

EFFECT OF MOISTURE ON ADSORPTION OF ELEMENTAL MERCURY BY ACTIVATED CARBONS

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Abstract

Experiments using activated carbon to capture elemental mercury (Hg^0) were performed using a bench-scale fixed-bed reactor and a flow reactor to determine the role of surface moisture in Hg^0 adsorption. Three activated carbon samples, which have different pore structure and ash contents, were tested for Hg^0 adsorption capacity. From both fixed-bed reactor and flow reactor experimental results, the moisture on activated carbon surfaces has been found to have a significant effect on Hg^0 adsorption. A common effect of moisture on Hg^0 adsorption was observed for all three samples, despite extreme differences in their ash contents, suggesting that this effect is not associated with ash content. Temperature programmed desorption (TPD) experiments performed on the carbon samples after the Hg^0 adsorption experiments indicated that chemisorption of Hg^0 is a dominant process over physisorption for the moisture-containing carbon samples, and diminished for the heat-treated moisture-free samples. X-ray absorption fine-structure (XAFS) spectroscopy results provide evidence that mercury bonding on the carbon surfaces was associated with oxygen through a mechanism likely involving electron transfer processes. The aromatic resonance-stabilized structures in equilibrium with the oxygen surface functional groups take up electrons from the mercury atoms. The active sites likely are hydrated functional groups that result from the hydrogen bond of the adsorbed water (H_2O). Removal of the adsorbed H_2O inhibits the equilibrium conditions that allow surface functionalities to become electron acceptors.

Introduction

Activated carbons are widely used in the removal of pollutants from water and gases. Direct injection of an activated carbon into the flue gas stream has been used as a relatively simple approach for controlling mercury emissions. Although research has been performed to study the adsorption of mercury by activated carbons, current knowledge of mercury adsorption by activated carbons is limited, presenting intriguing scientific questions related to the nature of the adsorption (physisorption or chemisorption) and the effects of mercury species type in the gas and solid phases.

Adsorption of Hg^0 by activated carbons at ambient temperatures (e.g., 23 °C) has been suggested to be a combination of chemisorption and physisorption, whereas chemisorption is prevalent at higher temperatures; e.g., 140 °C [1]. The Hg^0 adsorption capacity of activated carbons decreases with increasing temperature and decreasing

mercury concentration [1-3]. Many factors have been found to influence the efficiency of mercury removal, including carbon characteristics, flue gas composition, and the presence of active components (e.g., fly ash) [4]. The low concentrations of Hg^0 in the flue gases ($\sim 10 \mu\text{g}/\text{m}^3$) and short residence times ($< 3 \text{ s}$) of the injected sorbent require a large amount of activated carbon (high carbon/ Hg^0 ratio) in order to achieve adequate mercury removal [5, 6].

Studies have shown that sulfur-impregnated activated carbons exhibit significantly greater Hg^0 adsorption capacities compared to those of the thermally activated carbons [1-3, 7-9]. However, heteroatoms such as sulfur (S) and chlorine (Cl), which are reactive for Hg^0 capture, generally exist only as trace elements in thermally activated carbons. On the other hand, appreciable amounts of oxygen (O) are almost invariably associated with activated carbons in the form of surface carbon-oxygen complexes produced from the activation process. Carbon-oxygen surface complexes are by far the most important structure influencing the surface characteristics and adsorption behaviors of activated carbons [10]. So far, no known research has been done to understand the role of carbon-oxygen surface complexes in Hg^0 adsorption.

Krishnan et al. [1] showed that Hg^0 capture capacities of heat-treated [140 °C, flowing nitrogen (N_2)] activated carbon samples were far less than those of unheated samples. In addition, the same heat treatment applied to a sulfur-impregnated carbon showed no significant reduction of Hg^0 capture capacity. Based on these observations, they suggested that the active sites causing Hg^0 adsorption in the thermally activated carbons contained O, and these weakly bonded surface oxygen complexes were effective in capturing Hg^0 . The reduction of Hg^0 capture capacity for the heat-treated carbons was due to the loss of weakly bonded surface oxygen complexes.

However, it is generally believed that the major effect of heat treatment at low temperatures (e.g., 25-150 °C) on carbon surfaces is the removal of adsorbed H_2O molecules [11]. Extensive studies on water adsorption by activated carbons found that H_2O is adsorbed on the carbon surfaces by means of hydrogen bonding [12-16]. The oxygen complexes on carbon surfaces form primary adsorption centers, which bind the H_2O molecules at low relative pressures. Adsorbed H_2O molecules can then become secondary adsorption centers as the H_2O vapor pressure increases. In general, carbon-oxygen surface complexes are stable below 200 °C [10], but decompose to produce H_2O , carbon dioxide (CO_2), and carbon monoxide (CO) when heated to higher temperatures under an inert gas atmosphere. From the above discussions, it appears that the reduction of Hg^0 capture resulting from low-temperature heat treatment as observed by Krishnan et al. [1] might have been caused by the removal of moisture from the carbon surfaces. Infrared (IR) spectroscopic studies [17] have shown that the change of surface species occurred during the adsorption of H_2O . The surface oxygen species or oxidized ions, which are influenced by π electrons from the extensive aromatic systems in carbons, may play an important role in surface reactions, oxidation reactions in particular [18].

The main objective of the work reported in this paper was to understand Hg^0 adsorption by activated carbons and the effect of adsorbed H_2O on Hg^0 adsorption. The thermal stability of the adsorbed mercury was determined by temperature programmed desorption (TPD), and X-ray absorption fine structure (XAFS) spectroscopy was used to examine the nature of the mercury bonding on the carbon surfaces.

Experimental

Three activated carbons, a lignite-based activated carbon (FGD, Norit Americas Inc.), a bituminous-coal-based activated carbon (BPL, Calgon Carbon Corporation), and an activated-carbon fiber (ACN, American Kynol, Inc.) were tested for their Hg^0 adsorption uptake capacity in this study. The coal-based carbon samples as received (BPL, FGD) were ground and sieved to the desired particle size range and sealed in plastic containers. Selected characteristics of these carbons are shown in Table 1. BET (Brunauer-Emmett-Teller) and DR (Dubinin-Radushkevich) surface areas were measured by N_2 adsorption at 77K with relative pressure (P/P_0) up to 0.99, and carbon dioxide (CO_2) adsorption at 273K with P/P_0 up to about 0.03, respectively, using an adsorption apparatus (ASAP 2400, Micromeritics). All samples were degassed at 300 °C under vacuum for 3 h prior to the measurements. The total pore volume was evaluated from the N_2 adsorption isotherm at $P/P_0 = 0.99$, and the micropore volume was estimated from CO_2 adsorption at 273K using the DR equation. A CO_2 molecular density of 1.03 g/cm³ and a cross-sectional area of 0.187 nm² were assumed for estimating the DR surface area [19]. The moisture and ash contents of the samples were measured by using a thermogravimetric analyzer (TGA-7, Perkin Elmer). The ACN sample is derived from a phenolic resin, in the form of needled felt with over 92% carbon and the remainder oxygen and hydrogen [20], with no ash. By employing the ash-free ACN sample, the effect of ash associated with the FGD and BPL samples on Hg^0 adsorption, if it is significant, can be estimated.

Table 1 Characteristics of activated carbon samples

Characteristic	FGD	BPL	ACN
BET surface area (m ² /g)	540	1136	1250
CO_2 surface area (m ² /g)	470	976	1248
Total pore volume (cm ³ /g)	0.55	0.58	0.51
Micropore volume (cm ³ /g)	0.18	0.37	0.48
Particle size/fiber diameter (μm)	16-24	125-177	10 ^a
Moisture (% wt)	4.0	2.5	2.0
Combustible (% wt)	68.3	93.7	98.0
Ash (% wt)	27.7	3.8	0.0

^a From manufacturer's data sheet

Figure 1 presents the schematic diagram of the fixed-bed reactor experimental setup. Industrial grade N_2 gas was used as a purge and Hg^0 carrier gas. A quartz fixed-bed reactor (1.27 cm, I.D.) surrounded by a temperature-controlled electrical furnace was used. A dryer and an O_2 trap were used to remove trace H_2O vapor and O_2 , respectively, remaining in the purge and carrier gas stream. To determine whether mercury is in the elemental (Hg^0) or oxidized (Hg^{++}) forms in the reactor outlet, an additional electrical furnace operating at a temperature of 900 °C was added downstream of the reactor to convert Hg^{++} to Hg^0 [21]. The Hg^0 -laden gas mixture was generated using a Hg^0 -containing permeation tube in a constant temperature system (Dynacalibrator Model 190, VICI Metronic). An Hg^0 concentration of 58 ± 2 ppb ($476 \mu\text{g}/\text{Nm}^3$) in N_2 at a total flow rate of 340 mL/min was generated and used for the Hg^0 adsorption experiments. An

ultraviolet (UV) mercury analyzer (Model 400A, BUCK Scientific) was used to continuously measure the concentration of Hg^0 in the outlet stream. The experiments of carbon heat treatment for moisture removal, Hg^0 adsorption, and desorption can be performed consecutively *in situ*, using the experimental setup shown in Figure 1, so that moisture uptake due to exposure of the carbon sample to the atmosphere could be avoided.

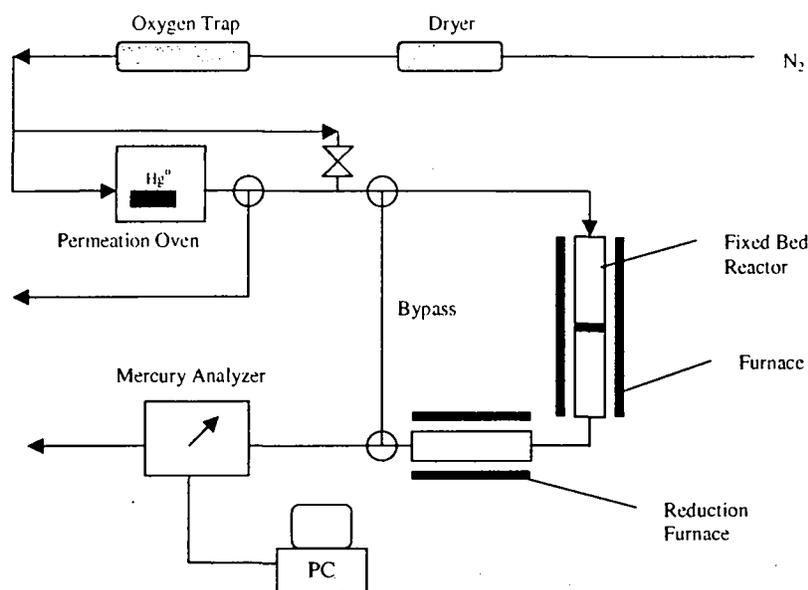


Figure 1. Schematic diagram of fixed-bed reactor setup

To perform a Hg^0 adsorption experiment on an as-received carbon sample, the Hg^0 -laden gas mixture was first sent through the bypass to establish the baseline Hg^0 concentration prior to adsorption. After loading the pre-weighed carbon sample (about 20-40 mg) into the reactor, distributed evenly on a fine frit and maintained at a temperature of 27 °C (slightly above room temperature), the Hg^0 -laden N_2 flow was switched from the bypass to the reactor. The adsorption experiment was performed for 2 h for convenience. The Hg^0 uptake for an adsorption experiment was evaluated using the area between the inlet Hg^0 concentration (baseline) and the breakthrough curve. Hg^0 adsorption experiments were also performed on the moisture-free carbon samples after heat treatment. To remove moisture from the as-received carbon sample (loaded into the reactor prior to Hg^0 adsorption), the sample was heated at a constant rate (8 °C/min) to 110 °C under a N_2 atmosphere, then held for 30 min. The reactor was then cooled to the Hg^0 adsorption temperature (27 °C) under N_2 flow, before the adsorption experiment, similar to that performed for the as-received samples, was started.

Temperature programmed desorption (TPD) experiments were performed to measure the thermal stability of the adsorbed mercury following the Hg^0 adsorption experiment. The reactor, containing the Hg^0 -exposed carbon sample, was purged with N_2 gas at 27 °C until the concentration of Hg^0 measured by the UV analyzer fell to insignificant levels (< 2 ppb). The sample was then heated at a constant heating rate (8 °C/min) to the final temperature of 420 °C. Blank TPD experiments using carbon samples without mercury

showed that there is no interference on the mercury analyzer with the loss of CO₂ and H₂O from the carbon surfaces. The amount of Hg⁰ desorbed during the TPD run was estimated from the area under the outlet Hg⁰ concentration curve. Preliminary TPD experiments showed that more than 90% of the adsorbed Hg⁰ was desorbed when the temperature reached 420 °C, so this was used as the final temperature.

A schematic of the flow reactor is shown in Figure 2. The reactor is 310.5 cm long, has an I.D. of 4 cm, and is constructed of quartz. Three gas sample ports are located along the length of the reactor, labeled SP1, SP2, and SP3, which provided residence times ranging from 5 to 18 s at a total flow rate of 0.014 m³/min [STP (standard temperature and pressure)]. The reactor is heated with three Lindberg, 3-zone electric furnaces in series. Once the baseline Hg⁰ concentration is established, activated carbon is fed into the top of the reactor using a fluidized-bed feeder. The gas-phase Hg⁰ concentration is measured at one of the sample ports by sub-isokinetically pulling a gas sample through a 1 μm filter, through a reducing furnace and finally to the UV analyzer. The detailed experimental procedures can be found elsewhere [22]. Dry carbon sample was obtained by connecting the feeder to a vacuum system and heating at 110 °C for 1 h prior to the test. To test the carbon sample with varied moisture contents, water was also added to the sample by placing the carbon in an enclosed vessel with a container of water for several hours, thereby increasing the amount of moisture in the carbon. The moisture content of the sample was tested by using a Infrared Moisture Determination Balance (AD-4714, A&D Co., Ltd.).

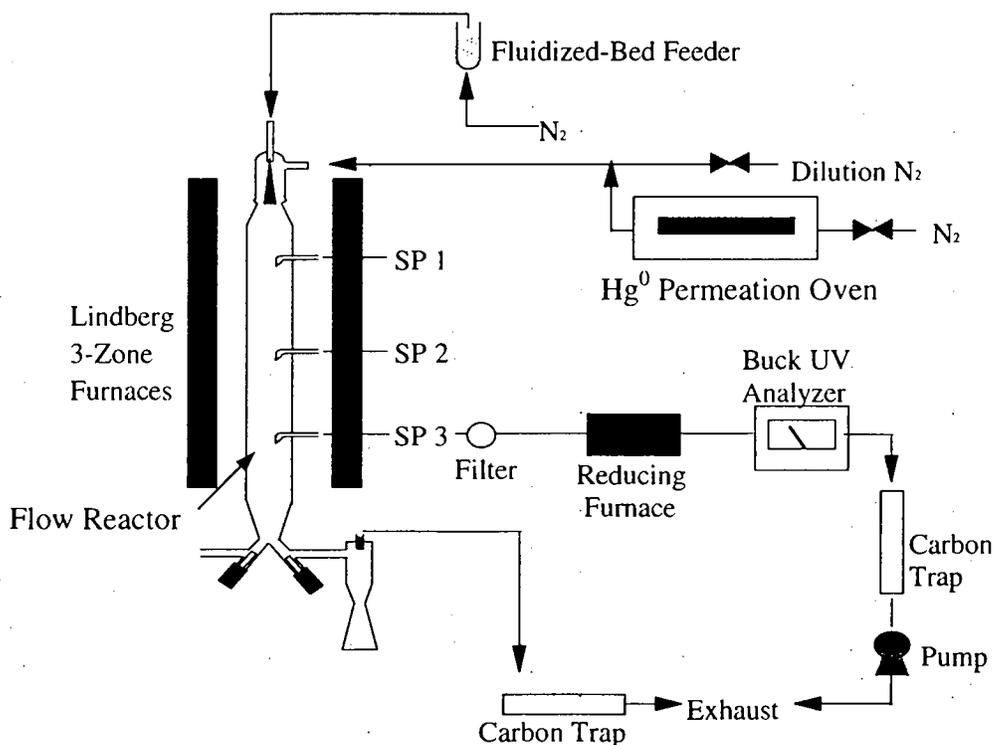


Figure 2. Schematic diagram of flow reactor setup

Both as-received and heat treated BPL and ACN carbon samples which had been exposed to Hg^0 were selected for XAFS spectroscopy analysis, in order to provide information on the nature of mercury bonding on carbon surfaces, except for the FGD carbon due to its high ash content. Details of the XAFS experimental procedures can be found elsewhere [23].

Results and Discussions

Figure 3 shows a typical Hg^0 concentration curve during adsorption breakthrough, Hg^0 desorption curve during N_2 purge, and TPD in the fixed bed reactor. Figure 4 presents amounts of Hg^0 adsorbed as a function of time during adsorption. Tests run with two coal-based as received (-AR) samples (BPL-AR, FGD-AR) show that the Hg^0 uptake of FGD-AR is slightly larger than that of BPL-AR: the latter has larger surface area and lower ash content. However, the Hg^0 uptake of the as-received carbon fiber sample (ACN-AR) is much larger than those of the coal-based carbon samples, although the total surface area of BPL is only 10 % less than that of ACN-AR sample (see Table 1). The very similar values of BET and CO_2 surface areas for the carbon fiber sample (see Table 1) suggest that ACN is a microporous (< 2 nm) carbon with homogeneous distribution of microporosity. The CO_2 surface areas of BPL and FGD samples are lower than their BET surface area, suggesting that the samples contain some mesopores. The average micropore width evaluated from CO_2 adsorption with the DR method gives a similar value of about 1.5 nm for both BPL and ACN samples, and 1.3 nm for the FGD sample. From the above results, it appears that there are no clear correlations between Hg^0 uptake capacity and carbon pore structure characteristics, such as surface area and porosity, as well as ash content.

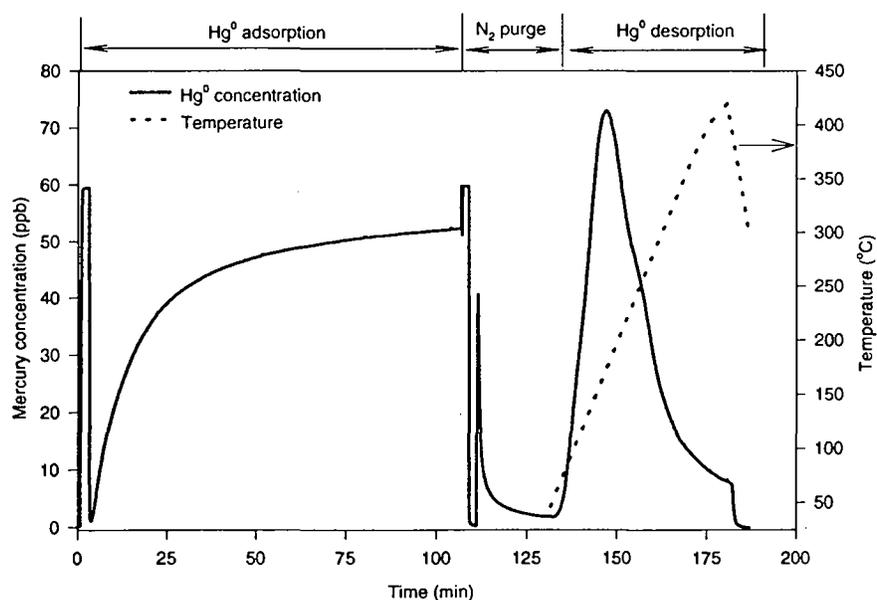


Figure 3. Mercury adsorption and desorption profile in fixed-bed reactor

Figure 4 shows that the Hg^0 uptake of carbon samples was drastically reduced to similar low values after low temperature ($110\text{ }^\circ\text{C}$) heat treatment. Such heat treatment effects were also observed by Krishnan et al. [1] for coal-based activated carbons. Heat treatment at such low temperatures ($110\text{-}140\text{ }^\circ\text{C}$) cannot change the pore structure, such as microporosity and surface area. However, adsorbed H_2O molecules on carbon surfaces are removed when heated at low temperatures; e.g., $25\text{-}150\text{ }^\circ\text{C}$ [11], suggesting that adsorbed H_2O plays an important role in Hg^0 adsorption.

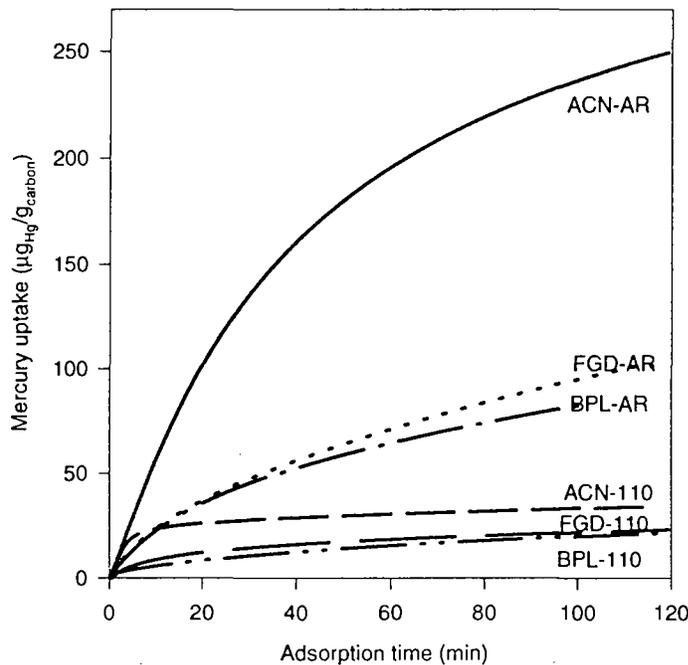


Figure 4. Mercury uptake of activated carbons as a function of adsorption time

FGD carbon with varied moisture contents (0, 4, and 16% H_2O) was tested in the flow reactor. The results shown in Figure 5 were performed at $100\text{ }^\circ\text{C}$ and a Hg^0 concentration of 86 ppb. Mercury removal using dry carbon is very low. At a feed rate of 9.5 g/hr, the removal is below 8%. The as-received carbon (4% moisture) performed better with a removal of 10% at a feed rate of 3 g/hr and increased to 30% at 6.4 g/hr. This shows that removal of moisture also has a strong effect on Hg^0 capture in the flow reactor condition. Increasing the moisture content of the carbon increased the Hg^0 removal significantly. At a feed rate of 6.4 g/hr, the removal doubled from 30% for the as-received carbon to 60% for the 16% water carbon. Note that this effect might be a result of evaporation of H_2O from the carbon surface lowering the temperature of the particle, subsequently causing higher removal. In the flue gas, however, the direction and driving force for H_2O evaporation will depend on the moisture content of carbon, as well

as the temperature and H₂O concentration. It can be found from previous study [4] that the presence of H₂O in a simulated flue gas does not seem to affect Hg⁰ uptake capacity. Tests were conducted to determine the moisture loss from the particle as it falls through the reactor with a 10 s particle residence time. Approximately, 50% of the moisture was lost. The extent to which moisture content of activated carbon affects Hg⁰ removal, the evaporation of H₂O from the moisture-containing carbon, and the temperature profile of the particle, needs further investigation. Nevertheless, the result from the flow reactor shows that the moisture content of activated carbon is also an important factor in Hg⁰ capture.

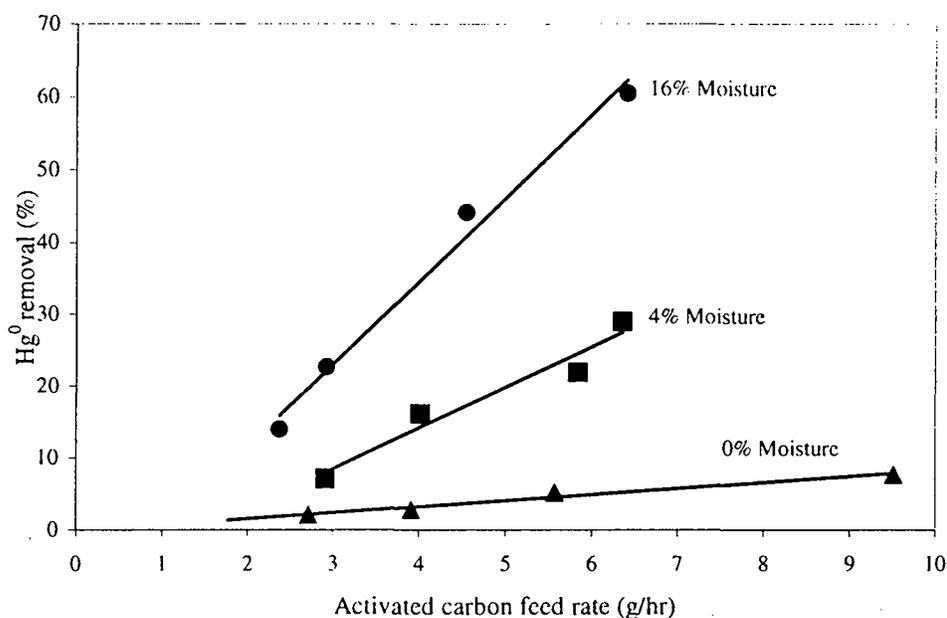


Figure 5. Mercury removal by FGD carbon with different moisture contents in the flow reactor at 100 °C and 86 ppb Hg⁰

To better understand the mechanism of Hg⁰ adsorption by activated carbon and how carbon surface moisture could affect Hg capture significantly, it would be important to know the nature of mercury bonding on the carbon surface. As shown in Figure 3 from the fixed bed reactor N₂ purge and TPD results, the chemisorbed Hg⁰ can be differentiated from physisorbed Hg⁰. The physisorbed Hg⁰ on the carbon surfaces is evolved during the purge period when the reactor gas is switched from the Hg⁰-laden N₂ at the end of the adsorption experiment to pure N₂ (27 °C). The mercury evolved during the subsequent TPD run is referred to as chemisorbed Hg⁰, since it is stable at the adsorption temperature under the inert gas atmosphere (N₂) and decomposes into gas species as the temperature rises. The amounts of Hg⁰ desorbed were calculated from the area under the outlet Hg⁰ concentration, and the results are presented in Table 2, expressed as a percentage of the Hg⁰ adsorbed that was measured during the adsorption experiment prior to the N₂ purge. Similar amounts of Hg⁰ were measured between duplicate runs with and without operating the reduction furnace, which suggested that the mercury evolved during desorption was Hg⁰ and not an oxidized form. The mass

balances between the adsorbed and desorbed Hg^0 in all cases were greater than 90%, and most of the Hg^0 adsorbed by the carbons was recovered by heating the samples to 420 °C.

For the as-received samples, more than 86% of the adsorbed Hg^0 was desorbed during the TPD runs at higher temperatures versus $\geq 54\%$ for their heat-treated counterparts. Hg^0 evolved from the coal-based, as received samples (BPL-AR, FGD-AR) during the N_2 purge accounts for only a small fraction of the total Hg^0 adsorbed. Adsorption and desorption processes on the carbon surface are known to be governed by a distribution of adsorption energies [24]. Chemical bonds formed between the adsorbed molecules and the adsorption sites of an activated carbon are often very energetic. Since the TPD experiments show that Hg^0 is evolved over a wide temperature range, Hg^0 bonds on the carbon surface probably involve different site types, which have varying bonding energies, implying that the nature of the carbon surface active sites for bonding Hg^0 depends on the sample characteristics. For the as-received samples, chemisorption of Hg^0 appears to be the predominant process. Note from Table 2 that a relatively large amount of Hg^0 for the ACN-AR sample was evolved during N_2 purge. As described, ACN is a microporous carbon with homogeneous distribution of microporosity. The physisorbed Hg^0 of ACN-AR in this case could be explained by its microporosity. The reduction of Hg^0 capture for the heat-treated samples is caused by the reduction of chemisorbed Hg^0 . Thus, it could be deduced that the removal of H_2O from the carbon surfaces by low-temperature treatment eliminates the active sites that can chemically bond Hg^0 .

Table 2 Mercury uptake from adsorption and recovery from desorption

Sample	Hg adsorption at 27°C		Hg desorption		Hg recovery (%)
	Hg captured ($\mu\text{g/g}$) ^a	N_2 purge (%)	TPD (%)		
ACN-AR	236	12	86		98
ACN-110	34	42	54		96
BPL-AR	83	5	93		98
BPL-110	20	20	71		91
FGD-AR	95	3	96		99
FGD-110	22	42	56		98

^a Amount of mercury adsorbed for 100 min on dry-carbon basis

Figure 6 shows the Mercury L_{III} -edge XANES (X-ray absorption near-edge structure) spectra of the five carbon samples, and the inflection point difference (IPD, eV) derived from the spectra. Sufficiently strong spectra have permitted the derivative analysis to be performed in order to obtain the IPD values, except for ACN-110, which could be due to its low mercury concentration. Huggins et al. [23] showed that the IPD values could be used as an effective parameter to identify the nature of the mercury bonding on carbon surfaces. It has been shown that the mercury surface compounds with the smallest and most ionic anions (O^{2-} , O^-) have the largest values of IPD (e.g., > 9.0), whereas those with the largest and more covalent anions have the smallest IPD values [23]. As shown in Figure 6, the IPD values derived from the XANES spectra are larger than 9.0. One of the as-received ACN samples gives an IPD value of 9.8, close to that of mercury acetate (10.6) [23]. Results of the XAFS analysis indicate that the Hg-O bond is significant for

the as-received carbon samples, which had been exposed to Hg^0 . The XAFS results are consistent with the TPD results in that most of the adsorbed Hg^0 was strongly bound on carbon surfaces and evolved at higher temperatures in all cases.

The above XANES results suggest that carbon-bound oxygen on the surface captures Hg^0 during the adsorption experiments. Different types of oxygen surface groups are believed to exist on activated carbon surfaces. Depending on their history of formation and activation temperature, they could be carboxyl, lactone, phenolic, and carbonyl groups [25]. Electron transfer processes are likely to be involved during the chemisorption of Hg^0 . Abundant evidence from the literature shows that different oxygen groups can participate in the electron transfer processes on carbon surfaces [18]. Extended π bonding in the extensive aromatic network of carbons permits electron clouds and charges to be highly delocalized. For example, the resonance-stabilized structures of the aromatic network in equilibration with the surface functional groups (e.g., quinonoid complexes) could take up electrons resulting in the functional groups' becoming anions.

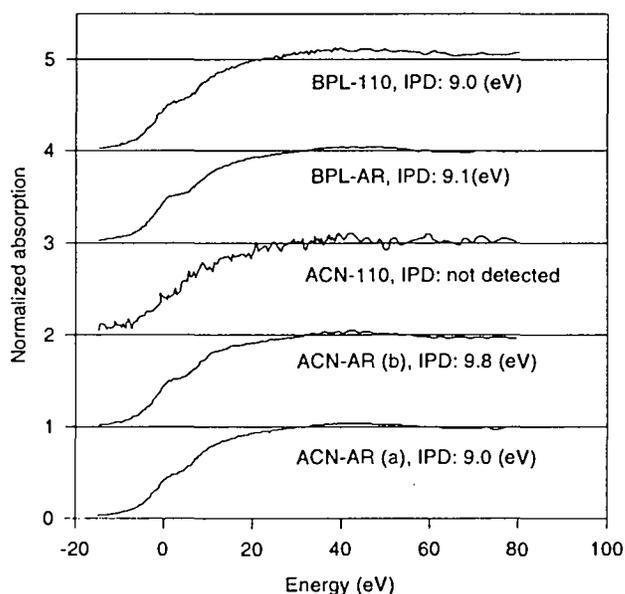


Figure 6. Mercury L_{III} -edge XANES spectra of activated carbons

Based on the above-proposed mechanism for Hg^0 oxidation, the observations that the desorbed mercury from the TPD experiments was found to be Hg^0 , and that the adsorbed H_2O has a significant effect on Hg^0 adsorption, could be explained as follows: when thermal energy is applied to a chemisorbed Hg^0 , such as a mercury-carbonyl complex, it would be favorable for the electron(s) to return to the mercury rather than breaking the C-O bonds. Although certain oxygen complexes would also decompose to produce CO_2

and H₂O at low temperatures (e.g., < 420 °C), it is not clear if Hg⁰ is bonded to complexes such as carboxyl and lactone groups. However, as described by Leon y Leon and Radovic [18], before the oxidation reactions can proceed they all have specific experimental requirements that must be met such as pH, oxygen exposure, and kinds of surface functional groups. The fact that the presence of surface moisture promotes Hg⁰ bonding could imply that surface groups for such bonding would probably involve certain hydrated surface functional groups, which arise from the hydrogen bond of adsorbed H₂O [26]. Simply removing the adsorbed H₂O at low temperature (< 150 °C) as moisture would inhibit the equilibrium conditions favoring the surface structures to be the electron acceptors. One or more types of oxygen functional groups could act as electron acceptors if specific conditions are met. It is not known what particular surface functional groups are responsible for Hg⁰ bonding from the current investigation. Further research is needed to characterize the carbon oxygen surface groups that act as electron acceptors to capture Hg⁰.

Conclusions

The moisture on activated carbon surfaces has been found to have a significant effect on Hg⁰ adsorption. The results from this study show that the Hg⁰ adsorption capacities of activated carbon samples were drastically reduced after removing their moisture. By comparing the results of an ash-free activated carbon sample (ACN) to those of coal-based carbons, it is concluded that mineral matter or metal oxides in the coal-based carbons do not play a role in this effect. It also appeared that no correlation could be established between the carbon pore structure and Hg⁰ adsorption capacity. Results of the TPD experiments show that chemisorption of Hg⁰ is a dominant process during Hg⁰ adsorption for the moisture-containing carbon samples. XAFS analysis provides evidence that Hg⁰ bonding on the carbon surfaces is associated with oxygen.

Results from both mercury desorption (TPD) and XAFS analyses suggest that surface oxygen complexes provide the active centers for mercury bonding. The mechanism of mercury bonding on the carbon surfaces likely involves an electron transfer process, in which the aromatic, resonance-stabilized structures in equilibrium with the surface functional groups would probably take up electrons from the Hg⁰. The observation that the presence of surface moisture promotes mercury bonding suggested that the oxygen surface groups capable of mercury bonding might involve certain hydrated functional groups, which could result from the hydrogen bond of the adsorbed water. Removal of the adsorbed H₂O at low temperature (< 150 °C) as moisture would inhibit the equilibrium conditions that allow surface functionalities to become electron acceptors.

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16. ABSTRACT The paper discusses experiments using activated carbon to capture elemental mercury (Hgo), and a bench-scale fixed-bed reactor and a flow reactor to determine the role of surface moisture in Hgo adsorption. Three activated-carbon samples, with different pore structure and ash content, were tested for Hgo adsorption capacity. From both fixed-bed and flow reactor experimental results, the moisture on activated-carbon surfaces has been found to have a significant effect on Hgo adsorption. A common effect of moisture on Hgo adsorption was observed for all three samples, despite extreme differences in their ash content, suggesting that this effect is not associated with ash content. Temperature-programmed desorption (TPD) experiments performed on the carbon samples after the Hgo adsorption experiments indicated that chemisorption of Hgo is a dominant process over physisorption for the moisture-containing carbon samples, and diminished for the heat-treated moisture-free samples. X-ray absorption fine-structure (XAFS) spectroscopy results provide evidence that mercury bonding on the carbon surfaces was associated with oxygen through a mechanism likely involving electron transfer processes. The aromatic resonance-stabilized structures in equilibrium with the oxygen surface functional groups take up electrons from the mercury atoms.			
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