Generation Rate of Carbon Monoxide from Burning Charcoal

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Abstract: Charcoal, often used as cooking fuel at some restaurants, generates a significant amount of carbon monoxide (CO) during its combustion. Every year in Japan, a number of cooks and waiters/waitresses are poisoned by CO emanating from burning charcoal. Although certain ventilation is necessary to prevent the accumulation of CO, it is difficult to estimate the proper ventilation requirement for CO because the generation rate of CO from burning charcoal has not been established. In this study, several charcoals were evaluated in terms of CO generation rate. Sample charcoals were burned in a cooking stove to generate exhaust gas. For each sample, four independent variables — the mass of the sample, the flow rate of the exhaust gas, CO concentration in the exhaust gas and the combustion time of the sample — were measured, and the CO generation rate was calculated. The generation rate of CO from the charcoal was shown to be 137–185 ml/min/kW. Theoretical ventilation requirements for charcoals to prevent CO poisoning are estimated to be 41.2–55.6 m^3/h/kW.

Key words: Carbon monoxide, Charcoal, Gas generation rate, Ventilation

Introduction

Carbon monoxide (CO) is a potent, lethal gas that can overcome exposed persons without warning. In recent years, CO poisoning in Japanese workplaces has been increasing and CO poisoning now accounts for about 50% of all industrial hazards due to chemical substances. Incomplete combustion in a portable gasoline-powered engine[1] used at a construction site is the most common cause of industrial CO poisoning in Japan, and improper using of cooking utensils such as a range or an oven in a restaurant is the second most common cause of CO poisoning. While natural gas and propane gas are the most prevalent cooking fuels in Japan, charcoal cannot be ignored because of the incident of CO poisoning. Since burning charcoal radiates intense infrared radiation and enhances the flavor of broiled meat, it is commonly used as a cooking fuel at some Japanese restaurants serving "Kabayaki" (barbecued eel), "Yakitori" (grilled chicken on a stick) or "Yakiniku" (roast beef). Charcoal also generates a significant amount of CO during its combustion which can easily cause accumulation of CO in a room. Every year in Japan, a number of cooks, waiters and waitresses are poisoned in the kitchen or semi-enclosed spaces by CO generated by burning charcoal. Although some mechanical ventilation is necessary to prevent the accumulation of CO in semi-enclosed spaces, it is difficult to estimate the proper ventilation requirement for CO control because the generation rate of CO from burning charcoal has not been established. Insofar as charcoal is concerned, no empirical evaluation of CO generation has been published to date; therefore, the presented study aimed to evaluate the generation rate of CO from burning charcoal under controlled laboratory conditions and estimate the ventilation requirements for the prevention of CO poisoning.

Experimental Methods

All sample charcoals used in this study were domestic oak charcoals (namely "Bincho-Tan") which are commercially available as solid fuel for cooking. "Bincho-Tan" is the most popular charcoal in the Japanese

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Table 1. Profile of sample charcoals

Sample	Trade name	Production region	Raw timber
A	Kisyu Bincho-Tan	Wakayama Pref.	Quercus phillyraeoides*
B	Tosa Bincho-Tan	Kochi Pref.	Quercus phillyraeoides
C	Hyuga Bincho-Tan	Miyazaki Pref.	Quercus glauca**
D	Bungo Bincho-Tan	Oita Pref.	Quercus glauca
E	Iyo Bincho-Tan	Ehime Pref.	Quercus phillyraeoides

*, **; a kind of live oak.
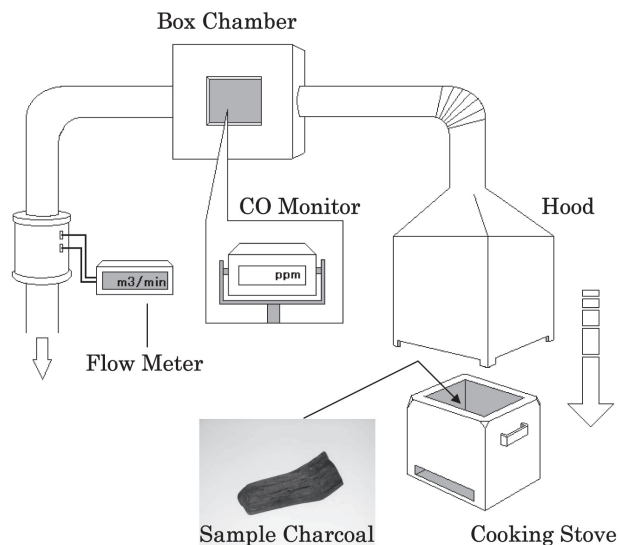
Fig. 1. Schematic diagram of the equipment used in the charcoal burning experiments.

kitchen because it keeps burning for a long time and is suitable for grilling. Table 1 shows brief profiles of the sample charcoals.

Figure 1 shows the experimental set-up for this study. A 50–100 g sample charcoal piece was weighed on an electric balance and was then burned in a Japanese traditional portable clay cooking stove; "Shichirin" (0.3 m × 0.3 m × 0.23 m). During the charcoal burning, the cooking stove was enclosed by a metal cover hood which sucked up all the exhaust gas from the burning charcoal. A flexible duct of ϕ80 mm was connected to the top of the cover hood, and the exhaust gas passed through a box chamber (0.3 m × 0.3 m × 0.3 m) which contained a real-time CO monitor (Gas Detector XC-2200 Model; New Cosmos Electric Co., Ltd., Japan). The box chamber had an observation window through which the CO monitor could easily be read. The path length of the exhaust gas from the hood take-off to the box chamber was about 1.5 m, which was thought to be sufficient enough to make the exhaust gas homogeneous[2]. The flow rate of the exhaust gas was measured continuously by means of an air flow meter (New Aero-Eye AE150D Q-system; Wetmaster Co., Ltd., Japan) which was located 2 m downstream of the box

chamber. Since the flow rate was regulated at approximately 2 m^3/min, the burning charcoal was sufficiently supplied with air induced through the clearance between the hood and floor. The combustion time of the sample charcoal was defined as the period from the ignition to the extinction in this experiment.

With the substitution of the four measurements – the mass of the sample, the flow rate of the exhaust gas, CO concentration in the exhaust gas and the combustion time of the sample – into the following equation, the generation rate of CO from each sample charcoal was obtained.

$$G = (V_{ex} \cdot t \cdot C_{CO} \cdot 10^{-6}) / t \qquad (1)$$

where G : generation rate of CO (m^3/min)

V_{ex} : average flow rate of the exhaust gas (m^3/min)

C_{CO} : average CO concentration in the exhaust gas (ppm)

t : combustion time of the sample (min)

In order to standardize each generation rate, the author converted them to per power (heat release rate) values using equation (2). Through this conversion, the effect of the fluctuations in the combustion conditions of each sample can be excluded. The calorific value of the oak charcoal used in this equation was 7.669 (kcal/g) based on data from a 2004 Fukuoka Forest Research & Extension Center study[3].

$$G \text{ (m}^3\text{/min/kW)} = G \text{ (m}^3\text{/min)} \cdot 860 \text{ (kcal/h/kW)} \cdot$$
$$t / 7.669 \text{ (kcal/g)} / w / 60 \qquad (2)$$

where w : weight of the sample (g)

All experiments were conducted in a well-ventilated laboratory which was free from ambient CO contamination.

Results and Discussion

The generation rates of CO from the burning charcoals are shown in Table 2. All data are given as the arithmetic mean of ten repeated tests. The generation rate of CO was shown to be 137–185 ml/min/kW. In spite of an ample air supply, which was much larger than the theoretically required air volume, a certain amount of CO was generated from the charcoal suggesting there are differences in the CO formation mecha-

Table 2. CO generation rate and ventilation requirement for each charcoal sample

Sample	CO generation rate (ml/min/kW)*	Ventilation requirement (m^3/h/kW)*
A	185 ± 31	55.6 ± 9.3
B	141 ± 18	42.5 ± 5.4
C	145 ± 14	43.5 ± 4.2
D	142 ± 23	42.6 ± 6.9
E	137 ± 16	41.2 ± 4.8

*Values are mean ± SD (n=10).

nisms between charcoal and other fuels[4–8].

The ventilation rate needed to maintain a constant concentration at a uniform generation rate was derived using a simple material balance formula[9]. The accumulation rate of a contaminant in a room can be described as follows.

Accumulation rate = Generation rate – Removal rate
that is,

$$V \, (dC/dt) = G – Q \, C \qquad (3)$$

where   V : volume of room
       G : generation rate
       Q : ventilation rate (effective exhaust flow rate)
       C : concentration of contaminant
       t : time
at a steady state,   dC = 0   then

$$Q = G / C \qquad (4)$$

By substituting numerical values for G and C in equation (4), the ventilation rate can be readily calculated. It should be noted that the ventilation rate is determined without regard to the room volume. According to equation (4), the ventilation requirement in the burning of charcoal to prevent CO poisoning can be obtained when the Threshold Limit Value (TLV) for CO is substituted for C. Table 2 shows the theoretical ventilation requirement for each sample. In this study, the current ceiling value for CO set by the National Institute of Occupational Safety and Health (NIOSH: 200 ppm) was adopted as the TLV. The result of the calculation indicates that the CO concentration in a room will be maintained below the TLV providing the ventilation rate in the room is 41.2–55.6 m^3/h/kW.

Considering the air-tightness of modern Japanese houses or buildings[10], the natural ventilation in some restaurants can't be expected to adequately remove generated CO. Therefore, workers in such restaurants should be informed that opened windows or doors will not provide sufficient ventilation, and some additional mechanical ventilation should be installed.

Without some practical and effective precautionary measures, the number of CO poisoning cases in the Japanese food-service industry will probably increase in the near future because the annual consumption of charcoal in Japan has recently been increasing. Although the kinds of charcoal and the methodology used in this study were somewhat limited, the result of this study is expected to be helpful for the design of ventilation systems at some restaurants.

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