory to reduce air pollution. Plants can filter atmospheric particles and absorb different gas pollutants. Increasing the number of plants around the laboratory functions as an air purifier and can serve as an indicator for air quality monitoring (33).
4. Administrative Controls: Reducing risk through procedures, rules, training, warning signs, posters, labels, or adjusting work duration. In the laboratory, this may include standard operating procedure (SOP) socialization, work instructions, and placement of safety signs in designated areas.

Personal Protective Equipment (PPE): Using protective equipment such as chemical masks. Masks with activated carbon and replaceable filters can filter dust, smoke, odor, vapors, and chemical gases generated during laboratory activities. There are two types of chemical masks: single-filter and dual-filter masks, with dual-filter masks providing twice the filtration efficiency compared to single-filter masks.

CONCLUSION

The concentrations of CO and CO_2 in five laboratories of the Chemistry Department at Sriwijaya University were measured, showing an average CO concentration of 2,0783 ppm and CO_2 concentration of 563,4614 ppm. These values are still below the threshold limits set by Peraturan Menteri Kesehatan Republik Indonesia No. 2 of 2023 which are 9 ppm for CO and 1000 ppm for CO_2 . However, the calculated risk assessment indicates an unsafe condition after practical activities, with RQ values exceeding one. It is recommended that the Chemistry Program at FMIPA UNSRI implement continuous risk management strategies to control laboratory exposure and prevent potential adverse health effects in the future.

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