Seasonal Variation Mechanism of PHC Content in the Surface and at the Bottom

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Abstract: Based on the survey data of Jiaozhou Bay in 1992, the vertical distribution and seasonal variation of PHC in surface and bottom waters of Jiaozhou Bay were studied, and the seasonal distribution, variation range and horizontal distribution trend of PHC content in the surface and bottom waters were determined. The results showed that PHC content in the surface and at the bottom of the whole water body from central Jiaozhou Bay to the northern part of the bay mouth of Jiaozhou Bay in May ranged from 0.006mg/L to 0.070mg/L, which constituted a slight pollution there. In August and October, PHC content in the surface of the water body of Jiaozhou Bay ranged from 0.019mg/L to 0.075mg/L, which didn’t constitute pollution; PHC content at the bottom of the water body of Jiaozhou Bay ranged from 0.007mg/L to 0.047 mg/L, which didn’t constitute pollution. From May to October, the level of PHC content in the surface of the water body of Jiaozhou Bay from low to high respectively appeared in the summer, the spring and the autumn; The level of PHC content in the bottom waters of Jiaozhou Bay from low to high respectively appeared in the summer, the autumn and the spring. The seasonal variation mechanism of PHC content showed that the PHC content in the surface was not subject to season but PHC content in the sources, and PHC content at the bottom was not subject to season but the accumulation and dilution effect of the PHC descending from the surface to the bottom. In terms of the scale of variation, the variation range of PHC content in surface and at the bottom of the waters in Jiaozhou Bay in May, August and October were basically the same. Moreover, the level of PHC content in the surface was relatively high and that at corresponding bottom was relatively high; the level of PHC content in the surface was relatively low and that at corresponding bottom was relatively low. In terms of the spatial scale, the horizontal distribution trend of PHC content respectively in the surface and at the bottom of the whole water body from central Jiaozhou Bay to the northern part of the bay mouth of Jiaozhou Bay in May, August and October were same. Moreover, the horizontal distribution trend of PHC in the surface and at the bottom were same when there was transportation of PHC from any source.

1. Introduction
Petroleum (PHC) is widely used in many industries. As a result, waste water and gas containing PHC are produced in the process of production and use. Through river flow transportation, oil spill transportation and open sea current transportation, the PHC firstly reaches the surface of water body and then migrates vertically to the bottom [1-11]. Therefore, based on the survey data of PHC content in Jiaozhou Bay in 1992, this paper studies the vertical distribution and seasonal variation of PHC in the surface waters and bottom waters of Jiaozhou Bay were studied, identifies the seasonal distribution, variation range and horizontal distribution trend of PHC content in the surface and at the bottom and
reveals the seasonal variation process and vertical settlement process of PHC in the waters of Jiaozhou Bay, thus providing scientific basis for the study on the vertical settlement and horizontal migration of HC in surface waters and bottom waters.

2. Materials and Methods Used in the Investigation of the Waters

2.1 Natural Environment of Jiaozhou Bay
Located in the southern part of Shandong Peninsula, between 120°04′-120°23′ E and 35°58′-36°18′N, Jiaozhou Bay is a typical semi-enclosed bay with an area of 446 km² and an average water depth of 7m. With the line between Tuan Island and Xuejia Island as the boundary, Jiaozhou Bay is adjacent with the Yellow Sea. There are more than a dozen seagoing rivers in Jiaozhou Bay, among which Dagu River and Yanghe River is of larger runoff amount and silt content, Haibo River, Licun River and Loushan River in Qingdao City belong to seasonal stream and show hydrological characteristics varying with seasonal changes [12,13].

2.2 Materials and Methods
The data of PHC in the waterbody of Jiaozhou Bay in May, August and October 1992 used in this study were provided by the North China Sea Monitoring Center, the State Oceanic Administration. Water samples were taken from thirteen stations set in Jiaozhou Bay in May, August and October respectively and were marked as H52, H53, H54, H55, H56, H57, H58, H59, H60, H61, H2014, H2015 and H2016 (Fig. 1). When the water depth is more than 10m, it is supposed to take samples from surface layer and bottom layer; when it is less than 10m, it is supposed to take from the surface layer only. This is the national standard method of sampling included in the national document “The Specification for Marine Monitoring” (1991)) [14].

Fig.1 Investigation sites in Jiaozhou Bay.

3. Results

3.1 Surface and Bottom
In May, PHC content in the surface of the waters of Jiaozhou Bay ranged from 0.006mg/L to 0.070mg/L and PHC content at corresponding bottom ranged from 0.007mg/L to 0.062mg/L, which indicated that the quality of the whole water body from central Jiaozhou Bay to the northern part of the bay mouth of Jiaozhou Bay met the third-class seawater quality standard in China (0.30mg/L) and there was a slight pollution of PHC.

In August, PHC content in the surface of the waters of Jiaozhou Bay ranged from 0.019mg/L to 0.056mg/L, which indicated that the quality of the surface waters of Jiaozhou Bay reached the
third-class seawater quality standard in China (0.30mg/L) and there was a slight pollution of PHC; PHC content at the bottom of the waters of Jiaozhou Bay ranged from 0.007mg/L to 0.035mg/L, which indicated that the quality of the bottom waters of Jiaozhou Bay reached the first-class and second-class seawater quality standard in China (0.05mg/L) and there was no pollution of PHC.

In October, PHC content in the surface of the waters of Jiaozhou Bay ranged from 0.028mg/L to 0.075mg/L, which indicated that the quality of the surface waters of Jiaozhou Bay reached the third-class seawater quality standard in China (0.30mg/L) and there was a slight pollution of PHC; PHC content at the bottom of the waters of Jiaozhou Bay ranged from 0.018mg/L to 0.047mg/L, which indicated that the quality of the bottom waters of Jiaozhou Bay reached the first-class and second-class seawater quality standard in China (0.05mg/L) and there was no pollution of PHC.

In summary, in May, PHC content in the surface and at the bottom of the whole water body from central Jiaozhou Bay to the northern part of the bay mouth of Jiaozhou Bay ranged from 0.006mg/L to 0.070mg/L, which indicated that the water body reached the third-class seawater quality standard in China (0.30mg/L) and there was a slight pollution of PHC both in the surface and at the bottom; in August and October, PHC content in the surface of the waters of Jiaozhou Bay ranged from 0.019mg/L to 0.075mg/L, which indicated that the quality of the surface waters of Jiaozhou Bay reached the third-class seawater quality standard in China (0.30mg/L) and there was a slight pollution of PHC; PHC content at the bottom of the waters of Jiaozhou Bay ranged from 0.007mg/L to 0.047mg/L, which indicated that the quality of the bottom waters of Jiaozhou Bay reached the first-class and second-class seawater quality standard in China (0.05mg/L) and there was no pollution of PHC.

3.2 Seasonal Distribution in the Surface
PHC content in the surface waters of Jiaozhou Bay ranged from 0.006mg/L to 0.070mg/L in May, from 0.019mg/L to 0.056mg/L in August and from 0.028mg/L to 0.075 mg/L in October. This indicated that PHC content in the surface waters in May, August and October ranged from 0.006mg/L to 0.070mg/L, and the level of PHC content from low to high respectively appeared in August, May and October. Therefore, the seasonal distribution of PHC content in the surface waters from low to high is summer-spring-autumn.

3.3 Seasonal distribution at the Bottom
PHC content in the bottom waters of Jiaozhou Bay ranged from 0.007mg/L to 0.062mg/L in May, from 0.007mg/L to 0.035mg/L in August and from 0.018mg/L to 0.047 mg/L in October. This indicated that PHC content in the bottom waters in May, August and October ranged from 0.007mg/L to 0.062mg/L, and the level of PHC content from low to high respectively appeared in August, October and May. Therefore, the seasonal distribution of PHC content in the surface waters from low to high is summer-autumn-spring.

3.4 Variation Range in the Surface and at the Bottom
In May, PHC content in the surface of the waters of Jiaozhou Bay reached a relatively high level of 0.006-0.070mg/L, and PHC content at corresponding bottom reached a relatively high level of 0.007-0.062mg/L. In August, PHC content in the surface of the waters of Jiaozhou Bay remained a relatively low level of 0.019-0.056mg/L, and PHC content at corresponding bottom remained a relatively low level of 0.007-0.035mg/L. In October, PHC content in the surface of the waters of Jiaozhou Bay reached a relatively high level of 0.028-0.075mg/L, and PHC content at corresponding bottom reached a relatively high level of 0.018-0.047mg/L. On the whole, the variation range of PHC content in the surface of the waters of Jiaozhou Bay was 0.019-0.022mg/L, and that at corresponding bottom was 0.011-0.027, which was basically same with the former. Therefore, it came to the conclusion that when PHC content in the surface was relatively high, PHC content at corresponding bottom was relatively high; on the contrary, when PHC content in the surface was relatively low, PHC content at corresponding bottom was relatively low.
3.5 Horizontal Distribution Trend in the Surface and at the Bottom
In May, PHC content in the surface decreased along the gradient from 0.042mg/L at Station 55 in the central water of Jiaozhou Bay to 0.010mg/L at Station 60 in the northern water at the bay mouth of Jiaozhou Bay; PHC content at corresponding bottom decreased along the gradient from 0.062mg/L to 0.014mg/L. This indicated that the horizontal distribution trend in the surface and at the bottom were same. Therefore, in May, the horizontal distribution trend of PHC in the surface and at the bottom of the water body between central Jiaozhou Bay and the northern part of the bay mouth of Jiaozhou Bay were same.

In August, PHC content in the surface increased along the gradient from 0.024mg/L at Station 55 in the central water of Jiaozhou Bay to 0.026mg/L at Station 60 in the northern water at the bay mouth of Jiaozhou Bay; PHC content at corresponding bottom increased along the gradient from 0.014mg/L to 0.016mg/L. This indicated that the horizontal distribution trend in the surface and at the bottom were same. Therefore, in August, the horizontal distribution trend of PHC in the surface and at the bottom of the water body between central Jiaozhou Bay and the northern part of the bay mouth of Jiaozhou Bay was same.

In October, PHC content in the surface increased along the gradient from 0.035mg/L at Station 55 in the central water of Jiaozhou Bay to 0.036mg/L at Station 60 in the northern water at the bay mouth of Jiaozhou Bay; PHC content at corresponding bottom increased along the gradient from 0.022mg/L to 0.023mg/L. This indicated that the horizontal distribution trend in the surface and at the bottom were same. Therefore, in October, the horizontal distribution trend of PHC in the surface and at the bottom of the water body between central Jiaozhou Bay and the northern part of the bay mouth of Jiaozhou Bay were same.

4. Discussion

4.1 Settlement Process
Through the effect of vertical water body [15-17], PHC changes greatly after passing through the water body. With PHC ion of strong hydrophilicity, it tends to combine with phytoplankton and phytoplankton particles in seawater. From spring to summer, and then to autumn, marine organisms begin to multiply in large quantities, and the number increase rapidly [13]. Because of the reproductive activities of plankton, colloids form on the surface of suspended particles, which makes the absorptive force of suspend particles reaches the highest level. With a lot PHC ion being absorbed onto suspend particles, PHC is brought to surface water. And then, it constantly sinks to the bottom of the sea under the influence gravity and current [1-11]. Therefore, the process in which PHC constantly sinks to the bottom of sea from surface water is exactly the process of settlement and migration of PHC.

4.2 Seasonal Variation Process in the Surface
PHC content in the surface waters of Jiaozhou Bay ranged between 0.006-0.070mg/L in May, 0.019-0.056 mg/L in August and 0.028-0.075mg/L in October. It can be seen that PHC content in the surface waters in May is close to that in October, while that in August was the lowest. Therefore, the seasonal distribution of PHC content in the surface from low to high was summer-spring-autumn.

In spring and autumn, PHC in the surface waters of Jiaozhou Bay was from river flows with similar high PHC content, so the PHC content was relatively high during the period. In summer, PHC came from oil spill at sea with low PHC content, so PHC content in summer was relatively low.

Therefore, from May to October, the seasonal distribution of PHC content in the surface of the waters of Jiaozhou Bay was summer-spring-autumn.

4.3 Seasonal Variation Process at the Bottom
PHC content in the bottom waters of Jiaozhou Bay ranged from 0.007mg/L to 0.062mg/L in May, 0.007mg/L to 0.035 mg/L in August and 0.018mg/L to 0.047mg/L in October. Therefore, the seasonal distribution of PHC content at the bottom from low to high was summer-autumn-spring.
In the spring, a high PHC content area formed in the surface waters of Jiaozhou Bay. The source of PHC was oil spill transportation at sea, and the PHC content was 0.042 mg/L. PHC content at the bottom was 0.062 mg/L, higher than that in the surface. These indicated that much PHC descended in a short time on the bottom and accumulated.

In the summer, a high PHC content area formed in the surface of the central water body of eastern Jiaozhou Bay. The source of PHC was oil spill transportation at sea, and the PHC content was 0.056mg/L. PHC content at the bottom was 0.035 mg/L, higher than that in the surface. These indicated that much PHC descended in a short time on the bottom and accumulated.

In the autumn, a high PHC content area formed in the surface of the coastal water at the entrance of Loushan River in northeast Jiaozhou Bay. The source of PHC was river flow transportation, and the PHC content was 0.075mg/L. PHC content at the bottom was 0.047 mg/L, higher than that in the surface. These indicated that much PHC descended in a short time on the bottom and accumulated.

Therefore, from May to October, the seasonal distribution of PHC content in the waters of Jiaozhou Bay from low to high was summer-autumn-spring.

4.4 Seasonal Variation Mechanism
In the surface waters of Jiaozhou Bay, the seasonal variation of PHC content was subject to the PHC content in sources. In spring and autumn, much PHC was transported through river flows; In summer, little PHC content was transported through oil spill at sea (Table 1). Thus, in the waters of Jiaozhou Bay, the content of PHC transported from sources determined the seasonal distribution of the PHC content in the surface, which was summer-spring-autumn from low to high. Therefore, the PHC content in the surface was not subject to season but the content of PHC transported form the sources.

| Season | Spring | Summer | Autumn |
|--------|--------|--------|--------|
| source | river flow | oil spill at sea | river flow |
| PHC content in the source | 0.070mg/L | 0.056mg/L | 0.075mg/L |

In spring and summer, little PHC was transported to the surface waters of Jiaozhou Bay through oil spills, while much PHC was transported through river flows (Table 2). Through the effect of vertical water body, horizontal water body and water body [15-17], PHC rapidly and continuously descended to the bottom of sea. In spring, PHC in the surface descended to the bottom and accumulated. In summer and autumn, PHC content in the surface decreased. PHC content in the bottom waters of Jiaozhou Bay was high in spring while low in summer (Table 2). Thus, in the waters of Jiaozhou Bay, the seasonal variation of PHC content in the surface was not same with that at the bottom. Therefore, PHC content at the bottom was not subject to season but the accumulation effect and dilution effect of PHC descending to the bottom.

| Season | Spring | Summer | Autumn |
|--------|--------|--------|--------|
| source | oil spill at sea | oil spill at sea | river flow |
| content of PHC transported to the surface | 0.042mg/L | 0.056mg/L | 0.075mg/L |
| content of PHC descending to the bottom | 0.062mg/L | 0.035mg/L | 0.047mg/L |

4.5 Variable Settlement
In terms of the scale of variation, the variation range of PHC content in surface and at the bottom of the waters in Jiaozhou Bay in May, August and October were basically same. Where there was much PHC in the surface of water, PHC content at corresponding bottom was relatively high; Where there was little PHC in the surface of water, PHC content at corresponding bottom was relatively low. These indicated that PHC rapidly and continuously descended to the bottom. According to the principle of vertical water body effect, horizontal water body effect and water body effect put forward by the
authors, PHC rapidly and continuously descends to the bottom of the sea, resulting in PHC content tending to be same in the surface and at the bottom with changes over time.

4.6 Spatial Settlement

In May, PHC in the central water of Jiaozhou bay was from the oil spill transportation at sea. PHC content was relatively high both in the surface and at the bottom. This indicated that much PHC descended to the bottom and accumulated. In the northern water at the bay mouth of Jiaozhou Bay, there was not any source of PHC transportation, and PHC content in the surface and at the bottom were relatively low. In this way, the horizontal distribution trend of PHC content in surface and at the bottom were same.

In August, in the northern water at the bay mouth of Jiaozhou Bay, there was not any source of PHC transportation, and PHC content in the surface and at the bottom were relatively low; in the central water of Jiaozhou Bay, there was not any source of PHC transportation, and the horizontal distribution trend of PHC content in surface and at the bottom were same.

In October, PHC in the northern water at the bay mouth of Jiaozhou bay was from the oil spill transportation at sea. PHC content was relatively high both in the surface and at the bottom. In the central water of Jiaozhou Bay, there was not any source of PHC transportation, and PHC content in the surface and at the bottom were relatively low. In this way, the horizontal distribution trend of PHC content in surface and at the bottom were same.

When there was PHC transported from sources, it was firstly transported to the surface and then rapidly and continuously descended to the bottom of the sea, resulting in PHC content tending to be the same in the surface and at the bottom; When there was no PHC transported from sources, PHC content in the surface and at the bottom were relatively low and their horizontal distribution trends tended to be same.

5. Conclusion

PHC content in the surface and at the bottom of the whole water body from central Jiaozhou Bay to the northern part of the bay mouth of Jiaozhou Bay in May ranged from 0.006mg/L to 0.070mg/L, which constituted a slight pollution there. In August and October, PHC content in the surface of the water body of Jiaozhou Bay ranged from 0.019mg/L to 0.075mg/L, which didn't constitute pollution; PHC content at the bottom of the water body of Jiaozhou Bay ranged from 0.007mg/L to 0.047 mg/L, which didn't constitute pollution.

From May to October, the level of PHC content in the surface of the water body of Jiaozhou Bay from low to high respectively appeared in the summer, the spring and the autumn; The level of PHC content in the bottom waters of Jiaozhou Bay from low to high respectively appeared in the summer, the autumn and the spring. The seasonal variation mechanism of PHC content showed that the PHC content in the surface was not subject to season but PHC content in the sources, and PHC content at the bottom was not subject to season but the accumulation and dilution effect of the PHC descending from the surface to the bottom.

In terms of the scale of variation, the variation range of PHC content in surface and at the bottom of the waters in Jiaozhou Bay in May, August and October were basically the same. Moreover, the level of PHC content in the surface was relatively high and that at corresponding bottom was relatively high; the level of PHC content in the surface was relatively low and that at corresponding bottom was relatively low. According to the principle of vertical water body effect, horizontal water body effect and water body effect put forward by the authors, PHC rapidly and continuously descends to the bottom of the sea, resulting in PHC content tending to be same in the surface and at the bottom with changes over time.

In terms of the spatial scale, the horizontal distribution trend of PHC content respectively in the surface and at the bottom of the whole water body from central Jiaozhou Bay to the northern part of the bay mouth of Jiaozhou Bay in May, August and October were same. In May, no PHC was transported to the northern water at the bay mouth of Jiaozhou Bay, and the horizontal distribution
trend of PHC content in the surface and at the bottom were same. In August, no PHC was transported to the northern water at the bay mouth of Jiaozhou Bay or the central water of Jiaozhou Bay, and the horizontal distribution trend of PHC content in the surface and at the bottom were same. In October, no PHC was transported to the central water of Jiaozhou Bay, while there was PHC transported to the northern water at the bay mouth of Jiaozhou Bay, where the horizontal distribution trend of PHC content in the surface and at the bottom were same. Therefore, in May, August and October, when there was PHC transported from sources, it was firstly transported to the surface and then rapidly and continuously descended to the bottom of the sea, resulting in PHC content tending to be the same in the surface and at the bottom; When there was no PHC transported from sources, PHC content in the surface and at the bottom were relatively low and their horizontal distribution trends tended to be same.

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