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Short communication

BBQ charcoal as an important source of mercury emission

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ABSTRACT

In this study, the environmental significance of mercury emission has been investigated with respect to the use of the barbecue (BBQ) charcoal. For this purpose, emission gas samples collected from a total of 11 barbecue charcoal products commonly available in the Korean market were analyzed. All of these products consist of both domestic (4 types) and imported products (7 types from three countries). The emission concentration of Hg varied widely from sample to sample ranging from 114 to 496 ng m^{-3}. The amount of Hg emission appeared to be affected by the diverse nature of raw materials and/or the processes involved in their production. In light of the recent reference exposure limits (REL) of Hg, it can be a potential threat to human health. As such, a proper regulation is desirable from a toxicological viewpoint to reduce the potential risk associated with the use of BBQ charcoal.

1. Introduction and methods

As a smokeless substance, charcoal yields a greater amount of heat in proportion to its volume than that from a corresponding quantity of wood [1]. Hence, it is frequently used for barbecuing and grilling meat and other foodstuffs. Because the charcoal is burned at high temperatures during the entire barbecuing process, the emissions from charcoal combustion come in direct contact with the foodstuffs and the nearby people. Knowing that mercury is released from combustion sources [2,3], the extent of Hg emissions can vary between different charcoal samples depending upon the raw material and processes involved in their production.

In order to investigate the potential effect of Hg emissions during livelihood activities, a total of 11 barbecue (BBQ) charcoals, commercially available in Korea, were collected and analyzed. These 11 products are listed in Table 1 and were found to consist of both domestic (4 types) and imported products (i.e., 3 from Indonesia, 3 from China, and 1 from Malaysia). These charcoal samples were then combusted, and emitted gases were initially collected in 10-L Tedlar bags through a vacuum sampler (ACEN Co. Ltd.). As a means to make a direct comparison between Hg concentration levels emitted by different charcoal samples, the charcoal was combusted in a consistent manner by adopting the same combustion protocol with an old-style Korean combustor. In addition, for the combustion of individual charcoal samples, an equal amount (i.e., 540 g) was used. The collection of Hg from the emission gases was initially made by Tedlar bag sampling system to secure sufficient quantity of Hg. These samples were then connected to the gold (Au) amalgam tubes for the application of the gold amalgam method by pulling the air at a constant flow rate by a mini-pump (MP-Σ 300, SIBATA, Japan). The flow rates for tube sampling were maintained at 1000 mL min^{-1} and checked each time before starting the experiment [4]. Each sample collected by the Au trap was desorbed thermally and detected at a wavelength of 253.7 nm by a nondispersive double beam, flameless atomic absorption system using a mercury analyzer (WA-4, Nippon Instrument Co., Japan). The precision of the Hg analysis by the combined bag sampling and Au amalgam method was achieved in 3.28–5.29% range, when expressed in terms of relative standard error (RSE%) for standard samples prepared at fairly comparable concentration range (260–337 ng m^{-3}) and sampling volume (1-L) [4]. The analytical performance of the instrumental set-up for the present approach including the bag-to-tube transfer of samples has been described in our recent work [4].

2. Results and discussion

The overall mean Hg concentration of 11 charcoal products was 242 ± 115 ng m^{-3}, as can be seen from Table 1. Note that various agencies have provided reference exposure limits (REL) of Hg^0 from

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Table 1
Basic information about the charcoal samples collected from different countries

Order	Country of origin	Sample code	Hg concentration (ng m^{-3})
1	Korea	K0	496
2	Korea	K1	201
3	Korea	K2	209
4	China	C1	217
5	China	C2	235
6	China	C3	153
7	China	C4	265
8	Malaysia	M1	206
9	Indonesia	I1	415
10	Indonesia	I2	153
11	Indonesia	I3	114
Mean ± S.D. (*N*)			242 ± 115 (11)

time to time for risk assessment purposes, e.g., 90 [5], 200 [6], 300 [7], and 1000 ng m^{-3} [8]. As a continuing effort to improve such criteria, the contaminated sites division of Health Canada proposed most recently a chronic REL of Hg^0 as 80 ng m^{-3} [9]. The calculated overall mean concentration is much higher than the recent reference exposure limit of 80 ng m^{-3} for Canada [9]. The highest concentration of Hg was observed in sample K0 (496 ng m^{-3}), which was more than 2 times higher than the other two samples from Korea (i.e., K1 and K2). In contrast, sample I1 from Indonesia showed the Hg concentration of 415 ng m^{-3}, which was over 3 times higher than the other two samples from Indonesia (i.e., I2 and I3). As such, the concentration of Hg varied widely from sample to sample, regardless of their origin. It is suspected that some producers use the improper raw materials for the production of charcoal such as used furniture (or household wooden products) containing such pollutants as volatile organic compounds (VOCs) or Hg. To our surprise, old furniture can also act as a source of Hg when used for charcoal production; Hg can come from the paints, as Hg compounds are used in some paint products (such as latex paint) to control microbial growth in paint cans and on painted surfaces [10]. Hence, based on the current study, mercury emitted from the BBQ charcoal combustion (i.e., 114–496 ng m^{-3}) seems to exceed the modern prescribed exposure limits, which have the potential to cause serious health impacts on humans, e.g., neuro-toxic, reno-toxic, and immuno-toxic effects [11].

In order to compare the relative source strengths of charcoal combustion as Hg emission source, the results obtained from the present study are compared against those available from other combustion sources (Table 2): coal (anthracite and bituminous) in power plants, electric furnace, industrial hazardous waste, and municipal waste [12]. The Hg levels seen from most of these sources (i.e., 8 out of 12) were comparatively higher than those quantified from the charcoal samples analyzed in this study. In addition, the industrial oil-fired boiler showed the Hg level of 230 ng m^{-3} which is quite comparable to the present study. The flue gas from a coal-fired steam boiler at a brewery in China exhibited Hg concentration of 740 ng m^{-3} [13]. In a fluidized bed combustion study of sewage sludge from Belgium, the Hg emission was reported as 0.753 g Hg h^{-1}. This study showed that out of the 8 heavy metals, only the capture of Hg in the fly ash was inefficient due to its highly volatile nature; however, the concentration of Hg in the stack gas fell within the legal standard (i.e., 5 g h^{-1}) [14]. The mercury level observed from automobile emission sources using gasoline, diesel, and LPG as fuel was approximately 10 times lower than the values measured in this study [15].

Table 3
Comparison of mercury emission factor from various anthropogenic sources

Order[a]	Type of source	Hg emission factor (g ton^{-1})
1	Coal-fired	0.238
2	Oil combustion	0.065
3	Cement production	0.1
4	Biomass combustion	0.03–0.1
5	Iron-steel production	0.04
6	Chloro-alkali plants	3.5
7	Crematoria	0.7
8	Charcoal	0.004[b]

[a] The data for 1–7 are based on Wang et al. [22].
[b] Average value derived from data shown in Table 1.

Previous studies have proven the high accumulation potential of Hg in human organs such as the liver and kidneys (by dietary exposure) to cause severe health problems [16]. If one considers that people generally come in very close contact with the combustion gases during the entire barbecuing process, there is a reasonable chance of mercury exposure to human beings both by the release of BBQ gases and by foodstuffs in contact with those gases. Because the concentration levels of Hg from the charcoal combustion can be as significant as from other man-made sources, the use of BBQ charcoal can be regarded as an important health threat to those who are exposed to such combustion gases.

Because of a high potential to accumulate in biota [17], Hg can be regarded as the most highly bioconcentrated trace metal in the human food chain [18]. Although the actual quantity of Hg transferable to the food via the BBQ process is not yet quantifiable, the transfer of Hg from charcoal combustion, if occurring, may pose potential risk to human health. It should also be addressed that the

Table 2
Comparison of mercury emission from various combustion sources

Order[a]	Combustion sources	Hg emission concentration[b] (ng m^{-3})	Description
1	Industrial oil-fired boiler	230	Bunker B
2	Coal fired power plant	13660	Anthracite
3	Coal fired power plant	3210	Bituminous (imported)
4	Coal fired power plant	2250	Bituminous (imported)
5	Iron manufacturing plant	9720	Electric furnace
6	Industrial waste incinerator	21250	Industrial hazardous waste
7	Municipal waste incinerator	9460	Municipal waste
8	Automobile exhaust (Gasoline)	3.8–16.8	At driving conditions
9	Automobile exhaust (Diesel)	2.8–8.5	At driving conditions
10	Automobile exhaust (LPG)	20.0–26.9	At driving conditions
11	Coal-fired steam boiler	740	Guizhou Beer Plant, China
12	Sewage sludge combustion	0.75 g Hg h^{-1}	Large-scale fluidized bed sludge combustor
13	Charcoal	242[c]	This study

[a] All data for 1–7, 8–10, 11, and 12 are selected from Park et al. [12], Won et al. [15], Tang et al. [13], and Van de Velden et al. [14], respectively.
[b] The concentrations for 1–7 and 11 are given for final stack emission, which includes reduction with certain air pollution control devices (APCDs) such as: Multi cyclone, electrostatic precipitators (ESP), and baghouse filters. The data for 12 is given in g h^{-1} unit for the stack emission gas as expressed in article.
[c] Average concentration from Table 1.

use of BBQ charcoal is made more commonly in indoor environments such as restaurant facilities in certain countries (e.g., Korea). If mercury vapor enters into the indoor facilities, it can be sustained for a period of few months to years on furniture, carpets, floors and walls due to high transferability between personal items [19]. Hence, in modern buildings of tight envelope structures, mercury vapors can be trapped for a long span, and inhabitants are prone to the continuous re-exposures.

As a standard measure to estimate the emission strength of Hg due to the charcoal combustion, the emission factor (EF) was calculated as mass of the Hg emitted per unit mass of the charcoal combusted [20]. The mean EF of Hg was estimated as $0.004 \pm 0.02\ g\ ton^{-1}$ based on our combustion study of the 11 charcoal samples (Table 3). The estimated EF value was relatively low in comparison to other major anthropogenic sources of Hg emission. However, the current estimate of EF from this study can provide a basis for upgrading information concerning the total Hg load to the atmosphere exerted by charcoal uses, if aided by sufficient consumption data from each region of the world.

3. Concluding remarks

Considering the momentous potential of creating health problems, the Canadian government has recently listed charcoal as a hazardous product under the section 3 of Hazardous products (Charcoal) regulations [21]. However, there are no such regulations concerning charcoal uses in other parts of the globe. If we compare the Hg emission from the charcoal to recent reference exposure limit of Canada (i.e., $80\ ng\ m^{-3}$), the overall mean concentration of Hg from the charcoal combustion found in this study (i.e., $240 \pm 115\ ng\ m^{-3}$) is considerably high. Although the estimates of emission factor from the charcoal combustion in this study ($0.004 \pm 0.002\ g\ ton^{-1}$) are comparably low with respect to other anthropogenic source types, the concerned authorities should place an effective control on the quality of the charcoal produced and their uses. In view of the extensive charcoal consumption worldwide, there is a pressing need to accurately evaluate its impact on human health and the indoor air quality.

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