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The distribution and occurrence of mercury in Chinese coals

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Abstract Mercury is one of the most concerned hazardous elements in coals. 1018 coal samples of different coal-forming periods, coal-accumulating areas and coal ranks all over the country were collected to study the distributions of mercury in Chinese coals. The modes of occurrence of mercury were studied with float-sink experiments of 10 coals from different basins in China and correlation analyses were conducted between concentrations of mercury and maceral and sulfur contents, as well as the ash yield. The theoretic concentrations and affinities of mercury in vitrinite, inertinite, clay and pyrite were then calculated following the methods proposed by Solari. The weighted average concentration of mercury in Chinese coals is 0.154 μg/g, which is similar to that in the word coals in general. The mercury concentrations vary largely in the coals of different coal-forming period and coal-accumulating areas as geological settings play key roles in determining the geochemistry of mercury. The concentrations of mercury in coals from south and southwest China and those from North China of C_3–P_1 are relatively higher while those from North China of J_{1-2} and Northeast of J_3–K_1 relatively lower. The general distribution trends of mercury are very similar to that of ash yield, sulfur contents in coals. Pyrite is the dominant carrier of mercury in most coals, especially in some high-sulfur coals with abundant epigenetic pyrite formed during diagenesis and metamorphism. Mercury has higher affinity to vitrinite than to inertinite in most coals, which accords with the geological origin of macerals and geochemistry of mercury.

Keywords Coal · Mercury · Concentration · Distribution · Modes of occurrence

1 Introduction

Mercury is an excellent proxy for periods of major volcanic activity in the geological record (Grasby et al. 2015; Thibodeau et al. 2016). Organic matters strongly control mercury sequestration over geological time (Grasby et al. 2013). Terrestrial mercury of atmospheric origin may potentially be transported to coastal sediments bound to organics or clay particles (Sanei and Goodarzi 2006; Outridge and Sanei 2010; Sanei et al. 2010; Kongchum et al. 2011; Sanei et al. 2014). As a highly toxic element (Yudovich and Ketris 2005; Dai et al. 2012b), mercury is a chemical of global concern owing to its long-range atmospheric transport and its persistence in the environment. Once emitted into the atmosphere, mercury can be transformed into highly toxic methyl-Hg in aquatic ecosystems and the living organisms can be affected by bio-accumulations (Fitzgerald et al. 1998). The mercury concentration in the atmosphere has increased by 250% while the mercury in surface water 25% and in deep sea 11% since the industrial revolution (Sunderland and Mason

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2006). The increasing industrialization in Asia has made it the largest regional mercury emissions source into the atmosphere, with east and southeast Asia accounting for about 40% of the total global anthropogenic mercury emissions (UNEP Chemicals Branch 2013).

The human activities are responsible for the inventory of global mercury. Coal combustion has been proven the largest anthropogenic sources of atmospheric mercury emissions (Galbreath and Zygarlicke 2000; Pacyna et al. 2006, 2010; Wilcox et al. 2012; Huang et al. 2016). The annual anthropogenic emission of mercury is estimated at nearly 31% of its total emissions (Pirrone et al. 2010) while coal burning for mercury emission is 475 tons in 2010 (UNEP Chemicals Branch 2013). About 100 tons of mercury are emitted into atmosphere from coal-fired power plants in China every years (Tang et al. 2016).

Extensive efforts have been made to control mercury emissions worldwide. The Minamata Convention on Mercury, the world's first legally binding treaty on reducing the mercury pollution, was signatured in 2013 under the endeavors of the United Nations Environment Program (UNEP) (UNEP 2013). Mercury has been listed as one of potential hazardous elements in the United States of America since the Clean Air Act Amendment was carried out in 1990. Mercury and Air Toxics Standards (MATS) was issued a final finding by the U.S. Environmental Protection Agency (EPA) for reducing emission of toxic air pollutants from power plants in April 14, 2016.

As the largest user and emitter of mercury, China faces extraordinary challenges. The limits of mercury concentration for coal-fired power plant flue gas was set at less than 0.03 mg/Nm^3 according to the Chinese standard GB/T 13223-2011. The distribution and occurrence of mercury in coals from various coal basins in China had been reported intensively (Dai and Ren 2007; Liu et al. 2007; Song et al. 2007; Wang et al. 2007; Zheng et al. 2007, 2008; Li et al. 2012; Jiang et al. 2015), especially those with higher content of mercury from Southwest China (Dai et al. 2006a, 2008; Wang 2009; Wang et al. 2012; Zhuang et al. 2012; Dai et al. 2013a, b, 2014; Chen et al. 2015; Li et al. 2016).

The modes of occurrence of mercury in coal are of growing concern. The confident level of mercury occurrence in coal was estimated 6 out of 10 (Finkelman 1994). It is generally considered that mercury can be presented in coal as sulfide and selenides, in forms associated with pyrite and marcasite (Ward et al. 1999; Hower et al. 2008; Kolker 2012), calcite and chlorite (Zhang et al. 2002), selenio-galena (Dai et al. 2006b, 2015), clausthalite (Hower and Robertson 2003), kleinite and cinnabar (Brownfield et al. 2005), sphalerite ($HgFeS_2$) and getchellite (Dai et al. 2006a). It can also organically bounded to organic matter (HgOM) (Rumayor et al. 2015), or even as HgS and metallic mercury (Hg^0) (Finkelman 1994; Yudovich and Ketris 2005). It is clear that mercury is mostly associated with pyrite, especially late-stage (epigenetic) pyrite deposited from hydrothermal basinal fluids (Hower et al. 2007; Dai et al. 2012a; Diehl et al. 2012; Kolker 2012). Besides, Mercury derived from the igneous intrusion distributed in both the organic matter and the minerals (Dai et al. 2012c). Syngenetic hydrothermal solutions were input during peat accumulation and thus led to high mercury concentrations in all the coal benches (Dai et al. 2013a). Mercury may re-deposited from the solutions and were adsorbed in the coal when the temperatures dropped to ambient levels (Finkelman et al. 1998). Mercury could also be driven off from the organic component in the coal by magmatic heat and then re-deposited nearby. So the concentrations of mercury are higher in altered coals near magmatic intrusions (Finkelman et al. 1998; Golab and Carr 2004; Dai and Ren 2007; Dai et al. 2012c).

The mercury concentrations of more than 1000 coal samples systematic collected around the country are determined to study the concentration and distribution characteristics of mercury in Chinese coals in this paper. Then, the modes of occurrence of mercury are studied with float-sink experiments of 10 representative coals of different rank from different basins in China and correlation analyses.

2 Sampling and methods

2.1 The distribution of mercury in Chinese coals

2.1.1 Coal sampling

The main coal-forming periods in China are Early Carboniferous (C_1), Late Carboniferous (C_3), Early Permian (P_1), Late Permian (P_2), Triassic (T), Early- Middle Jurassic (J_{1-2}), Late Jurassic to Early Cretaceous (J_3–K_1), Eogene (E). The geological distribution of coals in China can be divided into four main coal-accumulating areas, which are North China, Northeast China, Northwest China, South China and Southwest China. The sedimentary characteristics, coal-bearing properties and the coal qualities are quite different in different coal-accumulating areas (Mao and Xu 1999).

1018 coal samples covering the main coal-forming periods and the main coal-accumulating areas, were systematically collected to study the distribution of mercury in Chinese coals. The coal samples were collected continuously from the top to bottom of a coal seam with dimensions of 5 cm × 5 cm following ISO standard (ISO 18283:2006 Hard coal and coke-manual sampling). The geological and geographical distributions of the samples

Table 1 The geological and geographical distribution of the samples

District	Province	Coal-forming period								Number of samples
		E	J_3–K_1	$J_{1\text{-}2}$	T_3	P_2	P_1	C_3	C_1	
North China	Beijing			11						11
	Hebei			3			41	40		84
	Henan			13			82	1		96
	Jiangsu						15	3		18
	Neimenggu		30	13			11	12		66
	Ningxia						12	22		34
	Shaanxi			2			3	6		11
	Shandong	3		2			25	33		63
	Shanxi			29			30	27		86
Northeast China	Heilongjiang		62							62
	Jilin	12	4				4	1		21
	Liaoning	4	22	10			8	2		46
Northwest China	Gansu			20						20
	Qinhai			4						4
	Xinjiang			39						39
South and Southwest China	Guizhou					48				48
	Yunnan				3	14				17
	Fujian				2					2
	Guangdong					33				33
	Guangxi	30				48				78
	Hubei					19				19
	Hunan				11	7			14	32
	Jiangxi				31	33				64
	Sichuan				20	39				59
	Zhejiang					5				5

are shown in Table 1. The samples studied are well representative of the coal resource in China.

2.1.2 Analyses

The proximate analyses of the samples were determined according to ISO 11722:1999, ISO 1171:1997 and ISO 562:1998. Total sulfurs of the samples were determined according to ISO 351:1996. The coal ranks were determined according to the Chinese standard GB/T 5751-2009. The concentrations of mercury were determined by cold-vapor atomic absorption spectrometry (CV-AAS) using a Milestone DMA-80 Hg analyzer following ISO 15237: 2003. All those tests were conducted in Beijing Research Institute of Coal Chemistry, China Coal Research Institute. The precisions and accuracy of the determinations conform to the requirements of the standards.

Then the concentration and distribution characteristics of mercury based on coal-forming periods, coal-accumulating areas, coal ranks were discussed. The relationships between the mercury concentrations and sulfur contents, as well as the ash yield, were also analyzed.

2.2 The modes of occurrence of mercury

2.2.1 Coal sampling and density separation

Considering the characteristics of coal-forming periods, sedimentary basin types, coal properties in China, 10 steam coals consumed in large scale in China were chosen to study the modes of occurrence of mercury in Chinese coals. The main characteristics of the samples are shown in Table 2 and details are described by Bai (2003). The sampling procedures were as the same as in 2.1.1. The samples were divided into two parts, one for the basic analyses (see Table 6), the other for float-sink experiments.

The samples used for float-sink experiments were all crushed to less than 3 mm and the float-sink experiments were conducted following the Chinese standard GB/T 478-2008. Six density fractions, namely <1.3, 1.3–1.4,

Table 2 The representations of the 10 steam coal samples

Sample	Coal-forming period	Coal seam	Coal rank	
			GB/T 5751–2009	ISO 11760:2005
XLT	N	N_1^3	Lignite	Low-rank A
HLH	J_3–K_1	No. 14	Lignite	Low-rank B
TF	J_3–K_1	No. 4	Gas coal	Medium-rank C
YM	J_{1-2}	1^{-2}	Long flame coal	Low-rank A
SD	J_{1-2}	2^{-2}	Long flame coal	Medium-rank D
DT	J_{1-2}	No. 10	Weakly caking coal	Medium-rank C
PS	P_1	No. 4	Gas coal	Medium-rank C
HDG	P_1	No. 6	Long flame coal	Medium-rank D
CC	P_1	No. 4	Meager coal	Medium-rank A
YZ	C_3	16–17	Gas coal	Medium-rank C

1.4–1.5, 1.5–1.6, 1.6–1.8 and >1.8 kg/L, were obtained from each sample.

The proximate analyses, total sulfurs and the concentrations of mercury of the raw coals and products from density separations were determined as described in Chapter 2.1.1. The maceral compositions of products from density separations were determined by Zeiss Imager A2 m microscope according to ISO 7404-3 (Methods for the petrographic analysis).

2.2.2 *The modes of occurrence of mercury*

Correlation analyses between Hg and macerals, ash yield and sulfur contents were conducted using the raw coal and the six density fractions. Then the theoretical mercury content (C_i) in the macerals and minerals was calculated by muti-factor linear regression following the method proposed by Solari et al. (1989). According to Solari, a linear relationship is found between the mercury concentrations in coal sample (C) and in different macerals and minerals (C_i). The theoretical mercury concentration in minerals and macerals were determined by Eq. (1):

$$C = \sum_{i=1}^{n} C_i W_i \quad (1)$$

where, C is the mercury content in coal (μg/g), C_i is the theoretical mercury content in minerals and macerals (μg/g), W_i is the maceral composition of the products of different densities (%).

The affinities of mercury to vitrinite, inertinite and minerals (A_i) can be subsequently calculated by Eq. (2):

$$A_i = \frac{C_i W}{\sum_{i=1}^{n} C_i W_i} \times 100\% \quad (2)$$

where, A_i is the affinity of mercury to vitrinite, inertinite and minerals.

3 Results and discussion

3.1 The distributions of mercury in Chinese coals

(1) The concentrations of mercury in Chinese coals

The statistical characteristics of mercury in Chinese coals are shown in Tables 3 and 4. The histogram of mercury in

Table 3 The statistical characteristics of mercury in Chinese coals of different coal-forming periods

Coal-forming period	Range (μg/g)	Number of samples	Arithmetic mean (μg/g)	SD
E	0–1.1	49	0.214	0.211
J_3–K_1	0–0.8	118	0.096	0.101
J_{1-2}	0–2	146	0.122	0.179
T_3	0–6.2	67	0.261	0.695
P_2	0–1.1	246	0.221	0.186
P_1	0–1.1	231	0.168	0.133
C_3	0–0.8	147	0.199	0.158
C_1	0.1–0.4	14	0.216	0.088

Table 4 The statistical characteristics of mercury in Chinese coals of different districts

District	Range (μg/g)	Number of samples	Arithmetic mean (μg/g)	SD
South and Southwest	0–6.2	357	0.236	0.364
Northeast	0–0.8	129	0.093	0.102
North China C_3–P_1	0–1.1	363	0.179	0.142
North China J_{1-2}	0–2	106	0.148	0.225
Northwest	0–0.4	63	0.086	0.085

Chinese coals is shown in Fig. 1. The mercury concentrations from most Chinese coals range between 0 and 6.2 μg/g, with an arithmetic mean of 0.176 μg/g, which is close to the results by Dai et al. (2012b) and a little higher than world coals (Clarke and Sloss 1992; Ketris and Yudovich 2009).

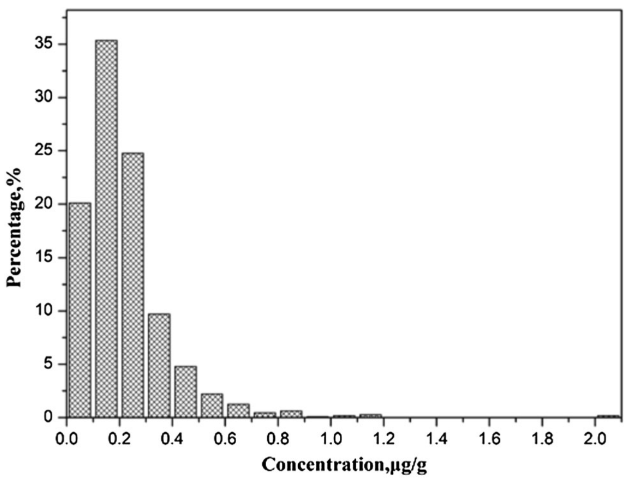

Fig. 1 The histogram of concentration of mercury in Chinese coals

Table 5 The concentrations of mercury in different rocks (μg/g)

Average concentration in coal	Abundance in the crust[a]	Ultrabasic rock[b]	Sandstone[b]	Limestone[b]
0.154	0.089	0.03	0.03	0.04

[a] Mu (1999)

[b] Liu and Cao (1987)

There are some inconsistencies between the mean concentrations of mercury in Chinese coals proposed by different researchers (Zhang 1999; Huang and Yang 2002; Bai et al. 2007; Dai et al. 2012b). Actually, some coals from P_2 in the Southwest China and from C_3–P_1 in North China has been investigated intensively for their relatively or abnormally higher mercury concentrations and the related pollutions (Zhao 1997; Ren et al. 1999a; Zhao et al. 2002). But little researches has been carried out on coals of J_{1-2} in the Northwest China with relatively low mercury concentrations as mentioned above, even though there are large quantities of coal resources. The objectivities of the results are deviated by the disproportion between samples studied and coal reserves in different regions when the arithmetic or geometric mean concentrations are used to assess the general distribution of mercury in Chinese coals.

As the coals in the same coal-accumulating basin share similar geological backgrounds and chemical properties (Mao and Xu 1999), it is reasonable to calculate the mercury concentrations by the combination of arithmetic means and the related coal reserves in different regions. The error from the disproportion between limited samples and their related reserves can be minimized when coal reserve-weighted factor is introduced. The weighted average concentration of mercury is determined as shown in Eq. (3):

$$C_m = \frac{\sum_{i=1}^{5} C_{di} W_{di}}{\sum_{i=1}^{5} W_{di}} \quad (3)$$

where, C_m is the weighted average concentration of mercury in Chinese coals (μg/g), C_{di} is the arithmetic means of mercury in coals from different coal-accumulating basin (μg/g), W_{di} is coal reserves in different regions [$\times 10^8$ t, from Mao and Xu (1999)].

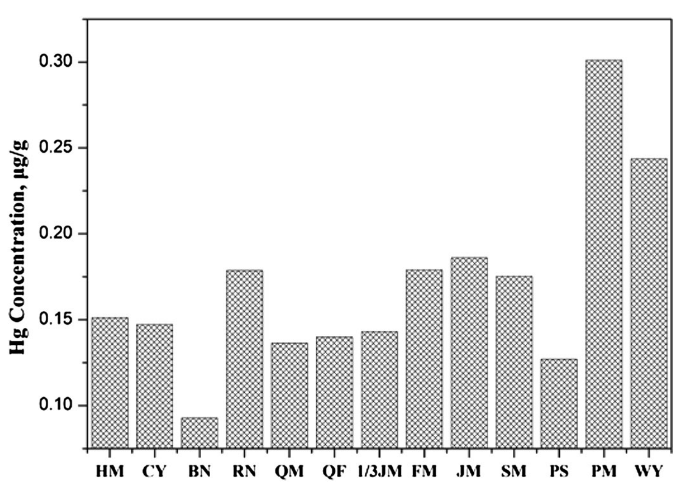

Fig. 2 The concentrations of mercury in coals of different ranks. *Note* HM, CY, BN, RN, QM, 1/3JM, FM, JM, SM, PS, PM, WY are the codes for brown coal, long flame coal, non-caking coal, weakly caking coal, gas coal, 1/3 coking coal, fat coal, primary coking coal, lean coal, meager lean coal, meager coal, anthracite respectively according to Chinese classification of coals

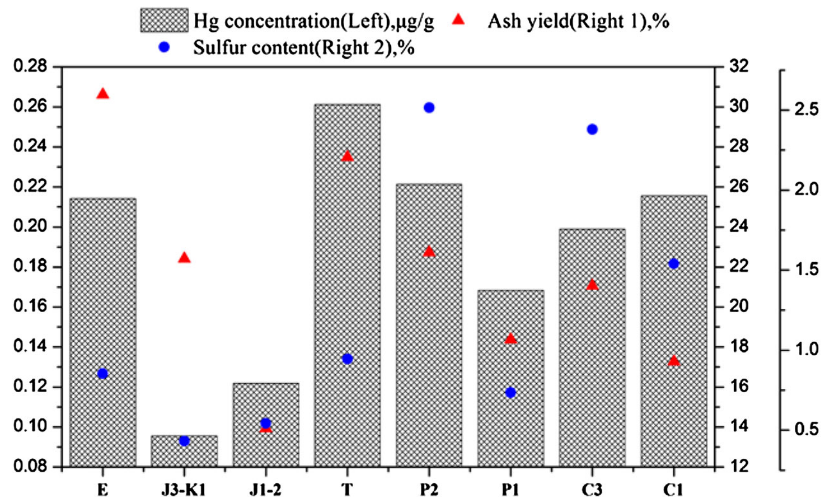

Fig. 3 The relationships between the mercury concentrations and ash yield, sulfur content in Chinese coals of different coal-forming periods

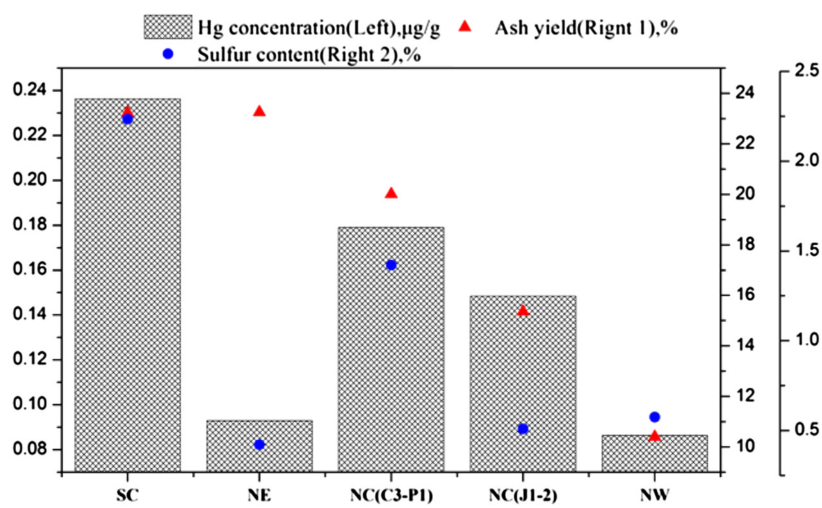

Fig. 4 The relationships between the mercury concentrations and ash yield, sulfur content in Chinese coals of different coal-accumulating areas (*SC* South and Southwest China, *NE* Northeast China, *NC* (C_3–P_1) North China C_3–P_1, *NC* (J_{1-2}) North China J_{1-2}, *NW* Northwest China)

The weighted average concentration of mercury in Chinese coals is 0.154 μg/g as illuminated in Table 5. Enrichment factors (EF) as shown in Eq. (4) (Ren et al. 1999a), can be used to indicate the enrichment of trace elements in coals. The concentration of mercury in Chinese coals is higher than that in the crust of the Earth, with the EF value up to 7.08. So the control of mercury pollution during coal exploitation and utilization should be emphasized, not only for its enrichment in coals but also for the much larger scale of coal utilization compared with other ores.

$$\mathrm{EF} = \frac{(\mathrm{Hg}/Sc)\mathrm{coal}}{(Hg/Sc)\mathrm{crust}} \tag{4}$$

where, the concentration mean of scandium in Chinese coal and in the crust are 4.40 and 18 μg/g, respectively.

(2) The distributions of mercury in Chinese coals

The distributions of mercury concentrations in coals of different coal-forming periods and coal-accumulating areas are shown in Tables 3 and 4. The mercury concentrations vary largely in the coals of different coal-forming periods. The average concentration of mercury in coals of Triassic (T) is highest in all coal-forming periods. The average mercury concentrations in coals of Early Carboniferous (C_1), Late Permian (P_2) and Eogene (E) are relatively higher than the average concentration of the Chinese coals. The average mercury concentrations in coals of Late Jurassic to Early Cretaceous (J_3–K_1) and Early-Middle Jurassic (J_{1-2}) are relatively lower than 0.15 μg/g. As the T, P_2 and C_1 are the main coal-forming periods in South China while J_3–K_1 and J_{1-2} in Northeast and Northwest China respectively, the mercury concentrations in coals

Table 6 The basic characteristics of coal samples studied

Samples	Proximate analyses (wt, %)			Hg (μg/g)	Maceral analysis (in volume, %)				$R_{o,\ max}$ (%)
	Ash yield	Volatile matter	Total Sulfur		Vitrinite	Inertinite	Exinite	Minerals	
XLT	9.39	52.73	0.60	0.036	83.12	5.08	9.26	2.54	0.47
HLH	25.56	48.42	0.56	0.250	69.91	5.64	1.88	22.56	0.33
TF	46.40	42.06	0.33	0.086	62.44	6.01	3.67	27.87	0.65
YM	21.31	41.13	2.61	0.240	54.91	29.45	3.37	12.27	0.47
SD	7.02	36.84	0.42	0.090	45.02	51.66	1.40	1.92	0.51
DT	14.66	31.07	1.79	0.300	27.54	63.68	1.79	6.98	0.81
PS	18.69	39.08	0.52	0.290	47.69	33.16	10.09	9.06	0.70
HDG	24.67	38.50	0.49	0.413	31.87	44.88	8.78	14.48	0.52
CC	17.65	14.77	0.26	0.069	58.52	27.42	0.00	14.06	1.89
YZ	14.60	46.23	4.00	0.210	69.98	18.81	4.98	7.23	0.62

Notes Ash yield and total sulfur are on dry bases, volatile matter is on dry and ash free basis

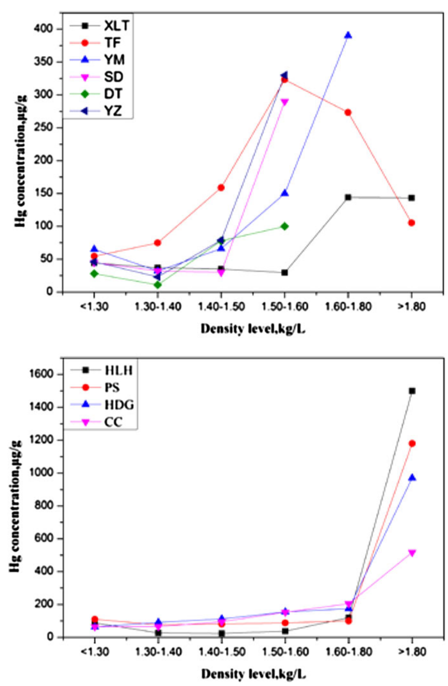

Fig. 5 The concentrations of mercury in different density fractions of float-sink experiments

from South China are relatively higher than those in North China in general.

The concentrations of mercury in coals of different ranks are shown in Fig. 2. There is no obvious relationship between mercury concentrations and the coal rank. But the mercury concentrations in meager coal and anthracite are relatively higher, with the arithmetic mean over 0.20 μg/g, which is largely attributed to their deposited geological settings and the metamorphic process (Ren et al. 1999b). As most high-rank coals in southern China have suffered magma and hydrothermal intrusion during post-depositional stage, relatively higher mercury contents are found in those coals.

(3) The preliminary study on the relationship between mercury and minerals

The relationships between the concentrations of mercury and the ash yield, sulfur contents in coals of different coal-forming periods and coal-accumulating areas are shown in Figs. 3 and 4 respectively. Mercury may be closely associated with minerals in coals, especially pyrite, as the mean concentrations of mercury and the ash yield, sulfur contents in coals of different coal-forming periods and coal-accumulating areas share the same trends. Extraordinary high sulfur concentrations are found in some P_2 coals from South China and C_3 coals from North China and the mercury concentrations are not as high as the sulfur content proportionately. Those coals are closely related to the hydrothermal activity during coal metamorphism.

3.2 Modes of occurrence of mercury in Chinese coals

(1) The distribution of mercury in different density fractions

The basic characteristics of the 10 coal samples studied are shown in Table 6 and the concentrations of mercury in different density fractions are shown in Fig. 5. The concentrations of mercury in the heaviest fraction are almost 10 times higher than that in the lightest fraction, especially for some coals from early Permian (P_1) in North China, such as PS, HDG and CC. So it can be easily concluded that mercury is mainly distributed in minerals for those coals. Besides, The concentrations of mercury in <1.3 kg/L fractions are apparently higher than that in 1.3–1.4 kg/L fractions for most coals, which is also come to the case of

Table 7 The correlation coefficients between mercury and macerals, ash yield and sulfur contents

Sample	Vitrinite	Inertinite	Clay	Pyrite	Ash yield	Total sulfur
XLT	0.94	−0.75	−0.46	−0.36	0.80	−0.48
HLH	−0.70	−0.64	0.63	0.99	0.78	0.98
TF	−0.41	0.81	0.40	−0.09	0.29	−0.12
YM	−0.76	−0.52	0.90	0.89	0.93	0.95
SD	−0.55	−0.59	0.97	0.98	0.97	0.98
DT	−0.54	−0.26	0.61	0.60	0.86	0.31
PS	−0.47	−0.58	0.89	0.99	0.80	0.96
HDG	−0.42	−0.36	0.87	0.94	0.90	0.83
CC	−0.91	−0.37	0.99	0.66	0.98	−0.80
YZ	−0.77	−0.49	0.90	0.80	0.88	0.80

Note Ash yield and total sulfur are on dry bases

Table 8 Calculated values of mercury in macerals and minerals

Samples	Maceral or mineral component (μg/g)				Significance testing	
	Vitrinite	Inertinite	Pyrite	Clay	R	F
YM	0.062	0.059	2.010	−0.383	0.93	4.17
SD	0.061	0.015	0.360		0.98	13.03
DT	0.020	0.060	0.108		0.68	0.56
PS	0.396	−1.037	1.392		0.95	11.27
HDG	0.128	0.114	0.412		0.32	0.15
CC	0.015	−0.079	0.574		0.98	51.98
YZ	0.099		−0.410	0.953	0.92	3.44
XLT	0.022		0.248		0.80	5.38
HLH	−0.368		1.607		0.78	4.57
TF	0.124		0.180		0.16	0.08

vitrinite. So the concentration of mercury in vitrinite is generally higher than in inertinite.

(2) Correlation analysis

The correlation coefficients between the concentrations of mercury and the petrographic constituents are shown in Table 7. It is generally considered that mercury mainly associated with sulfides in coals. Significant positive correlations lie between the concentration of mercury and total sulfur (or pyrite) in HLH, YM, SD and PS. Significant positive correlations lie between the concentration of mercury and ash yield (or clay mineral) in CC, YZ and DT, which indicated that mercury may be distributed in clay minerals as adsorbed state and isomorphism. Significant positive correlation lies between the concentration of mercury and the vitrinite in XLT, which indicated that mercury may dispersed in vitrinite as micro-fine particles or organically-bonded. Significant positive correlation lies between the concentration of mercury and the inertinite in TF, which need further study. Generally, the mercury is mainly distributed in pyrite and clay minerals in Chinese coals, and the concentration in vitrinite is higher than that in inertinite.

(3) The theoretical concentrations and affinities of mercury in coals

The concentrations of mercury in vitrinite, inertinite and minerals of coals calculated by Eq. (2) are shown in Table 8. It can be seen that mercury is more enriched in minerals than in macerals for all samples. As the concentrations of mercury in vitrinite are usually higher than that in inertinite, mercury is accumulated in reducing environments rather than in oxidizing ones. The distributions of mercury are notably different between two high-sulfur

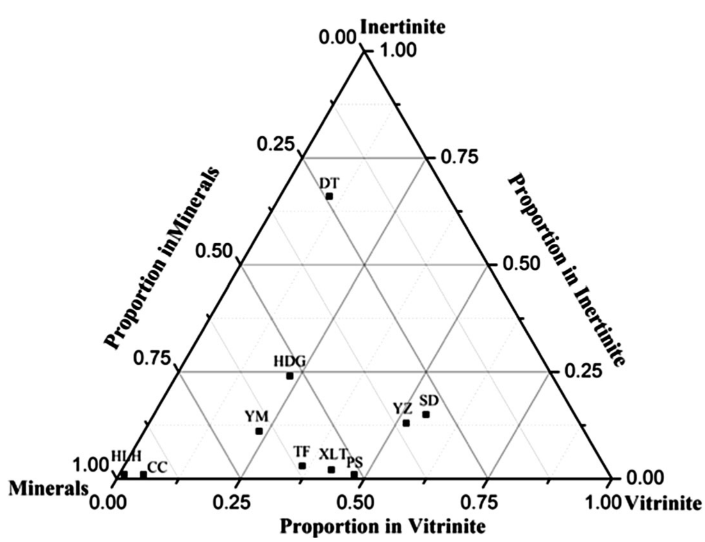

Fig. 6 Distribution of mercury in macerals and minerals of the coals studied

coals samples of YM and YZ. Mainly distributed in epigenetic granular pyrite particles of fissure vein in YM coal, mercury can be easily removed during coal washing. The mercury in YZ coal is mainly distributed in clay minerals while the pyrite dispersed in fine size in vitrinite is syngenetic originated.

The affinity (A_i) of mercury to vitrinite, inertinite and minerals of coals studied are shown in Fig. 6. It is easily concluded that mercury has higher affinities to minerals and vitrinite than inertinite.

In summary, the modes of occurrence of mercury are relatively complex and its affinity to minerals and macerals in different coals are different from each other. But there is a general trend that mercury occurs mainly in minerals, especially in epigenetic pyrite, and mercury is apt to be enriched in vitrinite rather than in inertinite.

4 Conclusions

The concentration and distribution characteristics of mercury in Chinese coals were studied with 1018 coal samples systematic collected around the country. The modes of occurrence of mercury are studied with float-sink experiments and correlation analyses of 10 representative coals of different rank from different basins in China. The main conclusions are as follows:

(1) The weighted average concentration of mercury in Chinese coals is 0.154 μg/g, which is similar to the average value in the world coal.

(2) Geological settings played key roles in determining the geochemistry and mineralogy of coals, and the mercury concentrations in the coals of different coal-forming period coal-accumulating areas are quite different. The concentrations of mercury in coals from south and southwest China and those from North China of C_3–P_1 are relatively higher while those from North China of J_{1-2} and Northeast of J_3–K_1 relatively lower. The general distributions of mercury are very similar to that of ash yield, sulfur contents in coals from different coal-forming periods and coal-accumulating areas.

(3) The modes of occurrence of mercury are relatively complex in Chinese coals. Correlation analyses and calculations have indicated that mercury occurs mainly in minerals, especially in pyrite. Mercury is apt to be enriched in vitrinite rather than in inertinite.

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