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Characterization of the Songhua River sediments and evaluation of their adsorption behavior for nitrobenzene

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Abstract

The explosion at a plant of the Jilin Petrochemical Corporation on 13 November, 2005, and the spill of an estimated 100 t of toxic substances (nitrobenzene as the main component) into the Songhua River received worldwide attention. This study has focused on the adsorption behavior of nitrobenzene that spilled onto sediments along the Songhua River, which was one of the efforts to evaluate the fate of nitrobenzene after the spillage event. The organic carbon contents of these sediments along the Songhua River varied from 2.1 g TOC/kg at Hulanhekouxia to 86.1 g TOC/kg at Jiuzhan. The average volumetric particle diameter also varied largely from 11 μm at Jiangchuan to 311 μm at Hulanhekouxia. The sediment in the Jiuzhan section showed the highest potential for nitrobenzene adsorption (8.3 mg/kg sediment), whereas, that at Hulanhekouxia exhibited the lowest adsorption capacity, of 1.6 mg/kg sediment. The nitrobenzene adsorption potential is linearly related to the organic carbon content of sediments (R^2 = 0.609), indicating that the organic carbon content is the main factor affecting the adsorption behavior of sediments along the Songhua River. Conclusively, the adsorption of nitrobenzene onto the sediments is insignificant, and the release of nitrobenzene from sediments is of minor importance.

Key words: nitrobenzene; adsorption; sediment characteristics; organic carbon content; particle size distribution

Introduction

The explosion at a plant of the Jilin Petrochemical Corporation on 13 November, 2005, and the spill of an estimated 100 t of toxic substances into the Songhua River received worldwide attention. The main pollutants were reported to be benzene, nitrobenzene, and aniline, among which nitrobenzene contributed to the most important portion (UNEP, 2006).

The permissible levels in surface water were 0.01 mg/L for benzene and 0.1 mg/L for aniline, and the level in the water source, for drinking water, was 0.017 mg/L for nitrobenzene (SEPAC and GAQSIQC, 2002). The peak concentrations of nitrobenzene in the Songhua River were much higher than those of regulation for the drinking water source (UNEP, 2006), and Harbin, which employed the Songhua River as the main drinking water source, stopped water supply for four days, to avoid possible contamination of the water distribution systems. It would take approximately one month for the polluted strip to transport from the discharge point to the end of the river. Therefore, it was important to know what would happen to nitrobenzene during the period.

It is well known that aqueous nitrobenzene can be transferred to other phases (e.g., air, ice, and sediments) through diffusion and partition, and transformed into other species through photolysis, hydrolysis, and biodegradation. All of these transferring and transformation processes of nitrobenzene will possibly affect the fate of nitrobenzene during the transportation of the polluted strip. To evaluate the fate of discharged nitrobenzene, investigation with regard to the transfer and adsorption behavior of nitrobenzene onto sediments, and the possibility of nitrobenzene release from the sediments has been one of the efforts supported by the Ministry of Science and Technology.

Previous studies show that nitrobenzene has exhibited a moderate adsorption potential and relative mobility in most kinds of soils. Briggs (1981) investigated the soil sorption coefficients (soil organic matter/water partition coefficients of K_{om} and soil organic carbon/water partition coefficients of K_{oc}) of nitrobenzene with four kinds of silty loam, reporting that the determined adsorption isotherms were linear over the applied concentration range and the mean K_{om} was 50 and mean K_{oc} was 86. Løkke (1984) studied the adsorption of nitrobenzene onto soils with different organic carbon contents, showing K_{oc} values of nitrobenzene in the range of 170–370. Additionally, Løkke (1984) reported the significant effect of soil organic carbon content on nitrobenzene adsorption. Burns and Roe Industrial Services Organization Paramas (1982) employed the EXAMS computer model to predict the environmental behaviors of nitrobenzene, showing that volatilization contributed most to nitrobenzene losses, whereas, sediment sorption led to a

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contribution as low as 2%. Lang *et al*. (1997) established a model, based on the results from experimental pools at a riverside, to predict the transportation and transformation behaviors of 23 organic pollutants including nitrobenzene in the Songhua River. They reported that the effects of evaporation and photodegradation were the main processes responsible for the decrease of nitro-aromatic hydrocarbon concentrations. On the basis of the riverside experimental results, they proposed the adsorption velocity constant (K_a) to be 0.051 ml/(cm^2·h) for nitrobenzene adsorption onto sediments.

In this study, to begin with, the characteristics of river water and sediments at different cross sections along the Songhua River were investigated. Subsequently, the adsorption capacities of nitrobenzene that spilled onto different sediments along the Songhua River were evaluated, and the effects of several factors on nitrobenzene adsorption onto sediments were studied. The above study is an important part of the project on the evaluation of environmental behaviors of nitrobenzene in the Songhua River after the explosion.

1 Materials and methods

1.1 Outline of the Songhua River and layout of the cross sections

Songhua River is 2,309 km long, starting from the Neng River and ending at the Heilong River. The drainage area of the Songhua River is 5.568 million km^2, which comprises of 61% mountainous area, 15% foothills, 23.9% plains, and 0.1% limnological regions.

Thirty cross sections, including a control cross section of Fengman in the upstream of the explosion point, were set up along the Songhua River (Fig.1). In general, 13 cross sections were in the Jilin Province and the other 17 sections were in the Heilongjiang Province. For the convenience of sampling and historical data references, the national and provincial monitoring cross sections were selected. The longitude and latitude of each cross section is presented in Table 1.

1.2 Sampling

Sampling in the Jilin Province was performed on 24 and 25 December, 2005, and sampling in Heilongjiang Province was carried out on 7 and 8 January 2006, respectively. River water and sediments (if possible being sampled) were simultaneously taken at each cross section for further analysis and characterization. Samples were preserved in an air-tight condition under cold temperature (the air temperature was consistently below –10°C) during sampling and were then kept in the dark at 4°C after being transported to the laboratory. Water samples were kept in EFEP (exhaustive fluorinated ethylene propylene) bottles and sediments were kept in stainless steel containers.

1.3 Nitrobenzene adsorption experiments

Sediments were freeze-dried before being employed for adsorption. Batch nitrobenzene adsorption experiments were conducted in capped triplicates with continuous rotary shaking (120 r/min) at 0.8 ± 0.2°C which was chosen to simulate the on-site condition of the river. To provide background electrolyte and hardness, 10 mmol/L of $Ca(NO_3)_2$ was spiked. Suspensions were filtered through 0.22 μm PES membrane filters before subsequent analysis of nitrobenzene concentrations.

1.4 Analysis and characterization

1.4.1 Water samples analysis

Temperature, pH, DO (dissolved oxygen), and TDS (total dissolved solids) were measured on site with portable

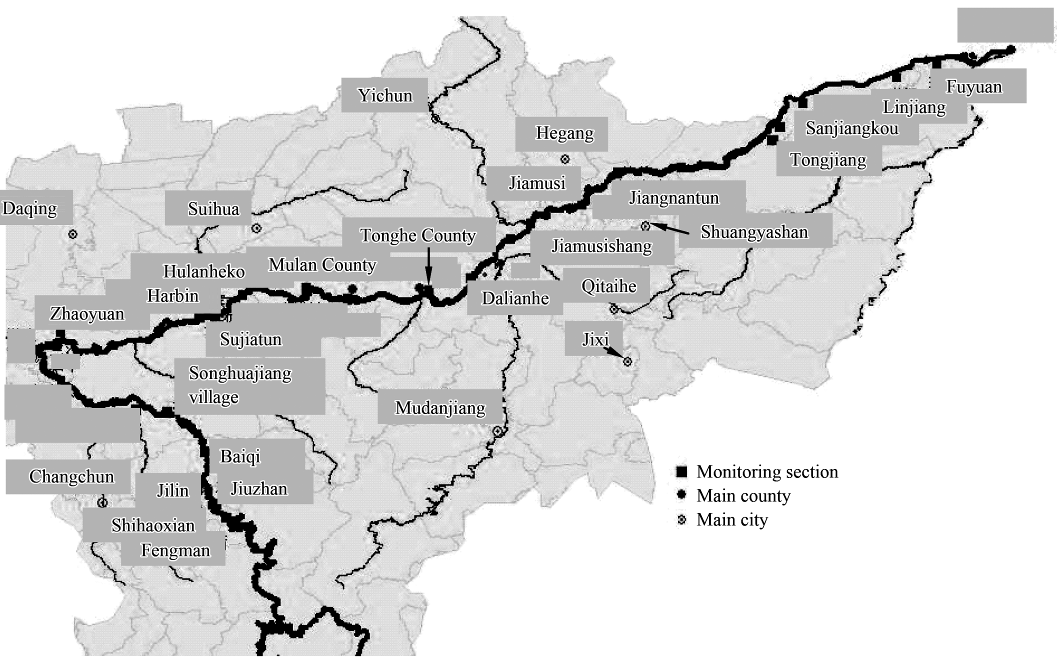

Fig. 1 Image of sampling sites along the Songhua River.

Table 1 Longitude and latitude of the cross sections along the Songhua River

No.	Section	Longitude (°E)	Latitude (°N)	No.	Section	Longitude (°E)	Latitude (°N)
1	Fengman (FM)	126.67	43.72	16	Zhushuntun (ZHSHT)	126.36	45.70
2	Shihaoxian (SHX)	126.50	43.91	17	Hulanhekouxia (HLH)	126.84	45.96
3	Discharging point (DP)	126.55	43.88	18	Mulanbaidu (MLBD)	128.15	45.91
4	Jiuzhan (JZH)	126.47	43.94	19	Dalianhe (DLH)	129.31	46.10
5	Baiqi (BQ)	126.46	42.21	20	Mudanjiangkoushang (MDJS)	N.A.	N.A.
6	Hougang village (HGV)	126.40	44.58	21	Mudanjiangkouxia (MDJKX)	N.A.	N.A.
7	Yushumiaoxi (YSHM)	126.15	44.75	22	Jiamusishang (JMSS)	129.94	46.69
8	Songhuajiang village (SHJ)	125.97	44.77	23	Jiamusi (JMS)	130.23	46.81
9	Zhenjiangkou (ZHJK)	125.21	44.87	24	Jiangnantun (JNT)	130.84	47.18
10	Songyuan (SY)	124.83	45.16	25	Huachuan (HCH)	130.66	47.04
11	Xidazuizi (XDZZ)	124.77	45.18	26	Fujin (FJ)	132.04	47.64
12	Ganshuigang (GSHG)	124.73	45.35	27	Tongjiang (TJ)	132.46	47.64
13	Sanjiangkouxia (SJK)	124.93	45.53	28	Tongjiangdonggang (TJDG)	N.A.	N.A.
14	Zhaoyuan (ZHY)	125.04	45.50	29	Linjiang (LJ)	N.A.	N.A.
15	Lalinhekouxia (LLHK)	129.31	46.10	30	Fuyuan (FY)	134.27	48.38

N.A.: not available data.

instruments when sampling. Turbidity was directly measured with a turbidity meter (Hach Co., USA.). Alkalinity (expressed as mg $CaCO_3$/L) was determined using the titrimetric method without pretreatment. Metals concentrations were determined with an inductively coupled plasma optical emission spectrometer (OPTIMA 2000 ICP-OES, PerkinElmer, USA.) after membrane filtration (0.45 μm).

1.4.2 Sediment organic carbon content measurement

After the sediments were freeze-dried and triturated, phosphate (volume ratio of 1:1) was added to the samples to remove inorganic carbon. After that, organic carbon content was determined with an Apollo 9000 TOC analyzer (Tekmar Dohrmann Co., USA), each sample was measured twice.

1.4.3 Nitrobenzene analysis

Aqueous nitrobenzene concentration was analyzed with a Waters Alliance 2695 separation module, equipped with a Waters 2996A photodiode array detector and a Waters XTerra® MS C18 reversed-phase column (250 mm × 4.6 mm i.d., 5 μm particle size). The mobile phase was a mixture of water, acetonitrile, and acetic acid (60% : 40% : 0.3%), isocratically delivered by a pump at a flow rate of 1.00 ml/min. The column was held at 25°C and the wavelength of the UV absorbance detector was acquired continuously between 260 and 270 nm, and chromatograms extracted at 263.3 nm. The runs lasted for 21 min with an isocratic mixture (70:30) of water and acetonitrile at a flow rate of 1.00 ml/min. The wavelength of the UV absorbance detector was determined in the range 220–450 nm.

1.4.4 Sediments characterization

After being freeze-dried, sediments were treated in the following procedures: peroxide oxidation for organic matter removal, air-dried, sieved, and dispersion (Doran and Jones, 1996). Next, particle size distribution of samples was determined with a Lasersizer2000 laser particle size analyzer (Malvern Co., UK) and the measurement was repeated thrice for each sample.

After particle size distribution analysis, these sediments were further characterized by determining the relative contents of sand (2.0–0.05 mm), silt (0.05–0.002 mm), and clay (< 0.002 mm) (Doran and Jones, 1996).

2 Results and discussion

2.1 Basic water characteristics at different cross sections

Table 2 presents the basic water characteristics at the main cross sections along the Songhua River. Water in the Songhua River was characterized as low temperature and low turbidity. The alkalinity and total hardness was also relatively low. As for the metal elements, Fe, Mn, Cu, and Al were presented but Pb and Zn were not detected along the Songhua River. Nitrate concentration was also detected with relatively low concentration. Generally, no significant changes of water quality were observed while the Songhua River transporting downstream.

2.2 Characterization of sediments from main cross sections

2.2.1 Organic carbon contents

Figure 2 presents the organic carbon contents of sediments at the main sections along the Songhua River. Sediments in JZH exhibited the highest organic content as 86.1 μg TOC/kg among these samples. The organic carbon content of sediments followed the sequence: JZH (86.1 g TOC/kg) > MDJKS (30.1 g TOC/kg) > SHX (27.0 g TOC/kg) > JCH (20.3 g TOC/kg) > HCH (19.9 g TOC/kg) > SJK (16.6 g TOC/kg) > DLH (12.7 g TOC/kg) > SJT (7.7 g TOC/kg) > HLHKX (2.1 g TOC/kg). Generally, the organic carbon content in percentage was in the range of 0.21% to 8.61%. SHX was the ditch for sewage discharging into the Songhua River, and JZH was the closest to the discharging and spilling site, among these sections.

2.2.2 Particle size distribution

Figure 3 shows the particle size distribution of sediments at the main cross sections along the Songhua River, and Table 3 indicates variations of average volumetric particle diameters. It is worth mentioning that d (0.1) signifies that 10% of the particles are smaller than the corresponsive value.

Table 2 Basic water characteristics at the main cross sections along the Songhua River

Sampling site	Turbidity (NTU)	NO_3^- (mg/L)	Ca (mg/L)	Mg (mg/L)	Fe (mg/L)	Mn (mg/L)	Cu (mg/L)	Al (mg/L)	Zn (mg/L)	Pb (mg/L)	Conductivity (μS/cm)	Alkalinity (mg $CaCO_3$/L)	Total Hardness (mg $CaCO_3$/L)
FM	N.A.	10.53	16.20	4.18	0.30	N.D	0.09	0.42	N.D.	N.D.	N.A.	57.8	57.9
DP	N.A.	8.30	17.98	4.28	N.D.	N.D.	0.03	0.01	N.D.	N.D.	N.A.	68.9	62.8
SHX	N.A.	8.65	16.98	3.92	0.09	N.D.	0.06	0.15	N.D.	N.D.	N.A.	63.1	58.8
JZH	N.A.	9.33	17.06	4.20	0.11	0.13	0.05	0.16	N.D.	N.D.	N.A.	66.6	60.2
BQ	N.A.	9.42	19.73	4.61	0.10	0.05	0.06	0.14	N.D.	N.D.	N.A.	73.4	68.5
SJK	N.A.	10.87	31.78	7.96	0.01	0.09	0.05	0.03	N.D.	N.D.	N.A.	140.0	112.6
Central of LJ	9.50	4.26	16.75	4.20	0.19	0.01	N.D.	0.11	N.D.	N.D.	415	76.1	59.4
Riverside of LJ	13.50	4.69	18.79	4.73	0.53	0.19	0.01	0.07	N.D.	N.D.	588	85.2	66.7
HYD	8.07	4.28	18.79	4.55	0.03	0.01	0.01	0.05	N.D.	N.D.	594	87.5	65.9
East of TJ	14.10	7.44	28.87	7.06	0.03	0.03	0.01	0.07	N.D.	N.D.	258	137.1	101.6
SJT	17.20	7.10	25.20	6.00	0.07	N.D.	0.01	0.13	N.D.	N.D.	222	109.9	88.0
DLH	7.62	8.21	31.81	7.46	N.D.	N.D.	N.D.	0.03	N.D.	N.D.	283	139.4	110.6
MDJKS	8.61	8.47	31.89	7.53	N.D.	0.01	N.D.	0.04	N.D.	N.D.	287	142.1	111.1
MDJKX	6.58	8.48	32.73	7.86	N.D.	0.02	0.01	0.03	N.D.	N.D.	295	147.0	114.6
HLHKX	3.75	7.79	26.99	6.29	N.D.	0.08	0.02	0.04	N.D.	N.D.	254	121.2	93.7
TJ	4.96	4.18	17.01	4.16	0.20	N.D.	0.01	0.12	N.D.	N.D.	412	80.1	59.9
JMSS	7.18	9.08	32.22	7.80	N.D.	N.D.	N.D.	0.03	N.D.	N.D.	301	148.2	113.1
JMS	13.60	7.44	25.86	6.47	0.09	0.02	0.01	0.17	N.D.	N.D.	230	122.1	91.6
HCH	12.10	7.53	31.11	7.46	0.03	0.06	0.03	0.07	N.D.	N.D.	279	144.4	108.8
JCH	17.10	6.50	27.71	6.88	0.06	0.15	N.D.	0.07	N.D.	N.D.	253	129.7	97.9

N.A.: not available data; N.D.: under detectable data.

Table 3 Particle size distribution analysis of sediments at the main cross sections along the Songhua River

Parameters for particle characterization	Sampling section								
	JZH	SHX	SJK	HLHKX	HCH	MDJKS	DLH	JCH	SJT
Average volumetric particle diameter (μm)	59 (5.6)	189 (5.7)	98 (0.9)	311 (12.6)	58 (0.6)	46 (1.4)	190 (0.2)	11 (0.1)	282 (2.5)
d (0.1)[a]	6 (0.3)	33 (1.4)	36 (0.2)	9 (0.5)	6 (0.1)	4 (0.1)	89 (0.9)	2 (0.1)	8 (3.5)
d (0.5)[b]	31 (2.9)	161 (3.0)	86 (0.3)	290 (15.7)	38 (0.1)	22 (0.1)	166 (0.)	10 (0.)	84 (1.6)
d (0.9)[c]	133 (20.9)	381 (14.9)	172 (1.0)	671 (18.4)	111 (1.1)	92 (2.3)	332 (1.6)	21 (0.1)	735 (3.3)

[a] 10% of the particles are smaller than the average value; [b] 50% of the particles are smaller than the average value; [c] 90% of the particles are smaller than the average value. Values in brackets are standard deviation.

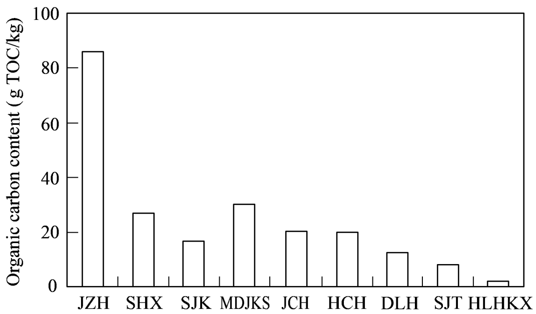

Fig. 2 Organic carbon contents of main cross sections along the Songhua River.

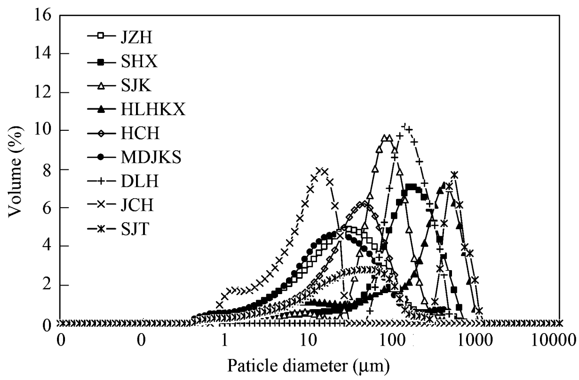

Fig. 3 Particle size distribution of sediments at main sections along the Songhua River.

The particle size distribution of sediments at different sections along the Songhua River generally followed normal trends, with the particle diameter ranging from several decades to hundreds micrometers. Comparatively, JCH was observed to have the lowest diameter and DLH exhibited the highest diameter.

Table 3 quantitatively compares particle diameter distribution of sediments at different sections. In particular, the average volumetric particle diameter followed the sequence: HLHKX (311 μm) > SJT (282 μm) > DLH (190 μm) > SHX (189 μm) > SJK (98 μm) > JZH (59 μm) > HCH (58 μm) > MDJKS (46 μm) > JCH (11 μm). Similar trends were also observed for parameters such as d(0.1), d(0.5), and d(0.9).

2.2.3 Sediments composition

Table 4 presents the ratios of clay, silt, and sand for sediments sampled at the main sections along the Songhua River and categories of these sediments.

According to the particle size ranges, sediments could be divided into three components: clay (< 0.002 mm), silt (0.05–0.002 mm), and sand (2.0–0.05 mm) (Doran and Jones, 1996). It is observed in Table 4 that the sediments along the Songhua River were mainly comprised of silt

Table 4 Sediment compositions of samples from different cross sections

Cross section	Particle size range (%)			Categorization
	Clay (< 0.002 mm)	Silt (0.05–0.002 mm)	Sand (2.0–0.05 mm)	
JZH	1.6	70.1	28.3	Silt loam
SHX	0.4	13.0	86.6	Loamy sand
SJK	0.7	19.8	79.5	Loamy sand
HLHKX	1.0	22.8	76.3	Loamy sand
HCH	4.2	60.4	35.4	Silt loam
MDJKS	6.2	71.6	22.2	Silt loam
DLH	0	0	100	Sand
JCH	11.0	89.0	0	Silt loam
SJT	3.2	37.4	59.4	Sandy loam

and sand, with silt being the most significant component of sediments from JZH, HCH, MDJKS, and JCH, and sand being the most significant part of the sediments from SHX, SJK, HLHKX, and DLH. Accordingly, JZH, HCH, MDJKS, and JCH could be categorized into silt loam, and SHX, SJK, and HLHKX could be categorized into loamy sand. SJT and DLH were categorized into sandy loam and sand, respectively.

By comparing Table 4 with Fig.2, it is clear that sediments with sand as the most significant component, generally contained low organic carbon.

2.3 Nitrobenzene adsorption behaviors

2.3.1 Sorption behavior

Figure 4 presents the adsorption of nitrobenzene onto the sediments from different cross sections along the Songhua River. JZH exhibited the highest adsorption capacity for nitrobenzene, with a value as high as 9.9 mg nitrobenzene/kg sediment. Sediments from cross sections of SHX, SJK, and JCH also showed relatively higher nitrobenzene adsorption capacity in comparison with that of HLHKX, which showed the lowest adsorption capacity of 1.6 mg nitrobenzene/kg sediment. Generally, the adsorption of nitrobenzene onto sediments was not significantly based on these results. Former studies reported that nitrobenzene was mobile to most kinds of soils (Briggs, 1981), and that the adsorption of nitrobenzene onto sediments was insignificant for the decrease of nitrobenzene concentration during nitrobenzene transportation along the Songhua River (Lang *et al*., 1997).

The partition coefficients of K_{sed} (sediment sorption coefficient) and K_{oc} (organic carbon/water partition coefficient) have been calculated from these results (Fig.4). MDJKS showed the lowest K_{oc} value of 204.6 L/kg and HLHKX showed the highest K_{oc} value of 1,594.5 L/kg. Generally, K_{sed} was positively correlated, whereas, K_{oc} showed negative correlation with nitrobenzene adsorption potential.

These results indicated that the adsorption potential of nitrobenzene onto sediments from the main sections along the Songhua River was relatively weak. The results of on-site sampling (on 24 and 25 December, 2005) and analysis also supported this result. Nitrobenzene was not detected in most of the monitored sediments, and the highest concentration was determined to be 1–3 mg/kg, in sediments from the JZH section. These results demonstrated that it was not easy for nitrobenzene to accumulate in the Songhua River sediments, and that the risk of secondary pollution, because of the nitrobenzene release from sediments along the Songhua River, was very low. This result could be attributed to the physical properties of nitrobenzene: a relatively high water solubility of 1,900 mg/L (Banerjee *et al*., 1980), a relatively low octanol/water partition coefficient ($\log K_{ow}$) of 1.6–2.0, and soil/sediment sorption coefficient (K_{sed}) (Mabey *et al*., 1982). Of course, the characteristics of sediments from the main cross sections along the Songhua River, especially the relatively low organic carbon contents, were responsible for the result.

2.3.2 Relationship between nitrobenzene adsorption and sediment characteristics

Figure 5 shows the relationship between sediment characteristics and nitrobenzene adsorption potential for sediments from different sections along the Songhua River. The nitrobenzene adsorption potential was observed to exhibit positive to organic carbon content for these sediments, at different cross sections (R^2 = 0.609), and a higher

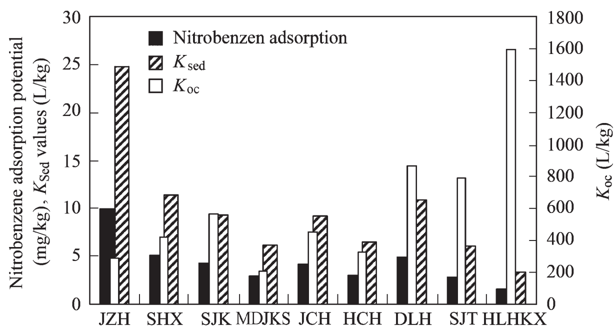

Fig. 4 Nitrobenzene adsorption potentials of sediments from different cross sections.

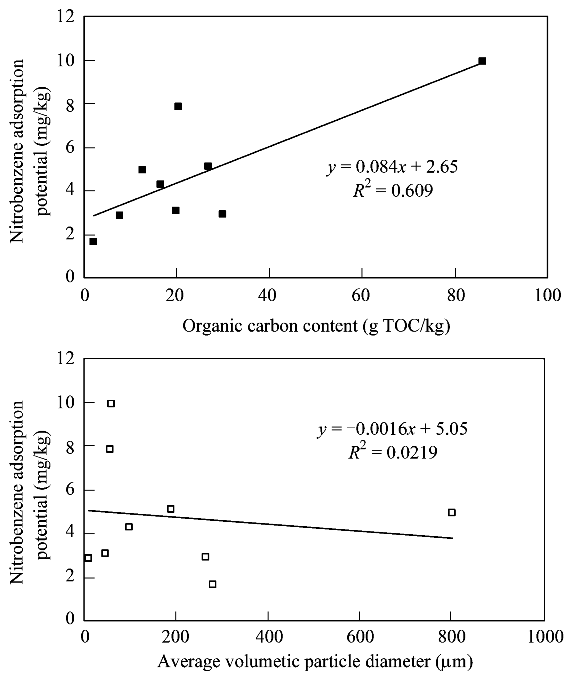

Fig. 5 Relationship between sediment characteristics and nitrobenzene adsorption potential for sediments.

organic carbon content contributed to increased nitrobenzene adsorption. On the other hand, no obvious trend was observed between the average volumetric particle diameter and nitrobenzene adsorption potential for the sediments from different sections (R^2 = 0.0219). Comparatively, organic carbon content showed more significant effect on nitrobenzene adsorption between different sediments than particle diameter did.

To further investigate the effects of sediment characteristics on nitrobenzene adsorptive behaviors, sediments (at cross sections of SJK and DLH), after being pretreated with peroxide oxidation or sieving, were respectively employed for nitrobenzene adsorption. Table 5 presents the effects of these two pretreatment procedures on nitrobenzene adsorption.

It is observed in Table 5 that H_2O_2 oxidation decreased nitrobenzene adsorption onto sediments. In detail, H_2O_2 oxidation contributed to the decrease of nitrobenzene adsorption potential by 8.5% and 14.7% for SJK and DLH, respectively. Interestingly, it is observed that the sieving pretreatment contributed to the steady increase of nitrobenzene adsorption potential. For example, the nitrobenzene adsorption potential of SJK100, which was sieved with a 100 mesh sieve, increased by 11.5% when compared with that without sieving.

For the adsorptive behaviors of nitrobenzene onto soils, the former studies reported that the adsorption potential was governed by the soil organic carbon content. Seip *et al*. (1986) studied the adsorption of nitrobenzene onto soils with different organic carbon contents of 0.2%, 2.2%, and 3.7% with column tests, and reported corresponsive K_{oc} values of 30.6, 88.8, and 103 for these soils. Løkke (1984) reported that the amount of nitrobenzene adsorbed onto soils was largely determined by the organic carbon content of the soils, whereas, the pH, cation exchange capacity, and incubation temperature were of minor importance. Additionally, Zhao and Lang (1990) investigated the adsorptive behaviors of organic compounds on natural sediments in the Songhua River and observed a linear isotherm for these organics, ascribing to the large amount of organic carbon within the natural sediments. Organic carbon within the sediments was viewed as being a strong adsorbent to organic pollutants because of the partition effects. H_2O_2 oxidation decreased the organic carbon content, and decreased the active sites available for nitrobenzene adsorption, thus resulting in the decrease of nitrobenzene adsorption onto sediments from the Songhua River.

Table 5 Nitrobenzene adsorption potential variations under different pretreatment procedures

Samples	Pretreatment procedure	Nitrobenzene adsorption potential (mg/kg)	Variation between with and without pretreatment (%)
SJK	Without pretreatment	4.01	Control samples
SJK	H_2O_2 oxidation	3.67	–8.5
DLH	Without pretreatment	3.88	Control samples
DLH	H_2O_2 oxidation	3.31	–14.7
SJK60	Sieving (60 mesh)	4.26	+6.2
SJK100	Sieving (100 mesh)	4.47	+11.5
SJK150	Sieving (150 mesh)	5.09	+26.9

Nitrobenzene concentration 1 mg/L; sediment content 2.0 g/100 ml; temperature 0.6°C; treatment time 24 h.

For the sediment from a specified section, the particle diameter was also an important parameter affecting nitrobenzene adsorption onto sediments. Sediment after being sieved showed lower diameter and higher surface area. When compared to those that were not sieved, the sieving procedure led to more sorbing sites being available for pollutants such as nitrobenzene, and contributed to subsequent higher potential for nitrobenzene adsorption. It is worth mentioning that it was observed during experiments that the sieving procedure was inclined to remove inorganic sand with higher diameter rather than those organic tiny species within sediments (data not available). These combined effects led to an increase in the nitrobenzene adsorption potential, which was increased by 26.9% for SJK, after being sieved through a 150 mesh sieve. Generally, for a specified sediment, the species with lower particle diameter showed a higher potential for adsorbing nitrobenzene than that with higher particle diameter. Comparatively, for sediments from different sections, no remarkable relationship was observed between particle diameter and nitrobenzene adsorption potential, as is indicated in Fig.5.

3 Conclusions

From the results presented earlier in this article, major conclusions may be stated as follows: (1) sediments at the main cross sections along the Songhua River show different characteristics in organic carbon content, particle size distribution and so on; (2) nitrobenzene generally exhibits mobility in most sediments at the main sections along the Songhua River, with nitrobenzene adsorption potential varying in the range of 1.62–9.93 mg/kg. The risk of nitrobenzene release from sediments and subsequent secondary pollution is negligible; (3) nitrobenzene adsorption potential is positively correlated with the organic carbon content and negatively correlated with particle diameter.

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