

# Prevention against carbon monoxide poisoning emanating from burning coal briquettes – Generation rate of carbon monoxide and ventilation requirement –

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**Abstract:** Carbon monoxide (CO) poisoning accidents occur every year in Japan, most of which are caused by the incomplete combustion of fuel, such as gasoline, light oil, and coal briquettes. To prevent CO poisoning in workers, it is essential to reduce the CO concentration in a working environment below the criteria threshold through ventilation. Although proper ventilation requirements for enclosed spaces are estimated from the generation rate of air pollutants, there is no empirical research evaluating the CO generation rate of coal briquettes. In this study, the author evaluated the CO generation rate of burning coal briquettes under controlled laboratory conditions and estimated the appropriate corresponding ventilation requirements. Despite the coal briquettes were burned under sufficient oxygen supply, the CO generation rates and the briquettes' consumption rates were 146–316 mL/min/kW and 1.65–3.61 g/min, respectively. Assuming the CO concentration limit was 50 ppm, the corresponding ventilation requirement was 174.9–378.7 m<sup>3</sup>/h/kW. The ventilation requirement was 43.7–94.7 m<sup>3</sup>/h/kW when the critical CO concentration was set at 200 ppm. Adopting the ventilation requirements set out in this study could facilitate proper ventilation and reduce the risk of CO poisoning.

**Key words:** Carbon monoxide, Coal briquette, CO poisoning, Ventilation, Working environment

## Introduction

Carbon monoxide (CO) is a colorless, odorless, and lethal gas. Its inhalation has been responsible for many fatal accidents within various fields and environments<sup>1–4)</sup> both in

Japan and abroad. Moreover, persistent industrial diseases caused by CO poisoning are pressing issues in contemporary Japan. CO poisoning accidents occur every year in Japan's industrial environment, and no downward trend in the number of accidents has been observed. Reports in 2016, 2017, and 2018 indicated that 70 (including one deceased), 24 (including one deceased), and 36 workers suffered from CO poisoning in Japan, respectively<sup>4)</sup>. Most recently, four workers suffered from CO poisoning by burning coal briquettes when assembling underground concrete block

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formworks<sup>5</sup>). Although the total number of industrial diseases caused by chemical exposures has decreased in recent years, CO poisoning has not; consequently, it now represents the most considerable portion of occupational poisonings.

In Japan, most industrial CO poisoning accidents are attributable to the incomplete combustion of fuel, such as gasoline, light oil, charcoal, and coal briquette, while CO poisonings during CO<sub>2</sub> arc welding occur as relatively rare cases<sup>6</sup>). The incomplete combustion of gasoline or light oil generally occurs when a portable internal combustion engine or a diesel-powered vehicle is used in a confined space without adequate ventilation<sup>7</sup>). Industrial charcoal is primarily used in restaurants and food processing plants for meat preparation. In contrast, coal briquettes are primarily used to cure fresh concrete at construction sites as they are convenient and economical. Owing to the economic benefit, it is unlikely that coal briquettes will be entirely replaced by relatively safer electric heaters anytime soon, despite their obvious disadvantage of generating CO.

To prevent the CO poisoning of workers, CO concentrations in working environments must be reduced below specific criteria through sufficient ventilation. However, estimating the proper ventilation required to control CO concentrations at a typical construction site seems complicated because several CO poisoning accidents have occurred despite using ventilation systems. Although proper ventilation requirements for enclosed spaces are estimated from the generation rate of air pollutants, there is no empirical research investigating the CO generation rate of coal briquettes. In this study, the author aimed to evaluate the CO generation rate of several burning coal briquettes under controlled laboratory conditions and estimate the proper ventilation requirements needed to prevent CO poisoning. Moreover, as the number of poisoning accidents caused by coal briquettes exceeds the number of the same accidents caused by charcoal every year, it is expected that burning coal briquettes generate more CO gas than burning charcoal. Hence, the author also aimed to compare the data of coal briquettes with that of charcoal obtained in a previous study<sup>8</sup>). The author believes that the knowledge of the CO generation rate will aid industrial hygienists and occupational health professionals when assessing workers' exposure risks.

## Materials and Methods

This study used four commercially available domestic coal briquette brands (Mitsuiroko, Sumifuku, Komeri, and

Jyuzen) in combustion experiments to measure their CO generation rates. All coal briquettes used in this experiment were standardized "No.4 size" items (approximately 1,400 g/piece) because they are the most commercially prevalent in the Japanese market. The coal briquettes were burned individually in a dedicated aluminum stove at a laboratory.

Fig.1 shows the experimental set-up for this study. The set-up configuration and the experimental procedure in this study are nearly similar to those used in previous studies<sup>6,8</sup>). A coal briquette sample was weighed on an electric balance (CS-3000; Ohyo Co., Ltd., Japan) with a readability of 1 g before and after combustion to determine its consumption gravimetrically. During the coal briquette's combustion, the aluminum stove was enclosed by a metal cover hood (0.35 × 0.35 × 0.7 m) that extracted the combustion gases through a flexible metal duct (φ100 mm) connected to the top of the cover hood. As shown in Fig.1, the CO concentration and flow rate of the combustion gas inside the flexible duct were continuously monitored through a real-time potentiostatic electrolysis type CO monitor (XP-333II CO meter; New Cosmos Electric CO., Ltd., Japan) and a Pitot tube airflow meter (Air Measure AMA 100DA; Shibata Giken Co., Ltd., Japan), respectively. The path length of the combustion gas from the cover hood to the CO monitor was approximately 2.5 m, which was deemed enough to make the combustion gas homogeneous through its self-mixing<sup>9</sup>). Because the flow rate inside the duct was regulated at approximately 2.3 m<sup>3</sup>/min, which was well beyond the stoichiometric air volume, constant fresh air was sufficiently supplied to the burning briquette through the clearance between the cover hood and floor. A CO alarm located beside the hood did not detect any CO leakage from the cover hood during the experiment. Moreover, the experimenter wore a personal CO alarm in preparation for any accidental exposure. The sample coal briquette's combustion time was set between 70 and 120 min depending on the burn-out rate (i.e., the weight of burn-out coal briquette per unit time) of each sample. All measurements were carried out in a well-ventilated laboratory (6 × 15.5 × 3.6 m) devoid of ambient CO contamination.

In this study, the CO generation rate of each sample was calculated by substituting three measurements (average flow rate of the combustion gas, average CO concentration in the combustion gas, and the combustion time) into the equation below<sup>6,8</sup>).

$$G = (Q_{AV} \cdot t \cdot C_{CO} \cdot 10^4) / t = Q_{AV} \cdot C_{CO} \cdot 10^4 \quad (1)$$

where

G: generation rate of CO [mL/min]

Q<sub>AV</sub>: average flow rate of the combustion gas [m<sup>3</sup>/min]

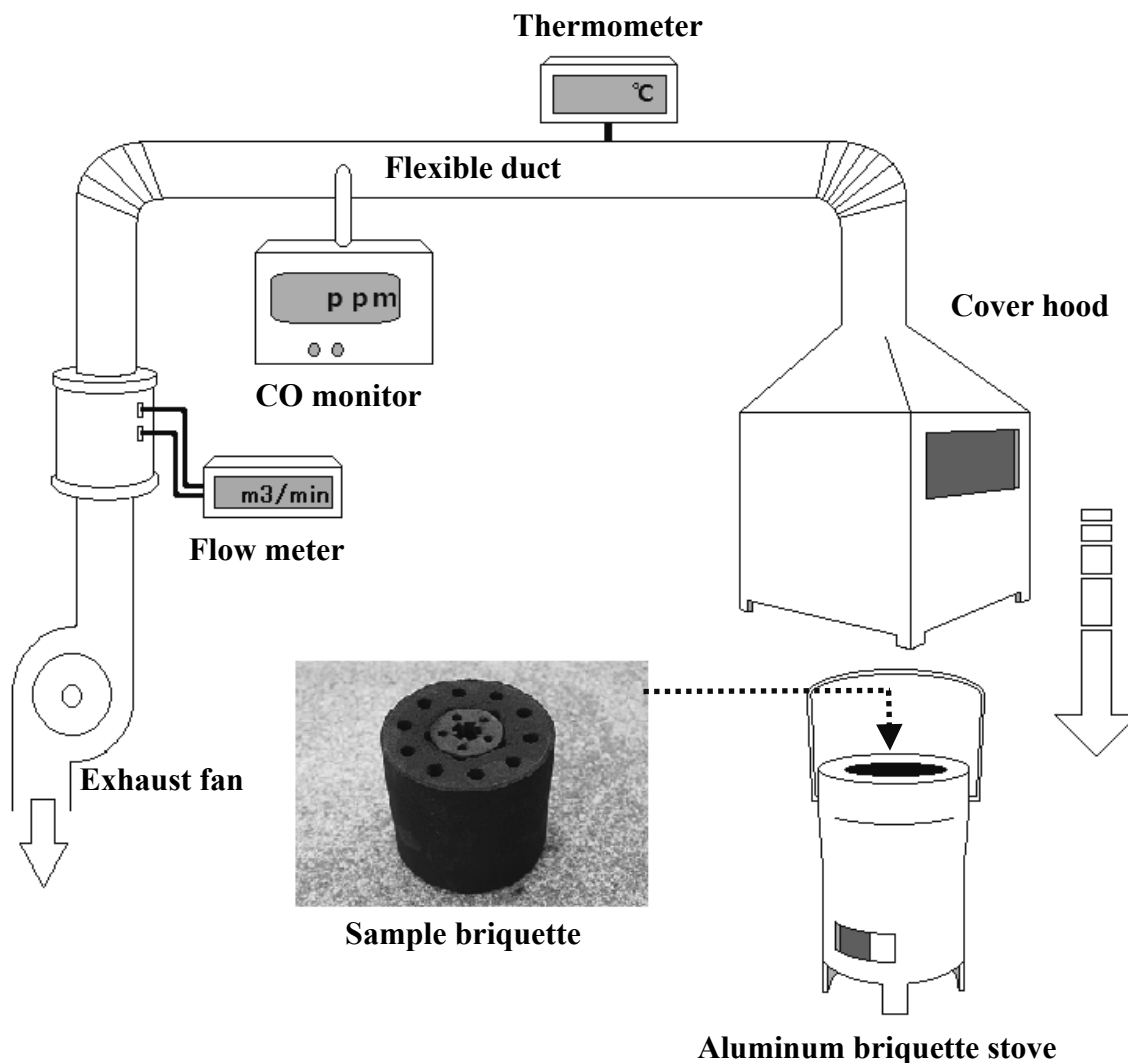


Fig. 1. Schematic diagram of the equipment used in the experiments.

$C_{CO}$ : average CO concentration in the combustion gas [%]  
 $t$ : combustion time of the coal briquette sample [min]

Thereafter, the author converted the CO generation rate of each sample to a per power value (heat release rate) using equation (2) to normalize the rate. By applying this conversion, the effect of the fluctuations due to variable combustion conditions in the experiments could be excluded. According to the coal briquette standard stipulated by the Japan Coal Briquette Industry Association, the calorific value of coal briquettes used in this equation was 5.5 (Kcal/g)<sup>10</sup>.

$$G \text{ [mL/min/kW]} = G \text{ [mL/min]} \cdot 860 \cdot t / (5.5 \cdot w \cdot 60) \quad (2)$$

where  $w$ : weight of the burned coal briquette [g]

860: (1 [kW]=860 [kcal/h])

## Results

The CO generation rates (corrected to the values at 25°C) and the burn-out rates of the samples are shown side-by-side in Table 1. The data in Table 1. reflects the average results of five replicate measurements. As indicated in the Table, both the measured CO generation rates and burn-out rates varied from sample to sample; they ranged from 146 to 316 mL/min/kW and from 1.65 to 3.61 g/min, respectively. During their combustion, coal briquettes exhibited higher CO generation rates than charcoal<sup>8</sup>, which led to more extensive ventilation requirements.

Generally, the ventilation rate necessary to maintain the constant concentration of a contaminant can be estimated from the following simple equation, assuming complete mixing (safety factor=1) and a steady state<sup>11, 12</sup>.

**Table 1. Measurement of the CO generation rate produced by burning briquettes**

Sample (brand)	Burn-out rate [g/min] <sup>A</sup>	CO generation rate [mL/min/kW] <sup>A,B</sup>
Mitsuuroko	1.65 ± 0.12	316 ± 15
Sumifuku	2.98 ± 0.08	192 ± 26
Komeri	3.61 ± 0.23	146 ± 19
Jyuzen	3.09 ± 0.14	221 ± 23

<sup>A</sup> Values are the arithmetic means of 5 measurements ± standard deviations.

<sup>B</sup> Corrected to the values at 25°C.

**Table 2. Theoretical ventilation requirements for the prevention of CO poisoning**

Sample (brand)	Ventilation requirement [m <sup>3</sup> /h/kW]	
	(exposure limit=50 ppm <sup>A</sup> )	(exposure limit=200 ppm <sup>B</sup> )
Mitsuuroko	378.7	94.7
Sumifuku	229.9	57.5
Komeri	174.9	43.7
Jyuzen	264.8	66.2

<sup>A</sup> OSHA PEL – General industry

<sup>B</sup> NIOSH REL (Ceiling value)

$$Q = G / C \quad (3)$$

where Q: ventilation rate (volume of ventilated air per unit of time)

G: generation rate of contaminant (volume of contaminant's vapor or gas phase generated per unit of time)

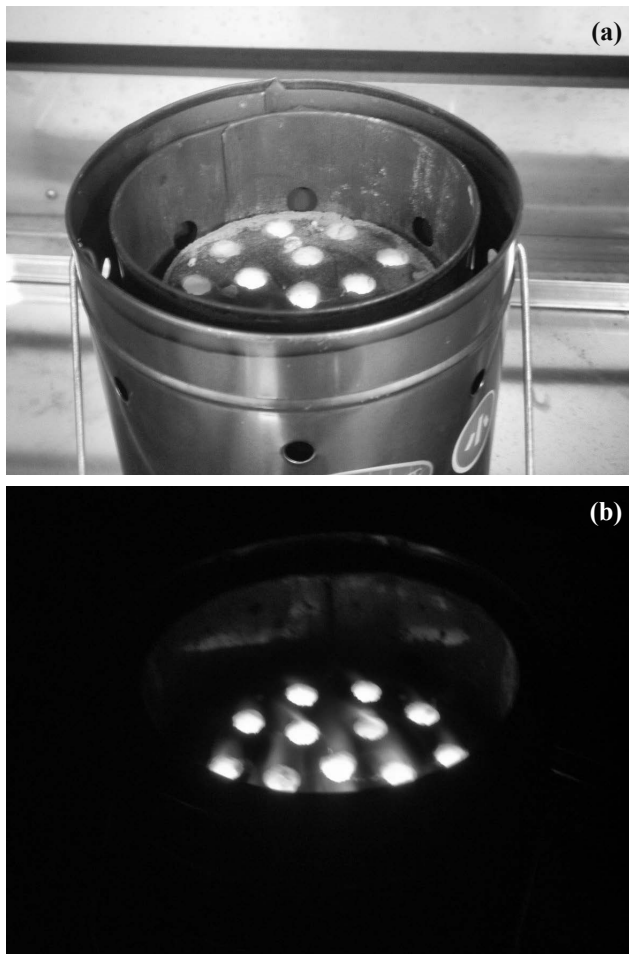
C: concentration of contaminant (air concentration of the contaminant expressed as a volume fraction)

Therefore, the ventilation rate required to prevent over-exposure can be calculated theoretically by substituting the measured generation rate and the contaminant's exposure limit for G and C, respectively. It should be noted that equation (3) does not include the variable that represents the room's volume. In the calculation, the current permissible exposure limit (PEL) of the Occupational Safety and Health Administration (OSHA) for CO (50 ppm) as well as the recommended exposure limit (REL) of the National Institute for Occupational Safety and Health (NIOSH) for CO ceiling value (200 ppm) were adopted. Regarding the PEL and REL, the calculated ventilation requirements ranged from 174.9 to 378.7 m<sup>3</sup>/h/kW (CO=50 ppm) and from 43.7 to 94.7 m<sup>3</sup>/h/kW (CO=200 ppm), respectively (Table 2.).

## Discussion

The CO generation rates of burning coal briquettes were 146–316 mL/min/kW; relatively large fluctuations were observed in each coal briquette brand's generation rates. These fluctuations are partially attributable to inevitable errors during sample weighing, introducing undesirable effects in the generation rates. Because the burned remnants of the coal briquette are brittle and collapse easily, some weight loss may have occurred during handling.

As described above, CO generation rates varied between samples. This variance may also be explained by the different flame appearances on the surfaces of each sample (Fig. 2). The different condition of the surface of each sample during combustion was probably due to a difference in the small amount of contained molding agents (resin, slaked lime, bentonite, etc.), which could have affected the appearance and size of the flames. Because a flame enhances CO oxidation, the coal briquettes' CO generation rate may have been suppressed when a sample was burned with vigorous flames. In fact, these flames were not visually observed in the sample that achieved the highest CO generation rate (Mitsuuroko brand; Table 1) during the



**Fig. 2.** A flame emerging from a burning briquette's upper surface.  
(a) with the light ON (b) with the light OFF

experiments, which supports the aforementioned hypothesis.

As shown in Table 2, the ventilation requirements for OSHA PEL (CO=50 ppm) and NIOSH REL (CO=200 ppm) obtained in the experiments were 174.9–378.7 m<sup>3</sup>/h/kW and 43.7–94.7 m<sup>3</sup>/h/kW, respectively. However, when the ventilation requirements are converted from values per power to values per coal briquette sample (No. 4 size), they can be expressed as 211.1–325.1 m<sup>3</sup>/h/piece (CO=50 ppm) and 52.8–81.3 m<sup>3</sup>/h/piece (CO=200 ppm). In both cases, it must be emphasized that these ventilation requirements are theoretical minimum ventilation volumes, which are generally insufficient and should be corrected at actual industrial sites to accommodate for incomplete mixing and insufficient oxygen supply. Depending on each site's specific circumstances, approximately 1–10 times larger ventilation volumes would be necessary to prevent CO poisoning effectively. The guideline concerning the correction factor

that needs to be multiplied with the theoretical ventilation volume can be quoted from the coefficients for incomplete mixing suggested by ACGIH<sup>(1)</sup>.

Although the risk of CO poisoning from burning coal briquettes can be reduced significantly through appropriate ventilation, in most cases, it is difficult to eliminate an unforeseen high CO spot at a working site. Therefore, regardless of the ventilation precautions in effect, personal protective equipment and CO alarm monitors remain necessary for workers when air stagnancy or hot spots may occur around them.

## Conclusion

An experiment in a laboratory measured CO generation rates of burning coal briquettes. This experiment indicated that the rates ranged from 146 to 316 mL/min/kW. The author calculated the theoretical ventilation requirements for preventing CO poisoning in a confined space based on these measurements. When assuming that the regulatory limit of CO concentration to be 50 ppm, the corresponding ventilation requirement ranged from 174.9 to 378.7 m<sup>3</sup>/h/kW. Likewise, when the CO concentration was assumed to be 200 ppm, the corresponding ventilation requirement ranged from 43.7 to 94.7 m<sup>3</sup>/h/kW.

## Conflict of Interest

The author declares that there is no conflict of interest.

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