Impact of oxy-fuel combustion gases on mercury retention in activated carbons from a macroalgae waste: effect of water


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The aim of this study is to understand the different sorption behaviours of mercury species on activated carbons in the oxy-fuel combustion of coal and the effect of high quantities of water vapour on the retention process. The work evaluates the interactions between the mercury species and a series of activated carbons prepared from a macroalgae waste (algae meal) from the agar-agar industry in oxy-combustion atmospheres, focussing on the role that the high concentration of water in the flue gases plays in mercury retention. Two novel aspects are considered in this work i) the impact of oxy-combustion gases on the retention of mercury by activated carbons and ii) the performance of activated carbons prepared from biomass algae wastes for this application. The results obtained at laboratory scale indicate that the effect of the chemical and textural characteristics of the activated carbons on mercury capture is not as important as that of reactive gases, such as the SOx and water vapour present in the flue gas. Mercury retention was found to be much lower in the oxy-combustion atmosphere than in the O₂+N₂ (12.6% O₂) atmosphere. However, the oxidation of elemental mercury (Hg⁰) to form oxidized mercury (Hg²⁺) amounted to 60%, resulting in an enhancement of mercury retention in the flue gas desulphurization units and a reduction in the amalgamation of Hg⁰ in the CO₂ compression unit. This result is of considerable importance for the development of technologies based on activated carbon sorbents for mercury control in oxy-combustion processes.

Keywords: mercury; activated carbons; industrial macroalgae waste; oxy-combustion
1. Introduction

Oxy-coal combustion is a promising technology in the field of CO₂ capture and sequestration (CCS). The basic principle behind this technology is to burn coal in a mixture of O₂ and recycled gas so that the resulting flue gas is mainly CO₂ and H₂O which simplifies the process of separation of CO₂ from the flue gas for further storage or beneficial use. Although this gas also contains small quantities of O₂, N₂ and minor concentrations of SOx and NOx, the CO₂ can be relatively easily separated before its capture (Buhre et al., 2005; Wall et al., 2013). The new oxy-combustion conditions may lead to certain changes with respect to conventional combustion conditions, which might involve modifications not only in the composition of the reactive gases (Normann et al., 2009; Liémans et al., 2011; Stanger and Wall, 2011; Ting et al., 2013), but also in the fate of the trace elements (Roy and Bhattacharya, 2014). Of the trace elements, mercury is the one of greatest concern because coal combustion is one of the major anthropogenic sources of mercury to the environment (Zhuang et al., 2011b; Roy et al., 2013).

Mercury is a highly toxic element whose environmental impact is widely recognised, which is why governments and several organizations have introduced measures to bring it under control (USEPA, 2011). In particular, one of the UNEP (United Nations Environment Programme) targets is to protect human health from the release of mercury and its compounds (UNEP, 2013), and a priority in this field, is the mercury released from coal combustion. However, in the case of oxy-combustion, mercury is not only an environmental problem but also a technological one since Hg⁰ can accumulate in the CO₂ compression units and damage the aluminium heat exchangers due to amalgamation of mercury with aluminium (Santos, 2010).
There are basically two ways to capture mercury during coal combustion processes. One of them is to install purpose-designed systems for mercury capture in power stations, and the other is to make use of already installed systems intended for the capture of other contaminants for the co-removal of mercury. A large number of the purpose-designed systems for capturing mercury species in gas phase are based on solid sorbents. Of these, activated carbons that are capable of physically or chemically adsorbing this element, are the most common (Sjostrom et al., 2010). The effectiveness of activated carbons, which have been evaluated not only at laboratory and pilot level, but also at industrial scale (Pavlish et al., 2010), depends on particle size, surface area, porosity, etc. (Lopez-Anton et al., 2002), and gas composition, since reactive gases can influence mercury speciation and mercury sorption mechanisms.

Numerous studies have already been performed on the application of activated carbons for mercury capture in gases from combustion, and to refer to all of them is outside the scope of this paper. However, the knowledge accumulated by these studies constitutes a solid basis to address the emerging problems associated with oxy-combustion that, given the current state of the art, are far from being understood. To achieve a solution to these problems it is first necessary to identify the mechanisms of heterogeneous mercury oxidation on the carbon surface and to determine how the gas composition may modify these mechanisms (Liu and Vidic, 2000; Miller et al., 2000; Granite and Presto, 2008). To achieve these goals, the effects of reactive gases need to be considered.

Although the effect of SO$_2$ on mercury adsorption is of great importance, it has not yet been fully clarified even in conventional combustion plants. Some authors (Uddin et al., 2008; Diamantopoulou et al., 2010; Morris et al., 2012) have concluded that SO$_2$ favors mercury adsorption, particularly in the presence of O$_2$, due to the formation of HgSO$_4$ on the surface. Other studies (Presto and Granite, 2007; Granite and Presto, 2008;
Sjostrom et al., 2009; Morris et al., 2010; Zhuang et al., 2011a; His and Chen, 2012), however, suggest that the SO$_3$ in flue gases leads to the formation of H$_2$SO$_4$ on the surface of the activated carbon which leads to pore blockage, inhibiting the adsorption of Hg$^0$. The role of water in mercury retention by activated carbons during conventional combustion is another variable whose influence on the adsorption mechanism has been explained in various ways. However, in the case oxy-combustion the role of water needs to be fully clarified because in this particular process, water vapor can be expected to be present in significantly higher concentrations. Apparently, the presence of water in the flue gas, even in the range of 5-10%, seriously impedes the removal of mercury (Cudahy and Helsel, 2000; Richards, 2005; Presto and Granite, 2007), probably due to the adsorption of water molecules into the micropore structure of the activated carbon, which reduces the number of the active sites available for mercury (Zheng et al., 2012). However, Li et al. (2002) found that moisture on activated carbon surfaces favours Hg$^0$ adsorption at room temperature.

To stress the importance of flue gas composition for mercury retention on activated carbon is not to imply that the characteristics of the activated carbon itself are not important. Typical activated carbons may capture Hg$^{2+}$, but in general they are not good sorbents for Hg$^0$. The retention of Hg$^0$ can be significantly enhanced by using activated carbons impregnated with sulfur, chlorine, bromine or iodine that chemically interact with Hg$^0$ (Assian and Kaghazchi, 2013; Rupp and Wilcox, 2014). The limitation that is often attributed to these impregnated materials is the cost of the preparation (Pacyna et al., 2010). This explains why the use of solid wastes as precursors for the preparation of activated carbons has emerged as a competitive way to produce these materials (Klasson et al., 2010). Satisfactory results for mercury retention have been obtained using renewable sources of carbon such as bamboo charcoal, poultry manure, waste tires,
chicken waste, etc (Skodras et al., 2007; Yaji et al., 2008; Tan et al., 2011). Although some of these sorbents have been tested at industrial scale (De et al., 2013), most of the studies have so far been focused on the development of good textural and chemical properties of the activated carbons with very little attention being paid to the effect that the gases in a full coal combustion atmosphere have on mercury retention. In addition, the results may be very different in an oxy-composition atmosphere and in one of air combustion due to their different gas compositions.

In view of these considerations this work focuses on the interactions between mercury species and a series of activated carbons prepared from a waste from the agar-agar industry in an oxy-combustion atmosphere, paying special attention to the role that the high concentration of water in the flue gases can play in the retention of mercury.

2. Experimental

The activated carbons used in this work were prepared from two types of precursor i) a macroalgae waste (algae meal) from the agar-agar industry (AM) and ii) a char (AMP) obtained by pyrolysis of AM at 750ºC. The conditions for obtaining both samples have been previously described (Ferrera-Lorenzo et al., 2014a). These precursors (AM and AMP) were chemically activated with KOH, in precursor/KOH proportions of 0.5:1 and 1:1. The activation temperatures used were 750 and 900ºC and the heating rate and N₂ flow rate were 5ºC/min and 150 ml/min, respectively (Ferrera-Lorenzo et al., 2013, 2014a). The activated carbons obtained from AM and AMP were labelled AMA and AMPA followed by the precursor/KOH proportions and the activation temperatures used (Table 1). These materials were washed with HCl 5M and deionized water, and dried before testing. A commercial sulphur-impregnated activated carbon developed for
Hg\(^0\) retention (Norit RBHG3), was employed as a reference material (Lopez-Anton et al., 2002).

The moisture content of the macroalgal waste was obtained following the UNE 32002 norm, on the basis of weight loss at 105°C over a period of 1 hour, and the ash content was determined by calcining the sample in a muffle at 815°C for 1 hour in the presence of oxygen, according to the UNE 32004 norm. The carbon, hydrogen and nitrogen contents of the samples were determined using LECO CHN-2000 equipment. The sulphur content was measured on a LECO S-144-DR equipment. The chlorine concentration was measured by means of an ion selective electrode after combustion in a calorimetric bomb. Textural characterization was performed by measuring the N\(_2\) adsorption at \(-196^\circ\)C on an automatic apparatus (Micromeritics ASAP 2420). Isotherms were employed to calculate the specific surface area, S\(_{\text{BET}}\), and Total Pore Volume, V\(_{\text{TOT}}\), at a relative pressure of 0.95. The micropore and mesopore size distributions were calculated on the basis of the density functional theory (DFT). The narrow microporosity (pore width smaller than 0.7 nm) was estimated from the CO\(_2\) adsorption isotherms at 0°C, taking 1.023 g cm\(^{-3}\) as the density of adsorbed CO\(_2\) and 0.36 as \(\beta\) parameter (the affinity factor that characterizes each adsorbate). The CO\(_2\) isotherms were used in conjunction with the Dubinnin-Raduskevich equation to calculate the micropore volume, \(W_0\), micropore size (\(L_0\)), and energy characteristic (\(E_0\)). The water vapour adsorption isotherms were determined at 25°C for water activity (aw) using a scale of 0 to 1. The equilibrium moisture content was expressed in grams per g of dry solid.

The laboratory device used for the retention of mercury is shown in Figure 1. The experimental device consisted of a glass reactor heated by a furnace and fitted with a thermocouple. The sorbent bed was prepared by mixing 30 mg of sample with 500 mg
of sand. Hg$^0$ in gas phase obtained by means of a permeation tube was passed through
the sorbent bed at a rate of 0.5 L min$^{-1}$ in a concentration of 100 μg m$^{-3}$. A synthetic gas
mixture consisting of 4% O$_2$, 1000ppm SO$_2$, 1000ppm NO, 100 ppm NO$_2$, 25 ppm HCl,
12% H$_2$O, 64% CO$_2$ and 20% N$_2$ was employed as the simulated oxy-combustion
atmosphere. To evaluate the effect of water vapour and reactive gases a series of
experiments were carried out in the same atmosphere without water, O$_2$+N$_2$ (12.6% O$_2$)
and N$_2$ atmospheres. The temperature of the sorbent was 150°C. The gas lines were
heated to avoid possible condensation. The mercury adsorption curves were obtained
using a continuous Hg$^0$ emission monitor (VM 3000). A dilution flow rate of 2 L min$^{-1}$
with air was added before the VM 3000. The mercury content after the retention
experiments was determined by means of an automatic mercury analyzer (AMA). The
duration of the mercury experiments was the time needed for the samples to reach
maximum retention capacity. The oxidation of the mercury was evaluated by capturing
the Hg$^{2+}$ in an ion exchanger resin (Dowex$^\text{®}$ 1x8), especially designed for the selective
extraction of Hg$^{2+}$ species (Fuente-Cuesta et al., 2014). The resin was placed at the exit
of the reactor prior to the Hg$^0$ continuous analyzer (Figure 1). The Hg$^{2+}$ in the resin at
the end of the retention experiments was determined by AMA. The resin had previously
been conditioned with a mixture of HCl:H$_2$O (1:1) at 90°C for 30 minutes and then
filtered and dried. The content of Hg$^{2+}$ condensate in the water and collected during the
experiments prior to the analyzer was determined by AMA.

3. **Results and discussion**

The chemical analysis data for the precursors and activated carbons from algae wastes
used in the present study have been detailed in previous works (Ferrera-Lorenzo et al.,
2013, 2014b). The activated carbons obtained from wastes of the agar-agar industry had
low ash (2.2-7.3%) and high carbon (83-91%) contents. The nitrogen content was higher than 3% whereas for RBHG3 (0.47%) and other activated carbons reported in the literature (Bermúdez et al., 2010) it is much lower. The important difference is the sulfur content which was 1% in the activated carbons and 6% in the impregnated RBHG3 carbon. Chlorine, which can also play an important role in mercury capture, varies in the different samples as a consequence of the efficiency of the washing process after activation. It is 0.02% in AMA0.5:1-750, 0.03% in AMPA1:1-900, 0.09% in AMPA1:1-750 and AMPA0.5:1-900 and 0.22% in AMPA0.5:1-750.

The specific surface area (S_{BET}) ranged from 813 (AMPA0.5:1-750) to 1982 m²/g (AMA0.5:1-750), and the total volume (V_{TOT} \ [p/p^0=0.95]), from 0.364 (AMPA0.5:1-750) to 0.914 cm³/g (AMA0.5:1-750) (Ferrera-Lorenzo et al., 2014b). Most of the adsorbents were microporous materials with a certain degree of mesoporosity development. The microporosity varied from 29% to 68% in the case of ultramicroporosity (<0.7 nm) and from 20% to 57% in the case of medium-size microporosity (0.7-2 nm). Mesoporosity development (2-50 nm) ranged from 10% to 14%. The ultramicroporosity volume was higher in the activated carbons obtained from AMP, whereas medium microporosity and mesoporosity was greater in the activated carbons obtained from AM. RBHG3 has a similar porosity distribution with a prominent microporous development. The activated carbon which presents the highest micropore volume calculated by CO₂ isotherms is AMPA1:1-900 (W₀=0.586 cm³/g⁻¹) followed by AMA0.5:1-750 (W₀= 0.514 cm³/g⁻¹), AMPA1:1-750 (W₀=0.449 cm³/g⁻¹), AMPA0.5:1-900 (W₀= 0.410 cm³/g⁻¹), AMPA0.5:1-750 (W₀=0.332 cm³/g⁻¹) and RBHG3 (W₀=0.266 cm³/g⁻¹).

Special attention has been paid in the present work to the H₂O adsorption at 25°C. Figure 2 shows the water vapour adsorption-desorption isotherms for samples
AMP1:1-750, AMPA0.5:1-900, AMA0.5:1-750 and RBHG3. As can be seen, the water vapour adsorption isotherms are of type V or S-shaped, which is typical of microporous materials. The process of water adsorption is due to both physical adsorption and chemical interaction with the surface groups. The activated carbons obtained from the algae meal and carbonized algae meal exhibit a higher water vapour adsorption than that of the commercial activated carbon (RBHG3). If the slopes of the isotherms in the lower P/P⁰ are carefully examined, it can be seen that all the isotherms have a convex shape, which suggests the presence of hydrophilic surface groups. At low relative pressure the macroalgae activated carbons present a higher water vapour adsorption than commercial activated carbon (RBHG3) which suggests a greater presence of hydrophilic groups in these materials capable of forming hydrogen bonds with water molecules. The sample activated at 900°C shows a lower adsorption capacity at low pressure, suggesting that at a high activation temperature, the surface groups disappear. As the pressure increases the influence of the textural development becomes more important. The isotherm which presents the highest adsorption capacity at moderate pressures corresponds to the activated carbon from the algae meal (AMA0.5:1-750), whereas RBHG3 displays the lowest adsorption capacity.

Table 2 shows the mercury retention capacities and the percentages of Hg²⁺ resulting from heterogeneous (gas-solid interaction) oxidation. The homogeneous (gas-gas interaction) mercury oxidation in the same flue gas composition has been studied previously (Fernández-Miranda et al., 2014). The confidence limit of the results is given as the standard deviation. To determine which characteristics of the activated carbon influence mercury retention all the sorbents were first tested in an atmosphere made up just of O₂ and N₂. The mercury retention capacities range from 1000-1600 µg g⁻¹ for all the activated carbons in this simple atmosphere. The char AMP shows the lowest
mercury retention capacity (20 µg g⁻¹), which is well below that of the activated samples. AMP has a BET surface area value of 4 m²/g (Ferrera-Lorenzo et al., 2014b) while the activated samples range from 800 to 2000 m²/g. Therefore, the development of texture is another factor to take into consideration for mercury retention. However, an examination of the different textural characteristics of the activated carbons reveals that there is no clear relationship between surface area, pore distribution and mercury capture. Varying the activation temperature and the proportion of precursor/activating agent leads to materials with different textural characteristics, but no correlation can be established between the surface area, ultramicropore volume, medium-microporous volume, mesoporous volume and mercury retention capacity. Therefore, the textural development is not the only factor affecting mercury retention. In the atmosphere formed by O₂ and N₂, the differences observed in the mercury adsorption curves (Figure 3) can be attributed mainly to variations in the chlorine content remaining in the material after washing. It is worth noting that the activated carbon with the highest chlorine content (AMPA0.5:1-750) shows the highest mercury retention capacity which is similar to that of the commercial carbon impregnated with sulfur. The positive influence of the presence of chlorine in carbon materials for mercury retention is well known. Chlorine species can generate chemisorption sites on carbon surfaces favoring the adsorption of mercury.

It must be emphasized that the activated carbons prepared from algae meal and algae meal carbonized in the atmosphere of O₂+N₂ can reach retentions of the order of the activated carbon impregnated with sulfur RBHG3 (Table 2). In an inert atmosphere (N₂) the retentions are much lower (<400 µg g⁻¹), in agreement with previous studies (Morris et al., 2012; Karatza et al., 2013) which demonstrates that O₂ plays a critical role in mercury sorption on carbon surfaces. In the absence of other oxidizing species the
presence of O$_2$ increases the mercury uptake. It has been suggested that mercury bonding on the carbon surface is associated with oxygenated groups, in particular, with lactone and carbonyl groups (Li et al., 2002, 2003).

The behaviour of mercury on a selection of the activated carbons where the gas composition simulates that of coal oxy-combustion is completely different (Table 2). It can be seen that, on the one hand, the mercury retention capacity is much lower in the reactive atmospheres than in O$_2$ and N$_2$ and that, between 20 and 60% of Hg$^{2+}$ results from heterogeneous oxidation in the oxy-combustion atmosphere. Figure 4 shows the mercury adsorption curves for a series of representative samples of activated carbons from algae meal in a simulated oxy-combustion flue gas (Figure 4a) and in the same atmosphere when it is dry (Figure 4b). The mercury analyzer, which only detects Hg$^0$, recorded that the mercury signal did not reach the baseline (22±3 µg m$^{-3}$). This could be because mercury was retained in the activated carbon and/or because of mercury oxidation.

A high concentration of water vapour in an oxy-fuel atmosphere has a considerable impact on the process and on all gas cleaning systems, the behaviour of mercury being no an exception. Mercury capture on solid sorbents may decrease as a consequence of the presence of water vapour in the atmosphere (Cudahy and Helsel, 2000; Richards, 2005; Presto and Granite, 2007; Zheng et al., 2012). In the particular case of the sorbents evaluated in this work, it can be seen (Table 2) that retention increased in the dry flue gas. This could have been a consequence of the high water vapour adsorption of the materials obtained from the algae waste, as can be seen from Figure 2. If the activated carbons from the algae waste are compared, those with the highest water adsorption capacity present the lowest mercury retention capacity in the oxy-combustion atmosphere (Figure 2, Table 2). The same conclusion can be drawn from
the results with the activated carbon RBHG3 which present the lowest water adsorption
capacity (Figure 2) and have the highest mercury retention capacity in the atmosphere
with water (Table 2). However, retention improves in the dry oxy-combustion
atmosphere for all activated carbons, where the retentions are of the same order, and
comparable to that of the reference activated carbon RBHG3. Previous results obtained
by the authors in similar conditions (Fernández-Miranda et al., 2014) demonstrated that
the presence of water vapor in the flue gas results in the formation of sulfuric acid
according to reactions I and II, reaction I being favored in the presence of CO₂. This
might lead to lower mercury retentions in the presence of water (Table 2), since the high
concentration of H₂SO₄ could result in almost complete pore blockage. It should be
noted that the formation of sulphuric acid is a consequence of reaction in the gas stream
and is not influenced by the sulfur content in the activated carbons.

\[
\text{SO}_2 (\text{g}) + \frac{1}{2} \text{O}_2 (\text{g}) \rightarrow \text{SO}_3 (\text{g}) \quad \text{(I)}
\]

\[
\text{SO}_3 (\text{aq,g}) + \text{H}_2\text{O (l,g)} \rightarrow \text{H}_2\text{SO}_4 (\text{aq}) \quad \text{(II)}
\]

In contrast, other authors (Morris et al., 2012) have observed that the formation of
H₂SO₄ on the carbon surface favors mercury retention through reaction III.

\[
\text{Hg(g)} + 2\text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{HgSO}_4 + \text{SO}_2(\text{g}) + 2\text{H}_2\text{O(l,g)} \quad \text{(III)}
\]

Mechanism (III) assumes that after being physically adsorbed onto the surface, Hg⁰ will
be oxidized to Hg²⁺. The Hg²⁺ will then become bound to Lewis base surface sites either
in carbon-oxygen or carbon-sulfur functional groups. In the present study and in both
the activated carbons from the algae waste and the activated carbon impregnated with
sulfur, the mercury was oxidized. However, Hg²⁺ was not retained in any significant
amount by the activated carbons, this mercury remaining in the gas phase or being
condensed in the water. Therefore, the factors that play a role against the retention of mercury by activated carbons in oxy-combustion processes can be summed up as follows:

i) The formation of a large amount of H$_2$SO$_4$ due to the high concentration of water vapour produced in oxy-combustion (up to 30%), which would block the mercury adsorption sites on the carbon surface.

ii) The slow kinetics of mercury adsorption from HgSO$_4$ due to the short contact time between the activated carbons and gas, which is less than 1 second (similar to the contact times in the injection of activated carbon in coal-fired power plants).

It should also be noted that even in a dry atmosphere, the mercury retention capacities of the activated carbons decrease in the presence of reactive gases compared to retention in an O$_2$+N$_2$ atmosphere. It is well known that NOx can promote mercury oxidation (Miller et al., 2000; Niksa et al., 2001; Fuente-Cuesta et al., 2012; Rodríguez-Pérez et al., 2013; Wu et al., 2013), but it can also favor SO$_2$ sulfation through reaction IV below. This reaction has been observed by the authors of the present study in previous experiments carried out under the same experimental conditions (Fernández-Miranda et al., 2014). The formation of SO$_3$ would then compete with the mercury for the same binding sites.

\[
\text{NO}_2 (g) + \text{SO}_2 (g) \rightarrow \text{NO} (g) + \text{SO}_3 (g)
\]  

(IV)

4. Conclusions
The results of this study confirm the essential role of O₂ in mercury capture by activated carbons. The activated carbons obtained from biomass algae waste showed a mercury retention capacity of the same order as the activated carbon impregnated with sulphur in an atmosphere free of reactive gases. The presence of reactive gases, mainly SO₂/ SO₃, and vapor water enhanced mercury oxidation. The Hg²⁺ produced was retained to a limited extent in the carbons. These results need to be taken into consideration when developing technologies for mercury control in oxy-combustion processes, where the presence of a large amount of water vapor may result against to mercury adsorption. The results also make it clear that such minor differences in the textural properties of activated carbons as those reported in this work are eclipsed by the chemical properties (Cl) of the materials and by the composition of the flue gas.

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Figure captions

**Figure 1.** Schematic diagram of the experimental device for mercury retention

**Figure 2.** Water vapour adsorption isotherms (at 25ºC) of the materials

**Figure 3.** Mercury adsorption curves corresponding to the carbon samples in an O$_2$+N$_2$ atmosphere

**Figure 4.** Mercury adsorption curves corresponding to the activated carbons in a) oxy-combustion and b) oxy-combustion water vapour-free atmospheres
Table 1.- Activated carbons obtained in the experimental conditions used

<table>
<thead>
<tr>
<th>Sample</th>
<th>Activation agent/precursor</th>
<th>Activation temperature (ºC)</th>
<th>N₂ flow rate (ml/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMA0.5:1-750</td>
<td>0.5:1</td>
<td>750</td>
<td>150</td>
</tr>
<tr>
<td>AMPA0.5:1-750</td>
<td>0.5:1</td>
<td>750</td>
<td>150</td>
</tr>
<tr>
<td>AMPA0.5:1-900</td>
<td>0.5:1</td>
<td>900</td>
<td>150</td>
</tr>
<tr>
<td>AMPA1:1-750</td>
<td>1:1</td>
<td>750</td>
<td>150</td>
</tr>
<tr>
<td>AMPA1:1-900</td>
<td>1:1</td>
<td>900</td>
<td>150</td>
</tr>
</tbody>
</table>

Nomenclature: AMA: Activated carbon from algae meal (AM); AMPA: Activated carbon from algae meal carbonized (AMP)

Table 2. Mercury retention capacities and heterogeneous oxidation percentages of the activated carbons in O₂+N₂, oxy-combustion and oxy-combustion water vapour-free atmospheres.

<table>
<thead>
<tr>
<th>Sample</th>
<th>O₂+N₂</th>
<th>Oxy-comb.</th>
<th>Oxy-comb/free H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hg ret. (µg g⁻¹)</td>
<td>Hg²⁺(g)ₜₐₜ (%)</td>
<td>Hg ret. (µg g⁻¹)</td>
</tr>
<tr>
<td>AMP</td>
<td>20±3</td>
<td>0</td>
<td>---</td>
</tr>
<tr>
<td>AMA0.5:1-750</td>
<td>1221±300</td>
<td>0</td>
<td>3.2±0.5</td>
</tr>
<tr>
<td>AMPA0.5:1-750</td>
<td>1607±100</td>
<td>0</td>
<td>---</td>
</tr>
<tr>
<td>AMPA0.5:1-900</td>
<td>1240±200</td>
<td>1</td>
<td>6.5±1.1</td>
</tr>
<tr>
<td>AMPA1:1-750</td>
<td>1428±200</td>
<td>0</td>
<td>12±2</td>
</tr>
<tr>
<td>AMPA1:1-900</td>
<td>1037±200</td>
<td>0</td>
<td>---</td>
</tr>
<tr>
<td>RBHG3</td>
<td>1649±200</td>
<td>1</td>
<td>127±10</td>
</tr>
</tbody>
</table>

Oxy-comb.: simulated oxy-combustion flue gas; Hg ret.: mercury retention capacity; Hg²⁺(g)ₜₐₜ: oxidized mercury by heterogeneous oxidation
Figure 1
Figure 2
Figure 3
Figure 4