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Speciation of mercury in FGD gypsum and mercury emission during the wallboard production in China

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HIGHLIGHTS

- Different mercury compounds are identified in typical Chinese FGD gypsums.
- 10–50% of mercury in the FGD gypsum would be emitted during wallboard production.
- The mercury emitted from re-use of FGD gypsum was 4.7 tons in 2008.

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ABSTRACT

During combustion of pulverized coals, most of the mercury (Hg) in coal volatilizes. With the wide use of dry and wet scrubber systems for flue gas desulfurization (FGD), various amounts of Hg are captured by coal combustion byproducts, such as, FGD gypsum. The specification of Hg in FGD gypsum is essential not only to determine the risk when the wastes are recycled or disposed but also to understand the behavior of Hg during coal combustion and the mechanisms of Hg oxidation along the flue gas path. In this study, a temperature-programmed decomposition technique was used in order to acquire an understanding of the Hg species associated with FGD gypsum. A series of Hg reference compounds were used to obtain the characteristic temperature of decomposition for each Hg compound. The decomposition temperature of the Hg species is in an increasing order as $Hg_2SO_4 < Hg_2Cl_2 < HgCl_2 <$ black $HgS < HgO <$ red $HgS < HgSO_4$. The results also indicate that $HgCl_2$ and HgS are the primary Hg compounds in FGD gypsum samples. Hg stability during the reutilization of FGD gypsum is important due to its health and environmental impact, and its value in improving the Hg emission inventory. The industrial calcining process of wallboard production is simulated in order to determine the Hg emission percentage during the reutilization of FGD gypsum. Results indicate that 12.1–55.1% of total Hg would be emitted from FGD gypsum in this process. A larger percentage of Hg will be emitted when the proportion of Hg_2Cl_2 and $HgCl_2$ is higher. The Hg re-emissions from FGD gypsum during wallboard production in China were estimated to be 4.7 tons in 2008.

1. Introduction

In 2009 the total amount of electricity production in China was 3664 billion kW h and 82% of the electricity is produced by coal-fired power plants [1]. The coal consumption was 1.39 billion tons for electricity generation in China in 2009 [2]. Coal-fired power plants are considered to be one of the largest anthropogenic sources of Hg emissions to the atmosphere. During the combustion of coal in the boiler, Hg released from the coal into the flue gas is in the form of gaseous elemental mercury (Hg^0). Once the volatile Hg exits the boiler, Hg interacts with HCl, SO_2 and unburned carbon and partially transforms into gaseous oxidized mercury (Hg^{2+}) via homogeneous (gas–gas) or heterogeneous (gas–solid) reactions. Particulate-bound mercury (Hg_p) is also formed after Hg^0 or Hg^{2+} is adsorbed physically to or reacts with the particles in the flue gas [3–6].

Flue gas from coal combustion may contain elemental mercury (Hg^0), mercury chloride ($HgCl_2$), mercury oxide (HgO), mercury sulfate ($HgSO_4$), mercury nitrate ($Hg(NO_3)_2$), and a number of other compounds [7]. Highly water soluble Hg^{2+} species can be captured efficiently in the wet flue gas desulfurization system (FGD) used for the removal of SO_2 and reacts with dissolved sulfides from the flue gas to form other Hg compounds [8]. Reliable information about the behavior of mercury and the extent of oxidation can be found by the identification of Hg species in the FGD gypsum. Temperature programmed decomposition method has been employed to

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specify Hg compounds in solid samples, such as coals, contaminated soils, sediments, iron-based sorbents, fly ashes and airborne particulate matters [9–15]. The results from analysis of different samples show that the Hg species can be identified by the respective characteristics of their release temperatures. Milobowski et al. [16] conducted a similar study of wet FGD products and analyzed the distinct decomposition curves of four pure Hg compounds. However, clear characteristic temperatures of HgS and HgO cannot be identified because the curves of these two compounds overlapped each other. Although HgS, HgO and $HgSO_4$ have been identified as compounds in the FGD sludge, no studies concerning the explicit identification of Hg species associated with FGD gypsum have been published. It is highly possible that other kinds of Hg compounds exist in FGD gypsum and remain to be identified. Since coal in China has variant and relatively high Hg content [17,18] and considerably lower Cl content, which plays a significant role in promoting the oxidation of Hg^0 to Hg^{2+}, results from previous studies for other countries can hardly be considered representative for China. Chinese FGD samples should be used in order to provide a comprehensive analysis for Hg speciation in the FGD products in China.

The emphasis of this study is to identify the characteristic release temperatures for different Hg compounds in FGD gypsum, and to provide general information on the typical Hg species existing in FGD gypsums in China. The goal of this study also includes the assessment of potential risks of Hg emissions during the reutilization process of FGD gypsum. For that purpose, we investigated Hg species in different gypsum samples by means of a temperature programmed decomposition process, and then simulated the wallboard manufacturing process to estimate the minimum Hg release. Useful knowledge can be achieved from this work to study the Hg oxidation mechanism and improve Hg removal efficiency of FGD in coal-fired power plants.

2. Experimental

2.1. Samples

Reference samples of a number of Hg compounds ($HgCl_2$, HgS, $HgSO_4$, HgO, Hg_2Cl_2, Hg_2SO_4) at a concentration of 1 ppm for pyrolysis were prepared by successive dry dilution. A sample of 0.1 g of a pure Hg compound was mixed with 10 g of treated gypsum which has been heated at 600 °C for 4 h to remove all the Hg species present in order to obtain sample containing 10,000 ppm of Hg. Then 0.1 g of the mixture was added to 10 g of treated gypsum. By repeating this process, Hg concentration in these samples was adjusted to 1 ppm.

Nine FGD gypsum samples were collected from eight different coal-fired power plants in China. The first two came from the same power plant but were produced on different days. As shown in Table 1, the coal type differs: six of them are bituminous coal and three are anthracite coal. The origin of coal also varies. All tested units are equipped with ESP and WFGD for PM and SO_2 removal. The plant in Guodian Tongling installs a selective catalyst reduction system (SCR) to reduce NO_x emissions.

2.2. Apparatus and method

As shown in Fig. 1, the test apparatus consists of a nitrogen source, a nitrogen flow meter, a quartz tube equipped with a temperature-controlled furnace, a high temperature furnace, a Lumex RA-915$^+$ Mercury Analyzer and active carbon to adsorb the residuary mercury. The detection limit of real-time gas mercury content is 2 ng/m^3. With a carrier nitrogen flow of 400 ml/min, the temperature of the programmable furnace increased from room temperature to 630 °C at a rate of 10 °C/min. A sample of 0.5 g of the solid in the tube reactor was heated, and the Hg compounds in the sample decomposed into the gas flow under its characteristic release temperature. To determine the exact release temperature a thermoelectric couple is attached to the reactor tube. All the Hg species are converted to Hg^0 in the next furnace at 800 °C, and measured by the Lumex. To avoid adsorption or deposition of the Hg species on the inner surface of the downstream tubing, a heating coil is wrapped around the outer surface of the tubing to keep the gas temperature high. The Lumex collects a new data set of the Hg content in the gas flow every five seconds. After continuous monitoring of Hg signal for almost an hour, a pyrolysis curve is produced including several distinct or partially overlapped peaks, depending on the sample being treated. Overlapping signals can be disintegrated using PeakFit software.

For unknown samples, after being treated in the programmed heating process, the pyrolysis curve can be obtained. Existing Hg compounds could be identified by comparison of the peak temperature with the characteristic temperatures of the specific reference samples. For instrumental calibration, the reference samples were heated before heating the samples with unknown Hg species. The experiment of temperature-programmed decomposition was conducted only when the pyrolysis curves of reference samples match well with the predetermined characteristic release temperature of each Hg compound.

During wallboard production with FGD gypsum as the raw material, the highest temperature exists in the calcining unit and is between 128 °C and 163 °C to promote hydration, and to avoid forming anhydrous calcium sulfate [19]. Typically the calcining process lasts for 1–2 h and provides favorable conditions for Hg potential release [20]. To simulate the wallboard production process, the gypsum samples were heated in the reactor tube with the temperature increasing to 163 °C from room temperature, and were maintained at 163 °C for 1 h. DMA-80 Direct Mercury Analyzer (Milestone, Italy), with a detection limit of 0.02 ng, was used for the analysis of total Hg content in the solid before and after the heating process to assess the percentage of Hg release.

Table 1
Information of the tested coals and power plants.

Sample	Coal type	Coal source	Air pollution control devices	Hg (ppm)	S (%)	Cl (ppm)
Plant 1	Anthracite	Guizhou	ESP + WFGD	0.17	1.13	117
Plant 2	Anthracite	Guizhou	ESP + WFGD	0.17	1.13	117
Plant 3	Bituminous	Shaanxi, inner Mongolia	ESP + WFGD	0.05	0.72	210
Plant 4	Bituminous	Huainan	ESP + WFGD	0.25	0.79	170
Plant 5	Bituminous	Shenhua, Shanxi	ESP + WFGD	0.14	0.55	90
Plant 6	Bituminous	Shanxi	SCR + ESP + WFGD	0.18	0.67	230
Plant 7	Bituminous	Shanxi	ESP + WFGD	0.13	1.24	260
Plant 8	Anthracite	Guizhou, Vietnam	ESP + WFGD	0.80	0.70	300
Plant 9	Bituminous	Yunnan	ESP + WFGD	0.32	0.28	80

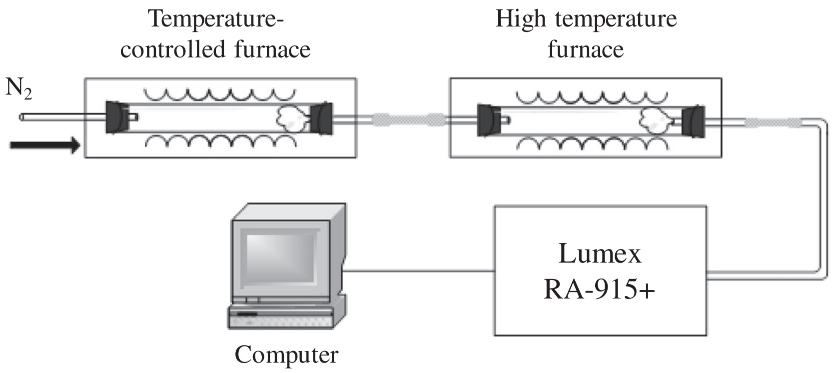

Fig. 1. Schematic diagram of the experimental set-up.

3. Results and discussion

3.1. Study of reference samples

The thermal decomposition curves obtained from the Hg reference samples, including $HgCl_2$, Hg_2Cl_2, HgS, HgO, $HgSO_4$, and Hg_2SO_4, are shown in Fig. 2. According to the peak temperature of each curve, thermal dissociation temperatures for reference samples can be determined and are shown in Table 2. It is shown that each Hg compound is indicated by one or two specific temperatures and has a different peak range. As shown in Table 2, the experiment was repeated for at least three times continuously to obtain the characteristic releasing temperature except for HgS. The experiment for HgS was repeated for 7 times because of the two different releasing temperature resulted from its crystallinity. Our results are compared with previous research to assess the correlation and consistency with those.

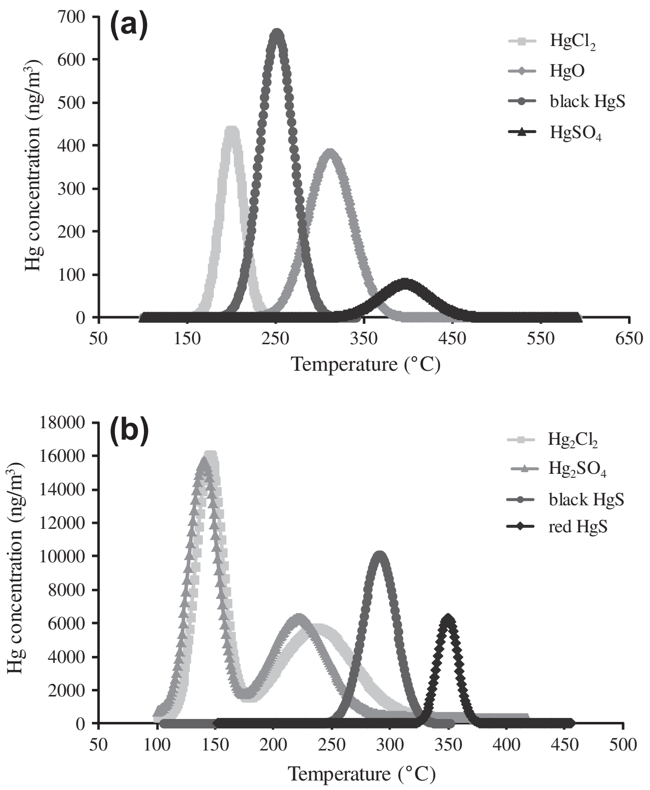

Fig. 2. Thermal decomposition profiles of reference mercury compounds. (a) $HgCl_2$, HgO, black HgS, and $HgSO_4$; (b) Hg_2Cl_2, Hg_2SO_4, black HgS and red HgS.

The decomposition temperature of $HgCl_2$ is 212 °C, the lowest temperature among the samples except Hg compounds. Pyrolysis of Hg_2Cl_2 begins approximately at the two temperature peaks (148 °C and 240 °C) appearing at the top of the table. It can be observed that the temperature range for the second peak is close to that of $HgCl_2$. This fact demonstrates that the two steps explained in the study by Lopez-Anton et al. (2010) exist in the decomposition of Hg_2Cl_2. By turning off the second furnace at 800 °C, a similar curve was observed demonstrating that the Hg signals result from the release of Hg^0. It also was previously demonstrated that all Hg species in solid samples were released as Hg^0 during the heating process [10]. Therefore, different Hg species contained in the FGD gypsum are converted to Hg^0 at different temperatures.

Two different HgS species, black HgS or metacinnabar and red HgS or cinnabar, were both analyzed resulting in distinct peaks due to their crystalline structures. Metacinnabar can be identified with its characteristic temperature which has a maximum at either 250 °C or 295 °C. The *D*-value for the two peak temperatures is 45 °C, which is the same as the *D*-value in other studies with the reference samples composed of pure compounds and silica flour [15]. Compared with metacinnabar the peak of cinnabar appears at a higher temperature, 350 °C. As already mentioned by Biester et al. [12], the structure of metacinnabar is cubic while the structure of cinnabar is triangular with Hg arranged on a rhombic lattice. Variation in mercury release temperatures for HgS may be attributed to different crystallinity.

The curve for Hg_2SO_4 shows two peaks with peak temperatures of 145 °C and 225 °C. The double peak is similar to that of Hg_2Cl_2 suggesting the consistency of pyrolysis among the mercurous compounds [21]. For $HgSO_4$, a flat peak is shown in the interval of 350 °C up to 450 °C with a peak temperature of 400 °C.

As shown in Table 2, the results of this study correspond well with the results from Milobowski et al. (2001) with similar Hg releasing temperatures for $HgCl_2$, HgS (black), HgO and $HgSO_4$. The order of the Hg releasing temperatures is considered similar to the results generalized by Lopez-Anton et al. ($Hg_2Cl_2 < HgCl_2 <$ black HgS < HgO < $HgSO_4$) [21]. This order also agrees with the study of Hg releasing temperatures using other solid samples, such as fly ash and glass [15,22]. Compared with the results of other research, variance in the peak temperature and its range of thermal decomposition are due to differences in heating rates, pressure and carrier gas flow rates. The distinct binding forms of mercury in different kinds of solids contribute to the difference in Hg releasing temperature between gypsum and soil. In gypsum Hg binds more efficiently to the finer particles in gypsum, 12% of the finest fraction retains about 63% of the mercury [23], which indicates that the structure of fine fractions have more impact on the trends in the decomposition of Hg compounds. Due to the high content of $CaCO_3$ in the soil it was thought that Hg is mainly absorbed on

Table 2
Thermal decomposition temperatures for reference samples and comparison with literature.

Hg compounds	High peak T (°C)	Standard deviation	Peak range (°C)	Experimental replicates	Milobowski et al. (2001)	
					Peak T (°C)	Onset T (°C)
Hg_2Cl_2	148, 240	2.45, 4.08	120–300	4		
$HgCl_2$	212	2.00	170–230	3	210	160
HgS	250 (50%)	1.63	200–300	4	300	175
(black)	295 (50%)	5.00	260–320	3		
HgS (red)	350	2.00	330–370	3		
HgO	325	3.00	260–370	3	300	230
Hg_2SO_4	145, 225	3.27, 2.45	120–265	4		
$HgSO_4$	400	4.08	350–450	4	425	250

$CaCO_3$ particles or incorporated into a calcareous matrix by dissolution and recrystallization processes that commonly occur in loess soils [10]. Since the reference samples used in this research are produced by means of successive dry dilution of treated FGD gypsum, unknown factors influencing Hg stability in gypsum should be considered. Based on this research, validity and reliability of the characteristic temperature of the pure Hg compounds for gypsum can be guaranteed.

It is noticed that the peak area under each decomposition curve is not the same when all the gypsum samples contain 1 ppm of mercury in theory. Earlier studies showed that Hg in coal is most likely to be bound to pyrite, followed by organic matter and silicates. Pyrite-bound Hg can be released by pyrolysis only at a temperature of 400–600 °C, which is out of the range of the thermal decomposition temperatures of reference Hg compounds [9]. Therefore, the results in this study represent only the Hg released during wall-board production, not the total Hg concentration in the samples. In addition, it turns out that there is variability in the total mass of mercury during the successive dry dilution process.

3.2. Study of FGD gypsum samples

The thermal decomposition curves of Hg compounds in tested FGD gypsums are shown in Fig. 3. The experiment of each unknown sample is repeated for more than three times until three similar pyrolysis curves are obtained to guarantee the reliability of the analysis of Hg species. The results of pyrolysis indicate the existence of various distinguishable Hg compounds in the tested samples. After overlapping peak resolving of the Hg signals of each sample, different Hg compound can be identified. For samples 1 and 2, the curve clearly shows that the gypsum contains $HgCl_2$ and black HgS, one with a peak temperature of 222 °C, and the other about 257 °C. The similarity of the two samples occurs because they are from the same power plant. Sample 3 suggests clear

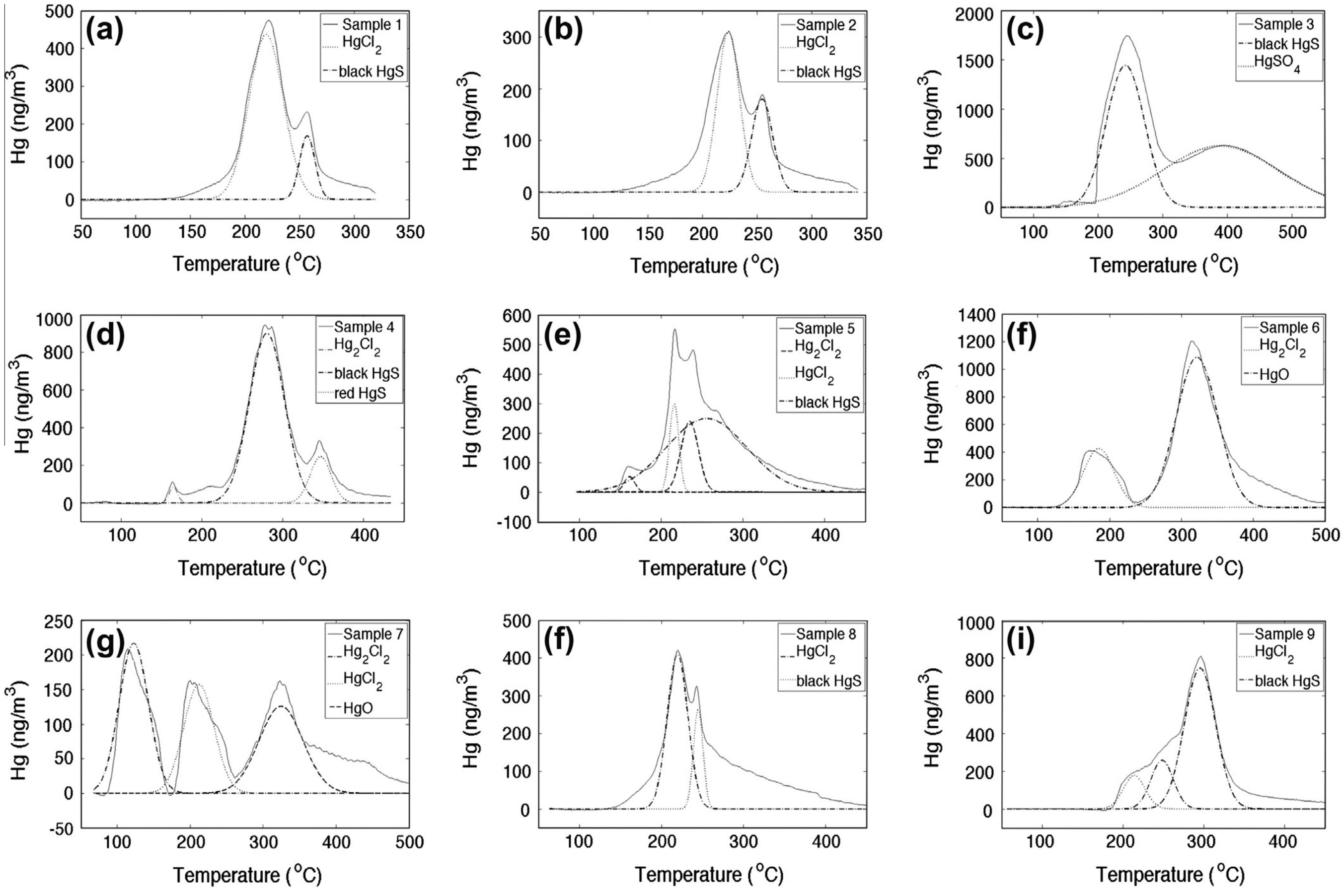

Fig. 3. Thermal decomposition curves of mercury compounds in tested FGD gypsums. (a)–(i) Are results for sample 1 to sample 9, respectively.

Table 3
Results of peak temperature (°C) and mercury speciation of tested FGD gypsum samples.

	Hg_2Cl_2	$HgCl_2$	Black HgS	Red HgS	HgO	$HgSO_4$	Experimental replicates
Standard	148 and 240	212	250 or 295	350	325	400	
1		222	257				3
2		224	255				3
3			245			394	5
4	165		285	350			3
5	160, 240	217	265				3
6	175				325		4
7	140	210			323		3
8		215	243				4
9		213	248, 297				4

Table 4
Mercury concentration in the FGD gypsum samples and mercury releasing percentage during wallboard production.

Sample	Coal type	Mercury (ppb)	Hg releasing percentage (%)
1	Anthracite	173	51.6
2	Anthracite	150	45.0
3	Bituminous	858	14.5
4	Bituminous	1920	14.2
5	Bituminous	904	40.0
6	Bituminous	2475	12.1
7	Bituminous	1000	55.1
8	Anthracite	529	51.0
9	Bituminous	657	13.0
Average	/	963	30.8

differences in Hg species from other gypsum samples tested. The characteristic temperatures of black HgS and $HgSO_4$ appear without the peak of mercury chloride. Hg_2Cl_2 was observed in sample 4, 5, 6 and 7 with peaks under 210 °C and range from 100 °C to 210 °C. Sample 5 shows a second characteristic temperature of Hg_2Cl_2 (240 °C) as well. Besides Hg_2Cl_2, two kinds of HgS of distinct crystallinity were observed in sample 4 with the two peak temperature of 285 °C and 350 °C. As can be seen in sample 7, 8 and 9, the peak temperature around 212 °C confirms the existence of $HgCl_2$. The curve with a peak around 325 °C in samples 6 and 7 corresponds well with the peak temperature for HgO. Black HgS was observed both in samples 8 and 9 with a characteristic temperature around 250 °C or 290 °C (243 °C, 248 °C and 297 °C). Table 3 summaries the existence of the respective Hg compounds in each sample.

After the calculation of peak area, the mass distribution of Hg compounds is shown in Fig. 4. The results show that $HgCl_2$ and HgS are the primary Hg compounds in the FGD gypsum; some of the other samples contain other species, such as HgO, Hg_2Cl_2 and $HgSO_4$. The different Hg species and the proportion of Hg compounds among these samples can be attributed to the composition of the flue gas, coal type and pollution control devices.

In case that any potential interference from the thermal release behavior of one Hg species on another Hg compound, solid samples such as gypsum and fly ash, added to a mixture of two or more pure Hg compounds, were analyzed using the sample method in previous study [15,21]. Mercury signals from the mixture were resolved into individual mercury peaks, which agree with the characteristic temperature of the individual Hg compound. The results show that the multi-Hg compounds could be identified and therefore do not interfere with each other.

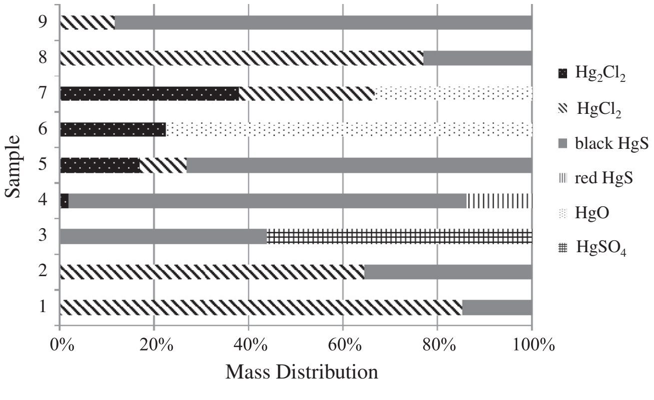

Fig. 4. Mass distribution of different mercury compounds.

3.3. Study of Hg release in wallboard production

The Hg concentration in the FGD samples was shown in Table 4. It can be seen that Hg concentration varies from 150 ppb to 2475 ppb. This is within the range of Hg concentration in FGD gypsum in China, which is 38–3404 ppb [24]. Different concentrations of Hg in coal utilization by-products may be attributed to many factors, such as the concentration of mercury in the feed coal, the flue gas temperature, the amount of unburned carbon, coal type, the presence of magnetite, the chlorine content and the ability of the ash to oxidize mercury [25–28]. Considering the distinct type of coal in different samples, we found that for the bituminous coal oxidized mercury was the dominant form in the flue gas due to the high chlorine content. Accordingly, FGD gypsum then has a higher Hg content, which ranges from 656 to 1919 ppb. This result agrees well with the research of Tan et al. (2004) [26]. Likewise, Wang et al. (2010) [29] reported the ratio of Hg^{2+} to total Hg in flue gas released from bituminous coal-fired boilers is significantly higher than that from the lignite coal-burning boilers.

As shown in Table 4, the Hg release percentage during wallboard production varies from 12.1% to 55.1%. The results generally can be divided into two groups: (1) Release around 10%; (2) Release around 50%. The release in the first group is considered to be a small release, and the other is regarded as a large release.

In addition, most of the characteristic temperatures are above or even much higher than 163 °C. However, when keeping the samples under 163 °C for 1 h, the Hg concentration in the carrier gas is maintained at a constant level indicating that the release rate of Hg from the sample changes slightly. Mercury releases from the solid phase held continuously under a constant temperature for 1 h results in a larger peak area and total release amount.

From Fig. 4 and Table 4, a correlation was found between the Hg species existing in the gypsum and its respective release amount. For samples 1 and 2, the release amount of mercury is similar due to the presence of the same Hg species and the proportion of each in the two samples. Because the first peak temperature of $HgCl_2$ (212 °C) is closer to 163 °C compared with other Hg species, and $HgCl_2$ constitutes the majority of the total Hg compounds, there appears to be a large amount of Hg release from the two samples. As can be observed from the curves for sample 3, there is no mercury chloride, and the first peak temperature for black HgS (245 °C) is far from 163 °C. It turns out that small releases occurred in sample 3. Since black HgS with a peak temperature of 290 °C constitutes 84% of the total Hg species in sample 4, it would be expected that the Hg release percentage is low. Although HgS accounts for a considerable portion of the total Hg compounds in sample 5, the sum of the other two compounds ($HgCl_2$ and Hg_2Cl_2) still accounts for nearly 30% of the total. Thus, the Hg release is nearly 40%. In regard to sample 6, since the area under the first curve with a peak temperature of 190 °C is relatively small, and since HgO with characteristic temperature above 300 °C will not contribute to the Hg release, there tends to be a small amount of release. Among the three peaks of sample 7, the first two peaks both are supposed to cause Hg release under 163 °C. Thus, a large release is observed. In sample 8 the existing $HgCl_2$, which will lead to an Hg release, directly takes over a substantial part of the total and results in large release. For sample 9, only the first peak ($HgCl_2$), which is a small proportion of the total amount, gives rise to an Hg release, while the main Hg species (HgS) hardly release from the solid under 163 °C. Hence a small release is obtained in sample 9.

A correlation between the Hg releasing percentage and the ratio of $HgCl_2$ and Hg_2Cl_2 to the total Hg compounds can be observed in Fig. 5. Mercury release during the heating process is large, around 50%, while the primary Hg compound in FGD gypsum is mercury chloride. Conversely if mercury sulfide or mercury sulfate is of a substantial amount, there tends to be a relatively small Hg releasing percentage, though there is mercury chloride of slight amount. Identification of Hg compounds and quantification of each compound in FGD gypsum is critical for estimating the releasing percentage of Hg during the reutilization process.

In 2009, China's total SO_2 emission was 22 million tons and 9 million tons were emitted from power plants [1]. Because of the increasing energy demand and high energy consumption, the power sector has been selected by the Chinese government as an important and promising target for emission reduction in 2010, particularly for SO_2. It is also mandated that small units with low combustion efficiency, totaling over 50 GW, should gradually be shut down; newly-built power units (not including combined heat and power units, CHP) must be larger than 300 MW, and all newly-built units as well as most existing ones must install flue-gas desulfurization (FGD) systems [30]. By the end of 2009, the installed capacity of FGD systems in coal-fired power plant is 460 MW representing 75% of all coal-fired utility generating capacity, compared with that of 15% in 2005 [1]. With the increasing application rate of FGD systems, more FGD byproducts with Hg will be produced. According to statistics, in China the wet FGD gypsum production was 35 million tons in 2008, doubling the total for 2007 [31]. If the average Hg concentration in FGD gypsum is taken to be 962 ppb, it follows that the Hg mobilization potential for FGD gypsum in China was about 33.7 tons in 2008. With a full-developed recycling system for FGD waste, 81% of the FGD gypsum recycled was used in gypsum wallboard production worldwide in 2009 [32]. The recycling industry for FGD products in China started only last century but has rapidly developed as a result of the increasing gypsum demand [33]. While a large portion of FGD waste is used for disposal and reclamation, the rate of multipurpose utilization is around 45% at present in China [31], mainly in the fields of wallboard production, cement additives and soil conditioner [34–36]. We find that the amount of FGD gypsum used as soil conditioner is negligible and we assume all the recycled FGD gypsum are used in the other two industrial processes. Since the heating temperature during the treatment of FGD gypsum as cement additives is similar to that of wallboard production [34], we assume the average release percentage of mercury during cement production is the same as that during wallboard production. Considering that 45% of the total gypsum is recycled and the average release percentage is 30.8%, Hg emission during the wallboard manufacturing process in 2008 was 4.7 tons, comparable to the emission from copper smelting, waste incineration, grassland/savanna burning and agricultural residue burning, etc. [37,38]. This result indicates that the re-use of FGD gypsum may cause significant re-emission of mercury and should be considered in developing Hg emission inventory.

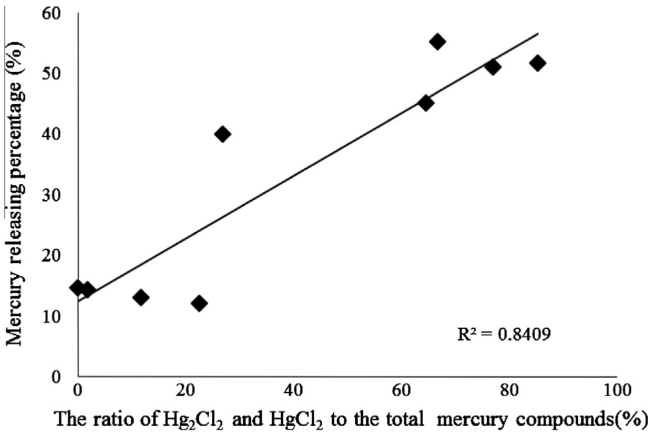

Fig. 5. Correlation between mercury releasing percentage and Hg_2Cl_2 and $HgCl_2$ content.

4. Conclusions

The existing Hg compounds in the FGD gypsum include Hg_2Cl_2, $HgCl_2$, black HgS, red HgS, HgO and $HgSO_4$, among which $HgCl_2$ and black HgS are the primary compounds. In the wallboard production process 10–50% of mercury could be released from the FGD gypsum into the atmosphere. The releasing percentage is closely related to the existing Hg species in the FGD gypsum. By identifying the Hg compounds in the FGD gypsum, the potential amount of mercury released can be estimated according to the different release temperature of each Hg species.

We estimate that 4.7 tons of mercury was released to the atmosphere during the reutilization of FGD gypsum. In order to make sustainable use of coal combustion byproducts, more FGD waste will be recycled and processed for utilization in industry. With the ratio of gypsum reused for wallboard production and cement additives increasing, there will tend to be a larger amount of Hg release from the heated FGD gypsum during industrial processes in the future. This part of Hg emission will be an important component of the total emission inventory. In order to reduce Hg emission during the utilization of the coal combustion byproduct, such as FGD gypsum, more rigorous and practical regulations should be established to ensure the feasibility and security of recycling waste. First, since the release of mercury primarily takes place during the heating process in industry for the removal of crystal water, other treatment such as adding desiccating agent in vacuum should be developed to remove the crystal water of gypsum and avoid heating the material. Second, we suggest increasing the amount of FGD materials for commercial utilization practices without heating treatment, such as agriculture applications. Third, to control Hg emission in the reutilization of FGD gypsum, active carbon can be added to absorb mercury in the gas flow.

Since mercury will be reutilized in other industrial fields as well, such as soil conditioner, the issue of potential for mercury release from this FGD gypsum needs to be investigated. Research should be encouraged to simulate production technology and to analyze the potential risks during the manufacturing processes. Besides reutilization, about half of the FGD gypsum has been disposed as solid wastes at present in China. Therefore, regulations concerning selecting a disposal site and construction and operation of containment need to be established. Experiments are required to provide site-specific statistics and investigate the Hg stability in the FGD gypsum washed by acid rain. For example, sequential leaching or extractions can be implemented to estimate the ability of mercury dissolving out from the solid phase in the solution of changing pH and oxidation.

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