Fuel 125 (2014) 73–80

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Partitioning of elements from coal by different solvents extraction

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HIGHLIGHTS

- We mainly discuss the partitioning of more than 30 elements during coal extraction.
- Elements with a higher content in coal are relatively enriched in the organic solvent extracts.
- The element contents in extracts are positively correlated with the polarity of solvent.
- The difference in extraction rate could reflect the organic affinity of elements with coal.

ARTICLE INFO

Article history:
Received 22 September 2013
Received in revised form 18 January 2014
Accepted 29 January 2014
Available online 24 February 2014

Keywords:
Coal
Organic solvent
Extract
Element
Partition

ABSTRACT

Mixed samples of the whole seam and coal ply sample #1, 3, 9, 10, 14, 19, and 23 of the No. 11 coal seam from the Antaibao mining district, Shanxi, China were conducted by the sequential chemical, carbon disulfide/N-methyl-2-pyrrolidone (CS_2/NMP) mixed solvent, and fractional (methanol, benzene, acetone and tetrahydrofuran (THF)) extraction experiments. More than 30 major and trace elements in the coal samples and resultant extracts were determined by means of instrumental neutron activation analysis (INAA), inductively coupled plasma atomic emission spectroscopy (ICP-AES), inductively coupled plasma mass spectroscopy (ICP-MS) and atomic fluorescence spectrometry (AFS) in order to investigate their partitioning during the extraction. The results show that: (1) generally, an element with a higher content in coal is relatively enriched in organic solvent extracts of the coal, though its content in the extracts is significantly lower than that in the original coal. However, some elements occurring as organic phase like Br, Mo, Ni, Sb and Se are relatively enriched in the extracts; (2) the contents of most studied elements in different organic solvent extracts of coal are positively correlated with the polarity of solvent, i.e. most elements have the highest content in the methanol extract, higher in the acetone and THF extracts, and the lowest in the benzene extract in the order of the solvent polarity; (3) most studied elements have the highest extraction rate by sequential chemical extraction, higher by CS_2/NMP mixed solvent extraction, and the lowest by fractional extraction. The difference in extraction rate could reflect the affinity of elements with small or large organic molecules in coal. In detail, elements Al, As, Co, Cr, Ni, and Zn more enriched in the fractional extracts have a higher affinity with small molecules, while the other studied elements are more related to larger molecules.

1. Introduction

Nowadays, many researches concentrated on of trace elements in coal on the purpose of environmental protection and coal associated resource exploration [1–8]. Organically-bound elements in coal have a strong migration ability during the coal combustion, and have a significant impact on the environment [8]. Unfortunately, few researches have focused on the inorganically-bound elements present in the organic components of coal, and most of them have been concerned with the demineralized coal by digestion, the separated coal petrographic constituents, and the low-density component of coal by float-sink experiment [9–12]. However, these separated sections could not represent the "pure" organic matter of coal.

Solvent extraction is mainly used to explore the composition and structure of the coal [13], and in the field of geochemistry, this method is utilised to extract biomarker in source rock [14]. In the

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http://dx.doi.org/10.1016/j.fuel.2014.01.098
0016-2361/

last 20 years, some researches have proved that mixed solvent such as CS_2/NMP show a high dissolving capability during the extraction of bituminous coal [15] and kerogen [16]. This indicates that the extraction of coal with appropriate organic solvents offers an opposite route in principle to rejecting coal mineral matter. So, the solvent extraction of coal is used to generate ultraclean fuel [17–19], and this process is very similar to coal liquefaction and solvent-refined coal generation processes [20]. However, it is more cost-effective due to relatively mild conditions (i.e. 300–400 °C and 1–5 MPa) and no hydrogen are employed [19,21]. This provides us with a new method to investigate the characterization of organically bound metals in coal organic matters. Some studies have recently reported the investigation of the remaining major and trace elements in coal extracts (hypercoal) by the thermal solvent extraction [18–26]. By analyzing a sub-bituminous Wyodak coal thermally extracted with 1-methylnaphthalene, Wang et al. [23] found that the extraction resulted in 73–100% reductions in the concentration of Li, Be, V, Ga, As, Se, Sr, Cd, Ba, Hg, and Pb. According to the former research achievements of coal extracts (more than twenty American APCS and Australian coal samples, two Chinese bituminous coals, and several British coal samples), Wijaya and Zhang [21] found that the transition metals, particularly Fe, have absolute predominance in the overall metals in coal extracts, and Fe is far higher than the other metals, regardless of coal rank and solvent polarity. Besides Fe, major elements Na, K, Ca, Mg, Si, Al, Ti and a portion of trace elements including Be, Sr, Ba, Hg, and Pb are also very likely to be present in hypercoal. However, by now it is still unknown about the partitioning characteristics of major and trace inorganically-bound elements in the same coal seam by different organic extraction at normal temperature.

The coal samples were collected from the Antaibao surface mine, Pingshuo mining district, Shanxi province, China, which is one of the largest surface coal mines in the world, with an annual output of more than 16 Mt. Our previous researches discussed the geochemistry characteristics of sulfur and trace elements in the No. 11 coal seam from this district [27–29] and the difference of rare earth element (REE) distribution in the solvent extracts of different coal plies [30], but other inorganically-bound elements are not involved, especially hazardous elements (As, Cr, Ni, Se etc.). Based on the organic solvent extraction technology on the ply samples of the No.11 coal seam, we mainly discuss the partitioning of more than 30 major and trace elements in the different plies of the same coal seam by different solvent extraction in this paper.

2. Geological setting and sampling

The No. 11 coal seam is minable throughout the whole Pingshuo district, and is of high volatile bituminous in rank (the mean maximum reflectance of vitrinite is 0.65%). The peat swamp of the No. 11 coal developed on a tidal-flat and sandbank environment and seawater invaded during peat accumulation [29,30]. At the sampling location, the No. 11 coal has a thickness of 5.09 m; the 24 incremental channel samples (24 coal plies) were carefully collected following the macrolithotype of coal seam (Fig. 1). Among them, plies 2 and 3 contain a thin layer of carbonaceous mudstone partings [29], and plies 1, 3, 9, 10, 14, 19, and 23 (plies 3 and 9 are

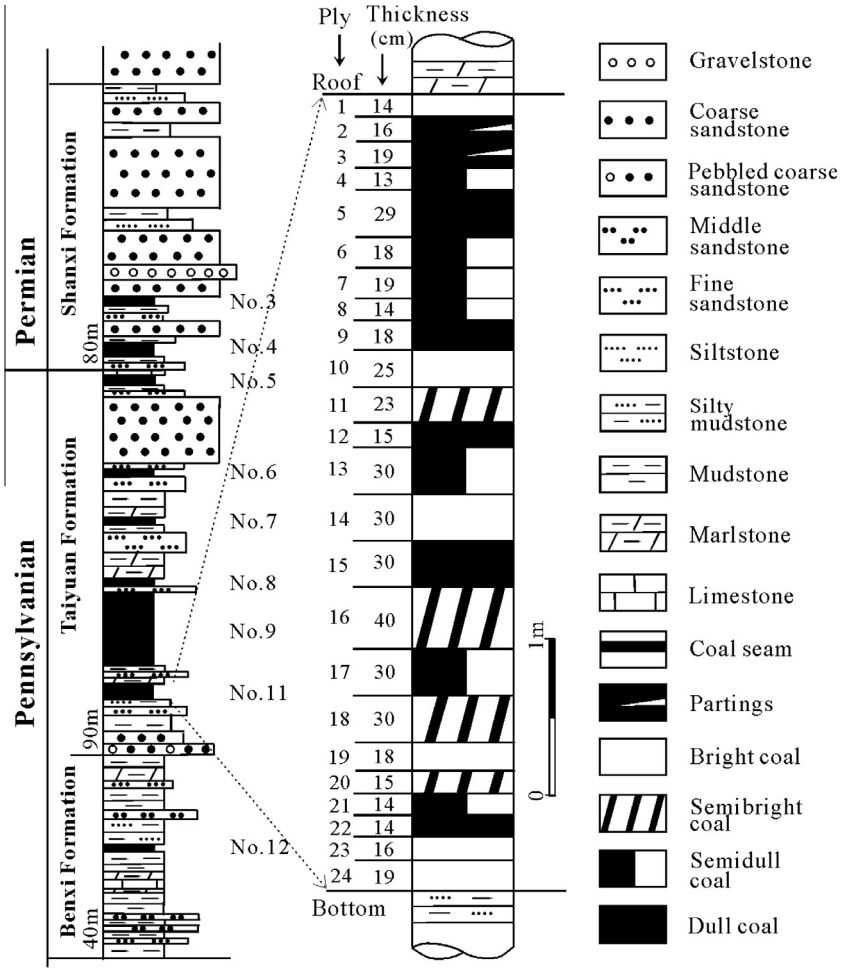

Fig. 1. Stratigraphic column of coal-bearing strata in the Antaibao mining district (from Wang et al. [30]).