Environmental Informatics Archives, Volume 3 (2005), 270 - 277
EIA05-035
ISEIS Publication Series Number P002
© 2005 ISEIS - International Society for Environmental Information Sciences

The Contents and Distribution of Iron in Natural Colloids

Ding Chen, Ai-rong Zheng*, Chun-lan Liu, Min Chen
Department of Oceanography and Institute of Subtropical Oceanography, Xiamen University, Xiamen, Fujian Province, P. R. China, 361005

Abstract. In traditional oceanography research, colloids were usually studied together with the dissolved phase, which made the recognizing of the biogeochemistry cycle and the biological availability of elements deflected to some extent. Actually colloids can easily absorb some radioactive isotopes, trace elements and organic compounds to its surface. As a result, they play a significant role in the presentation and transportation of elements in the ocean. In this paper, the contents and distribution of iron in two fractions (<10kDa and 10kDa~0.22μm) were studied in the water from Jiulongjiang River, Jiulongjiang River estuary and south Xiamen Bay of China during Apr.2004 and Mar.2005. The result showed that concentrations of Fe^{3+} in absolutely dissolved phase varied from 2.8~31.9μg/L and that of Fe^{2+} was below detection limit(<0.5μg/L) to 8.6μg/L, Fe^{3+} and Fe^{2+} in colloidal phase were <2.5μg/L~10.0μg/L and <0.5μg/L~50.4μg/L, respectively. It was found that Fe^{3+} mainly distribute in absolutely dissolved phase and the majority of colloidal phase was Fe^{2+}. Moreover, the concentrations of total iron in all phases were highest in samples from estuarine water. Fe^{2+} which is thought to be used directly by algae was very few in August in both natural colloids phase and absolutely dissolved phase during the blooms of phytoplankton.

Keywords: absolutely dissolved phase, natural colloidal phase, iron, seasonal variations, bioavailability

1. Introduction

In traditional oceanography research, colloids were usually studied together with the dissolved phase, which made the recognizing of the biogeochemistry cycle and the biological availability of elements deflected to some extent. Actually colloids can easily absorb some radioactive isotopes, trace elements and organic compounds to its surface with the character of small grain size, large specific surface area and the abundant of organic functional group. As a result, it plays a significant role in the presentation and transportation of elements in the ocean. Since the usage of Cross-flow filtration (CFF), we can study colloid separately apart from those common "dissolved" phase filtrated by the 0.45μm sieve.

Iron is thought to be an important biological and geochemical trace element in the ocean. It is one of necessary nutritional elements for phytoplankton and the rate of which phytoplankton uses carbon, nitrogen and phosphorus could be influent by species and contents of iron. But the concentration of iron in the natural aquatic environment was very low, what's more, a considerable portion of the dissolved iron was in colloidal phase. In some estuarine water or coastal water, about 13%~93% of iron was in the form of colloid (Guieu et al.,1998; Kuma et al.,1998). The results of experiments which used colloid as the only source of nitrogen, phosphorus and iron to culture micro-algae (Marine *Chlorella*, Platymonas *subcordiformis* and *Isochrysis galbana*) showed that natural colloid contains nutritive elements required by the growth of marine micro-algae, and obviously accelerated the upgrowth of the micro-algae (Zheng et al., 2004). Hence the study of iron contents in natural colloid is valuable for comprehending its species, distribution, source and sink in the aquatic environment as well as the bioavailability of iron. In this paper, the sea-end water of Jiulongjiang River was collected as the presentation of fresh water, the estuary water of Jiulongjiang River was collected as the presentation of estuarine water and the surface water of south Xiamen Bay as the presentation of seawater. The iron contents of different species in both the 10kDa~0.22μm fraction colloid and absolutely dissolved phase (10kDa) were determined, so as to realize the distribution of colloid iron in rivers, estuaries and seas and provide referential dates for the studies of characters of colloids and the biogeochemical

* Corresponding author: arzheng@jingxian.xmu.edu.cn

cycling of iron.

2. Materials and methods

Samples of fresh water, estuary water and sea water were collected from Jiulongjiang River to south Xiamen Bay showed in Fig.1 during April 2004, August 2004, November 2004 and March 2005. Sampling times, the latitude and longitude of sites and the salinities are given in Tab. 1. The surface water were collected using clean plastic buckets, the salinity was measured by the salimeter and then brought to laboratory by argentometry.

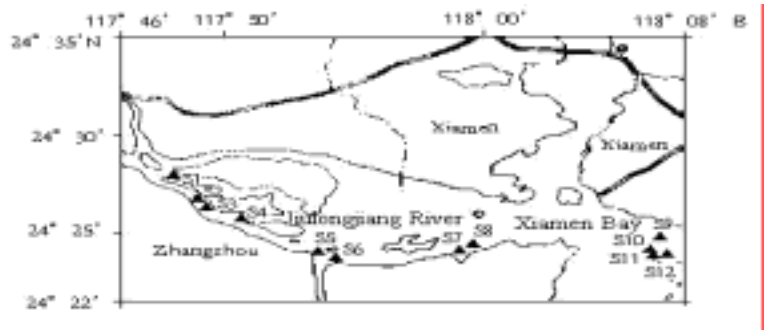


Figure 1 Diagrammatic sketch of sampling sites from Jiulongjiang River to south Xiamen Bay

Table 1 Sampling sites of Jiulongjiang River Estuary and south Xiamen Bay

No.	Time	Latitude and longitude		Salinity (‰)	Type
S1	Apr. 24th, 2004	24°27.844′N	117°48.020′E	0.072	Fresh water
S7	Apr. 24th, 2004	24°24.150′N	117°58.801′E	9.972	Estuary water
S9	Apr. 24th, 2004	24°24.912′N	118°06.706′E	28.44	Sea water
S4	Aug. 16th, 2004	24°25.673′N	117°51.103′E	<1.60	Fresh water
S6	Aug. 16th, 2004	24°23.927′N	117°54.541′E	16.00	Estuary water
S12	Aug. 16th, 2004	24°23.774′N	118°07.071′E	31.54	Sea water
S2	Nov. 12th, 2004	24°26.918′N	117°49.380′E	2.38	Fresh water
S5	Nov. 12th, 2004	24°24.271′N	117°53.687′E	15.16	Estuary water
S11	Nov. 12th, 2004	24°24.351′N	118°06.925′E	33.38	Sea water
S3	Mar. 5th, 2005	24°26.526′N	117°49.602′E	<0.12	Fresh water
S8	Mar. 5th, 2005	24°24.533′N	117°59.326′E	5.55	Estuary water
S10	Mar. 5th, 2005	24°23.919′N	118°06.738′E	19.94	Sea water

Natural colloids were disjoined using methods the same as Zheng et al. (2002). Waters were pre-filtered through a 0.22 μm pore-size cartridge filter immediately after its arrival to laboratory to remove suspended particulate matter and get the sample we called "dissolved" phase (<0.22μm). Then a cross-flow ultrafiltration system (Amicon H10P10-20, 10kDa) was used to collected colloids and the enrichment factor*(Fc)* was ~40. The fraction passed thought the membrane was absolutely dissolved phase, and the remaining fraction was a mixture of truly dissolved phase (<10kDa) and colloid (10kDa~0.22μm).

Concentrations of total iron in the pre-filtered (C_p), ultrafiltrate (C_u) and retentate were analysed by Phenanthroline spectrophotometric determination with detection limit of 3μg/L and Fe^{3+} by KSCN spectrophotometric determination with detection limit of 2.5μg/L. Concentrations of Fe^{2+} were calculated by the difference of total iron and Fe^{3+}. Concentrations of phosphorus in colloid (C_r) were calculated as:

$$C_r = C_p - C_u \tag{1}$$

Four parallel dates were measured for the relative standard deviation and the recoveries were also determined.

3. Results and discussion

3.1 Contents and distribution of phosphorus in different waters

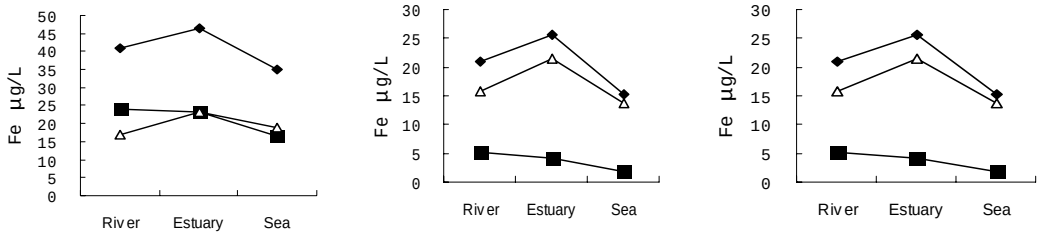
Concentrations of total iron, Fe^{3+} and Fe^{2+} of waters from different sources were shown in Tab. 2 (ND stands for undetected and the same as below). The concentrations of total iron from different sources waters in absolutely dissolved phase (<10kDa) varied between 6.1 and 32.6μg/L and the concentrations of Fe^{3+} were 2.8~31.9μg/L while that of Fe^{2+} were below detection limit (<0.5μg/L) to 8.6μg/L. The concentrations of total Fe from different sources waters in colloidal phase（10kDa~0.22μm）ranged from below detection limit (<3μg/L) to 55.8μg/L and the concentrations of Fe^{3+} were <2.5μg/L~10.0μg/L and the Fe^{2+} ranged from below detection limit(<0.5μg/L) to 50.4

Table 2 Contents (μg/L) and distribute proportions of iron in different phase

Source	iron species	Time	"Dissolved" Phase	Absolutely dissolved phase	Colloid （C_r）	C_u/C_p%	C_r/C_p%
River	Total Fe	April	57.0	25.4	31.6	44.6	55.4
		August	35.5	25.0	10.5	70.3	29.7
		November	59.9	24.1	35.8	40.3	59.7
		March	11.7	6.1	5.6	51.8	48.2
	Fe^{3+}	April	28.2	25.4	2.8	90.1	9.9
		August	35.2	25.2	10.0	71.6	28.4
		November	22.0	19.2	2.8	86.9	13.1
		March	10.8	6.00	4.8	55.5	44.5
	Fe^{2+}	April	28.8	ND	28.8	0.0	100.0
		August	0.3	ND	0.3	0.0	100.0
		November	37.9	5.00	32.9	13.1	86.9
		March	0.9	0.1	0.8	9.2	90.8
estuary	Total Fe	April	88.4	32.6	55.8	36.9	63.1
		August	25.0	19.5	5.5	78.0	22.0
		November	61.4	23.1	38.3	37.7	62.3
		March	10.7	8.0	2.7	74.9	25.1
	Fe^{3+}	April	37.3	31.9	5.4	85.5	14.5
		August	24.3	19.3	5.0	79.6	20.4
		November	21.6	17.5	4.1	81.0	19.0
		March	9.5	7.3	2.2	76.7	23.3
	Fe^{2+}	April	51.1	0.7	50.4	1.4	98.6
		August	0.7	0.2	0.5	23.8	76.2
		November	39.8	5.6	34.2	14.2	85.8
		March	1.2	0.7	0.5	60.8	39.2
Sea	Total Fe	April	40.1	26.5	13.6	66.1	33.9
		August	27.5	20.5	7.0	74.5	25.5
		November	62.9	22.2	40.8	35.2	64.8
		March	9.7	10.4	ND	100.0	0.0
	Fe^{3+}	April	17.9	17.9	ND	100.0	0.0
		August	27.7	21.0	6.7	75.9	24.1
		November	16.3	16.3	ND	100.0	0.0
		March	3.5	2.8	0.7	78.9	21.1
	Fe^{2+}	April	22.2	8.6	13.6	38.7	61.3
		August	ND	ND	ND	-	-
		November	46.6	5.9	40.8	12.6	87.4
		March	6.2	7.6	ND	100.0	0.0

μg/L. The concentration of Fe^{3+} in absolutely dissolved phase was 1~9 times higher than in colloidal phase, and the concentration of Fe^{2+} in colloidal phase was at least 3 times higher than in absolutely dissolved phase. The content of total Fe in these two phase were comparable.

Table 2 also shows that for all sources of waters except the seawater in March, contents of total Fe in absolutely dissolved phase make up 35.2%~78.0% of the "dissolved" total Fe while those of colloidal phase make up 22.0%~64.8%, which is a little lower than the absolutely dissolved phase. These dates was coincided with the dates reported in literatures before of 13%~19% (Guied et al.,1998; Kuma et al., 1998). Contents of Fe^{3+} in absolutely dissolved phase make up 55.5%~100.0% of the "dissolved" Fe^{3+} while those of colloidal phase make up as less as



dissolved phase **absolutely dissolved phase** **colloidal phase**

Figure 2 Distribution of iron in waters from different source (◆—total Fe；■—Fe^{3+}；△—Fe^{2+})

0.0%~44.5% of them; contents of Fe^{2+} in absolutely dissolved phase make up only 0%~38.7% of the "dissolved" Fe^{2+} (except for March river of 60.8%) and the colloid cost 61.3%~100.0% (except for March river of 39.2%). We can learn that in most conditions, Fe^{3+} distributes mainly in absolutely dissolved phase (<10kDa) while colloid (10kDa~0.22μm) contains more Fe^{2+} in natural aquatic environment.

In Fig.2, we plotted the relationship between the source of the samples and the average value of Fe concentrations of different species in four seasons, the tendencies of total Fe in all these three phase were estuary>river>sea. Yan et al. (1992) mixed the river water and sea water without filtered and found that content of iron in the filtrate <0.4 μm became higher in conditions of low salinity. He indicated this phenomenon might be caused by iron polymer's breakup during the mix of river water and sea water. In our study, the increase of iron content in the filtrate <0.22 μm from estuary water confirmed the quite significant effects of iron polymer's breakup during the mix of river water and sea water in estuarine areas.

Table 3 Distribution of Fe^{2+} and Fe^{3+} in absolutely dissolved phase and colloidal phase (percentage of total iron)

Source	Phase	Time	Fe^{3+} %	Fe^{2+} %
River	Absolutely dissolved phase	April	100.0	0.0
	(C_u)	August	100.0	0.0
		November	79.4	20.6
		March	98.6	1.4
	Colloidal phase	April	8.9	91.1
	(C_r)	August	95.0	4.8
		November	8.0	92.0
		March	84.8	15.2
Estuary	Absolutely dissolved phase	April	97.9	2.2
	(C_u)	August	99.1	0.9
		November	75.7	24.3
		March	90.8	9.3
	Colloidal phase	April	9.7	90.3
	(C_r)	August	90.3	9.7
		November	10.7	89.3
		March	82.2	17.8

Sea	Absolutely dissolved phase	April	67.5	32.5
	(C_u)	August	100.0	0.0
		November	73.5	26.5
		March	26.7	73.3
	Colloidal phase	April	0.0	100.0
	(C_r)	August	95.2	-
		November	0.0	100.0
		March	-	-

When we concerned the Fe^{3+}, the distributed tendency of it in "dissolved" phase, absolutely dissolved phase and colloidal phase seemed quite uniform, which was decreased from river to the sea. And the Fe^{2+} of estuary was minimum in absolutely dissolved phase while maximum in "dissolved" phase and colloidal phase. Thus we can make conclusion that during the progress of mix of river water and seawater, the product of iron polymer's breakup which makes the Fe^{2+} concentration of "dissolved" phase in estuarine water raised was mostly Fe^{2+} but not Fe^{3+}. In the other hand, the Fe^{2+} concentration of absolutely dissolved phase in estuarine water didn't appear to raise then, as discussed before, we considered it was the distributed pattern of Fe^{2+} in colloid that dominated the distribution of "dissolved" Fe^{2+} and showed that the product of iron polymer's breakup in estuarine water was mainly colloidal grain a bit smaller than previous but didn't entered the absolutely dissolved phase directly.

Percentage of Fe^{3+} and Fe^{2+} in absolutely dissolved phase and colloidal phase (Tab.4) indicated that Fe^{3+} predominated the total Fe of absolutely dissolved phase from different sources at the percentage of 67.5%~100.0%(except the March seawater of 26.7%), and the major of colloidal phase in April and November was Fe^{2+} of about 89.3%~100.0% and turned to Fe^{3+} in August and March of about 82.2%~95.2%. This distributed variation of Fe^{2+} associated with season in colloid will be discussed in section 3.2.

The results of our experiment showed that Fe^{2+} mainly presented in colloidal phase(10kDa～0.22μm)and Ozturk et al.(2003) made similar conclusion before as there was a certain connection between Fe(II) and Col Fe. The highest and lowest Fe(II) values were coincident with the highest and lowest concentrations of Col Fe. For with the pH of seawater, Fe of higher valence must be reduced to the bioavailable form so as to be absorbed or utilized by phytoplankton (Ou et al.,2003), the results of our study supported the viewpoint of Chen et al.(2003) that: colloidal iron was another source of Fe for growth of marine phytoplankton. Experiments used colloid as the only Fe source to culture micro-algae (Zheng et al., 2004) showed in the colloid concentration ranged chosen, sea colloid can enhance the relative growing rate of micro-algae (Marine *Chlorella*, *Platymonas subcordiformis* and *Isochrysis galbana*), moreover, the relative growing rate of micro-algae of all these three micro-algae were increased linearly with the increase of COC concentration. Since Fe^{2+} was more abundant in colloidal phase (10kDa~0.22μm) and the Fe can be used directly by algae is Fe^{2+}, with the increase of volume ratio between retentate (mixture of truly dissolved phase and colloid) and ultrafiltrate (1~10kDa) the Fe^{2+} can be used directly by algae became more, which strengthen the promotion of colloid to algae.

3.2 Seasonal variation of phosphorus contents in colloid

The seasonal variation of Fe in the absolutely dissolved phase compared with that of colloidal phase showed that: firstly, the variation of total Fe in colloidal phase was coincide with the Fe^{2+} in the gross, confirmed once more that iron in colloid was mainly Fe^{2+}. Total iron in the absolutely dissolved phase didn't vary apparently during April, August and November, only decreased a little in August, and was very similar with the variation of Fe^{3+} indicating the domination of Fe^{3+} in the absolutely dissolved phase.

Secondly, Fe^{2+} in the absolutely dissolved phase was quite low in both April and November while Fe^{2+} in colloid was much in April but little in November. The warm weather in August makes the phytoplankton blooms in this season and Fe^{2+} can be used by phytoplankton directly, we can infer from Fig.3 and Fig.4 that phytoplankton used Fe^{2+} in he absolutely dissolved phase first in April. Since the content of Fe^{2+} in the absolutely dissolved phase was limited, phytoplankton than began to use Fe^{2+} in colloid after run out the absolutely dissolved Fe^{2+} (the evidence was concentration of absolutely dissolved Fe^{2+} in August was very low and even reach zero in some samples). Chen *et al.* (2003) indicated that both the natural oceanic and coastal colloidal organic matter complexed Fe (1 nm–0.2 μm) can be biologically available to the marine diatom even though its uptake was lower than the low molecular weight counterparts. So, colloidal Fe^{2+} was an important iron store for phytoplankton. Under the condition of lower phytoplankton mass in November, Fe^{2+} in both absolutely dissolved phase and colloidal phase raised a little. The

studies with biogeochemical cycle of marine colloid pointed out that marine colloid mostly derive from the polysaccharides release by the phytoplankton and the bacteria. What's more, the dissolution of phytoplankton and bacteria cells, ingestive behavior of zooplankton and bacteria also produce colloid(Wells and Goldberg, 1994). The increase extent of colloidal Fe^{2+} was more apparently than absolutely dissolved Fe^{2+}, since the oxidation of inorganic Fe^{2+} in surface seawater is very fast and there is balance between inorganic Fe^{2+} and Fe^{3+} in the seawater (Qin *et al.*, 1998), we presumed that the direct production of phytoplankton activities may be Fe^{2+}, and Fe^{2+} was kept at high concentration because of the reduced micro-environment in colloid (Qin et al., 1998).

For Fe^{3+}, it didn't vary largely no matter in which phase in April, August and November, and even increased in part of August samples. That suggested that Fe^{3+} didn't influent heavily by phytoplankton mass and season, river input or other source might be one of the reasons of Fe^{3+} variation. Moreover, iron content of each species in every

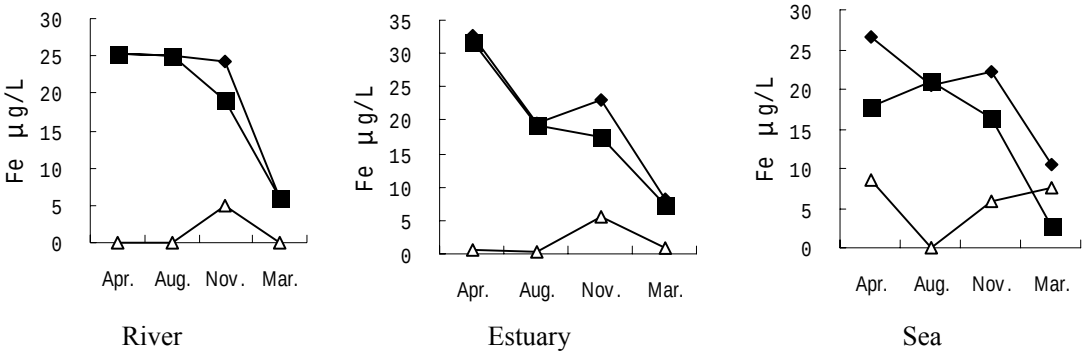


Figure 3 Seasonal variation of iron contents in absolutely dissolved phase
(◆—total Fe；■—Fe^{3+}；△—Fe^{2+})

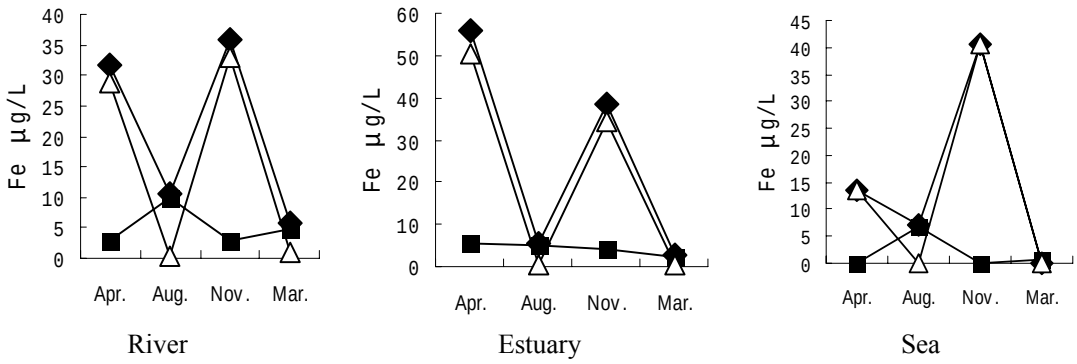


Figure 4 Seasonal variation of iron contents in colloidal phase
(◆—total Fe；■—Fe^{3+}；△—Fe^{2+})

sample of March in this experiment was very low. The amount of rainfall of Jiulongjiang River basin and south Xiamen Bay was quite large during the sampling time of March, but the large rainfall mass didn't bring to the estuary and sea more iron but decreased the content of iron on contrast, which might implied that the major source of iron to Jiulongjiang River estuary and south Xiamen Bay may not river input but other source to be studied in the future.

3.3 Recovery rate and relative standard deviation

As shown in Tab. 4, the recovery rate of Fe^{3+} raged from 85.6% to 118.5%, most of which measured up the standard in the literature earlier (Guo et al., 1994). That means no apparently loss or pollution of Fe^{3+} occurred through the procedure of ultrafiltration. The recovery rate of total Fe was a bit lower, which was 52.9%~116.4%, suggested that total Fe was effected by the procedure of ultrafiltration more. What's more, because of other reasons during the sampling and determination of iron, the results we've got couldn't be exact very much, but it was not the impediment for us to make a macro estimation of the whole tendency of iron distribution and its bioavailability. The relative standard deviations were 0.0%~10.3% for Fe^{3+} and 1.8%~15.8% for total iron.

Table 4 Recovery rate of iron content in colloids from different sources and seasons

Source	Time	total iron	Fe^{3+}
River	April	65.3	98.1
	August	106.1	107.5
	November	88.6	108.2
	March	103.9	113.9
Estuary	April	52.9	98.0
	August	116.2	118.5
	November	71.3	85.6
	March	93.0	94.3
Sea	April	85.3	106.3
	August	110	113.3
	November	54.2	100.7
	March	116.4	107.9

The principal source of experimental error was that the retentate trapped in the ultrafiltration system couldn't be discharged completely after the procedure of ultrafiltration while it would be diluted if distilled water was used to wash it out. As a result, the concentration of retentate should be something deviated from the real value and cause the fluctuation of recovery rate. In addition, the ultrafiltrate was concentrated to some extent during the ultrafiltration but the extent was hard to decide. It is the concentration of ultrafiltrate that a little bit higher than the actually value resulted in the lower value of the colloid concentration.

4. Summary

In most conditions, Fe^{3+} distributes mainly in absolutely dissolved phase (<10kDa) while colloid (10kDa-0.22 μm) contains more Fe^{2+} in natural aquatic environment. In our experiment, the increase of total iron content in the filtrate <0.22 μm from estuary water probably indicated that iron polymer's breakup during the mix of river water and sea water in estuarine areas can effect the distribution of iron in different phase significantly. Fe^{2+} which can be used by phytoplankton directly was first run out in absolutely dissolved phase and than the colloidal phase in August, so, colloidal Fe^{2+} was an important iron store for phytoplankton. And Fe^{3+} didn't influent heavily by phytoplankton mass and season, river input or other source might be one of the reasons of Fe^{3+} variation.

Acknowledgements

This research was supported by a fund from the Ministry of Education, China for the plan of chief teacher in universities.

References

Bauer J. E., Ruttenberg K. C. , Wolgast D. M., et al.(1996). Cross-flow filtration of dissolved and colloidal nitrogen and phosphorus in seawater: results form an intercomparison study . Marine Chemistry.55:33-52.

Chen M., Dei Robert C.H., Wang W.X., et al. (2003). Marine diatom uptake of iron bound with natural colloids of different origins. Marine Chemistry. 81:177-189.

Gao Y., Jin D., and Cheng Z. (1994). Distribution and contribution of nano-and picoplankton chlorophyll in Xiamen harbour. Oceanologia et Limnologia Sinica. 25(1):87-92.

Guieu C., Martin J. M., Tankere S. P. C., et al.(1998).On trace metal geochemistry in the Danube River and Western Black Sea. Estuarine Coastal and Shelf Science. 47:471-485.

Guo L.，Coleman C. H. Jr., Santschic P. H. (1994). The distribution of colloidal organic carbon in the Gulf of Mexio. Marine Chemistry. 45:105-119.

Guo L., Santschi P. H. (1997).Composition and cycling of colloids in marine environments . Reviews of Geophysics.35(1):17-40.

Kuma K., Katsumoto A., ishioka J. N. et al. (1998). Size-fractionated iron concentrations and Fe(III) hydroxide solubilities in various coastal waters . Estuarine Coastal and Shelf Science.47: 275-283.

Li L., Zhang Z., and Wang Z. (2001). Significance of colloids in the transport and transformation of trace metals at Daya Bay. Journal of Ocean University of Qingdao. 31(2):269-274.

Nishioka J., Takeda S., Wong C. S. et al. (2001). Size-fractionated iron concentrations in the northeast Pacific Ocean: distribution of soluble and small colloidal iron. Marine Chemistry.74:157-179.

Ou M., Zhang M. and Feng Y. (2003). Effects of various iron forms on the growth of chlorella vulgaris in seawater. Journal of Ocean University of Qingdao. 32(4):627-633.

Ozturk M., Bizsel N. and Steinnes E. (2003). Iron speciation in eutrophic and oligotrophic Mediterranean coastal waters; impact of phytoplankton and protozoan blooms on iron distribution. Marine Chemistry. 81:19-36.

Qin Y., Zhang M. and Zhou G. (1998). Iron sources, existing forms and their limiting action on the primary productivity of phytoplankton in seawater. Journal of Oceanography of Huanghai & Bohai Seas. 16(3):67-75.

Santschi, P. H. *et al*.(1995). Isotopic evidence for the contemporary origin of high-molecular- weight organic matter in ocean environments. Geochim. Cosmochim. Acta. 59: 625-631.

Wells. M. L. and Goldberg E. D. (1994). The distribution of colloids in the North Atlantic and Southern Oceans. Limnol. Oceanogr. 39: 286-302.

Yan L., Stallard R. F., Crerar D.A. et al. (1992). Experiment evidence on the behavior of metal bearing colloids in low-salinity estuarine water. Chemistry Geology. 100:163-174.

Zhang E., Zhang Z. and Tian Y. (2003). Study of colloidal trace metals in Nansha region. Acta Oceanologica Sinica. 25(2):136-140.

Zhao W.H. (2000). New advances in studies on marine colloid. Oceanologia et limnologia sinica. 31(2):221-229.

Zheng A., Chen M. , Zheng X., et al. (2002). The effect of marine colloids on the growth of photosysthetic bacteria. Marine Pollution Bulletin. 45:290-294.

Zheng A., Chen M. Lv E., et al. (2004). The effect of nitrogen, phosphorus and iron in marine colloids on the growth of micro-algae. Advance of Nature Science. 14(3):339-343.