Decreasing and Migration Process of Oil Spill at Sea

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Abstract: Based on the survey data of Jiaozhou Bay in May, August and October 1992, the migration and variation of PHC content in offshore oil spill in Jiaozhou Bay were studied. In August, Station 2106 at the eastern central Point of Jiaozhou Bay was taken as the source of offshore oil spill, and its PHC content was 0.056 mg/L. A series of concentric circles with different gradients formed around there, and there was a descended distribution trend from the center to the periphery along the gradient. The content of PHC decreased from 0.056 mg/L at the center to 0.024 mg/L in the central water, 0.027 mg/L in the northwest water, 0.041 mg/L in the northeast water and 0.048 mg/L in the southeast water. According to the horizontal absolute loss velocity model of material content, it was calculated that the horizontal absolute loss velocity of PHC content in the surface waters from the eastern central water to the central water of eastern Jiaozhou Bay in August was 0.45 Yang Dongfang absolute number, and it decreased to 0.42 in the northwest water, 0.36 in the northeast water, and 0.29 in the southeast water. According to the horizontal relative loss velocity model of material content, it was calculated that the horizontal relative loss velocity of PHC content in the surface waters from the eastern central water to the central water of eastern Jiaozhou Bay in August was 8.03 Yang Dongfang absolute number, and it decreased to 7.50 in the northwest water, 6.42 in the northeast water, and 5.17 in the southeast water. Therefore, with Station 2106 in the eastern central Point of Jiaozhou Bay as the source of offshore oil spill, there was a descended PHC content distribution trend from the center to the periphery with the horizontal absolute loss velocity of 0.29-0.45 Yang Dongfang absolute number and the horizontal relative loss velocity of 5.17-8.03 Yang Dongfang relative number. The rising PHC content distribution was consistent with that of the horizontal absolute (relative) loss velocity of PHC content; that of the central water < that of the northwest water < that of the northeast water < that of the southeast water. PHC content indicates the variation amount from the source to certain water, namely terminal value. The horizontal absolute (relative) loss velocity of PHC content indicates the variation process from the source to certain water, namely process value. This reveals that both the terminal value and the process value of PHC content present the migration process of PHC content in waterbody. According to the horizontal velocity model of Yang Dongfang material content, the decreasing and migration process of PHC content toward the periphery along the gradient can be calculated and quantified.

1. Introduction
In Jiaozhou Bay, where there are oil storage bases, there are many incoming and outgoing ships, as well as oil spills at sea. Once offshore oil spill occurs, petroleum (PHC) will migrate and decrease toward the periphery from the high content area at the source. Thus, the PHC content is transported through the ocean to the whole bay [1-11]. Therefore, according to the investigation data in 1992, the terminal value and process value of PHC content can be calculated with the horizontal loss velocity.
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, 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, H2104, H2105 and H2106 (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 stations in Jiaozhou Bay](image)

3. Results

3.1 Source
In August, PHC content in Station 2106 in the eastern central water of Jiaozhou Bay reached a high level of 0.056 mg/L and thus formed a high PHC content area. There were a series of concentric circles with different gradients forming around there and a descended distribution trend from the center to the periphery along the gradient. The content of PHC decreased from 0.056 mg/L at the center to 0.024 mg/L in the central water, 0.027 mg/L in the northwest water, 0.041 mg/L in the northeast water and 0.048 mg/L in the southwest water (Fig. 2).

In August, a high PHC content area formed in the center of eastern Jiaozhou Bay, which indicated...
that the source of PHC was the migration of oil spill at sea and the PHC content was 0.056 mg/L. There was a descended distribution trend from the center to the periphery along the gradient. The content of PHC decreased from 0.056 mg/L at the center to 0.024 mg/L in the central water, 0.027 mg/L in the northwest water, 0.041 mg/L in the northeast water and 0.048 mg/L in the southeast water. Then, at the same time, whether the horizontal loss of flows with the same PHC content but toward different directions was consistent in the process of migration at sea.

3.2 Distance from the Central Station to Surrounding Stations
In August, five stations were set up in the central water of eastern Jiaozhou Bay. With Station 2106 at the center, there are Station 55 in the central bay, Station 57 in the northwest bay, Station 2105 in northeast bay and Station 59 in the southeast bay. The distance between Station 2106 in the center and each of the other four stations is shown in Figure 3, and the value of PHC content at each station is shown in Table 1.

Table 1 Location and PHC content value of each station

| Station | longitude | latitude    | PHC content (mg/L) |
|---------|-----------|-------------|--------------------|
| 2106    | 120°19'0" | 36°08'0"   | 0.056              |
| 55      | 120°15'18"| 36°07'06"  | 0.024              |
| 57      | 120°16'0" | 36°10'06"  | 0.027              |
| 2105    | 120°20'0" | 36°10'0"   | 0.041              |
| 59      | 120°19'12"| 36°06'42"  | 0.048              |

Fig. 2 PHC content distribution at the surface layer in August 1992 (mg/L)

Fig. 3 The connection between the central station and each station in eastern Jiaozhou Bay
The calculation process of the distance between the Station 2106 at the center of east Jiaozhou Bay and Station 55 in the central Bay is as follows: To assume that the distance from Point 2106 to Point 55 is \( L_1 \) and consider that \( l'=1858 \text{m} \), \( L_1 \) is obtained. 
\[
L_1^2 = [(18-15+60/60-18/60) \times 1858]^2 + [(7-7+60/60-6/60) \times 1858]^2 \\
L_1 = 3.80 \times 1858 = 7075.05(\text{m})
\]

The calculation process of the distance between the Station 2106 at the center of east Jiaozhou Bay and Station 57 in the northwest bay is as follows: To assume that the distance from Point 2106 to Point 57 is \( L_2 \) and consider that \( l'=1858 \text{m} \), \( L_2 \) is obtained.
\[
L_2^2 = [(19-16+0+60/60-0/60) \times 1858]^2 + [(8-10+0/60-6/60) \times 1858]^2 \\
L_2 = 3.66 \times 1858 = 6803.93(\text{m})
\]

The calculation process of the distance between the Station 2106 at the center of east Jiaozhou Bay and Station 2105 in the northeast bay is as follows: To assume that the distance from Point 2106 to Point 2105 is \( L_3 \) and consider that \( l'=1858 \text{m} \), \( L_3 \) is obtained.
\[
L_3^2 = [(19-20+0+60/60-0/60) \times 1858]^2 + [(8-10+0/60-6/60) \times 1858]^2 \\
L_3 = 2.23 \times 1858 = 4154.61 (\text{m})
\]

The calculation process of the distance between the Station 2106 at the center of east Jiaozhou Bay and Station 59 in the southeast bay is as follows: To assume that the distance from Point 2106 to Point 59 is \( L_4 \) and consider that \( l'=1858 \text{m} \), \( L_4 \) is obtained.
\[
L_4^2 = [(19-19+0+60/60-12/60) \times 1858]^2 + [(8-6+0/60-42/60) \times 1858]^2 \\
L_4 = 1.44 \times 1858 = 2686.07(\text{m})
\]

### 3.3 Horizontal Loss Velocity Model of Yang Dongfang Material Content

The authors put forward “the horizontal loss velocity model of Yang Dongfang material content”, which consists of the horizontal absolute loss velocity model of material content and the horizontal relative loss velocity model of material content.

The horizontal absolute loss velocity model of material content: to assume that the surface material content in the waterbody of Jiaozhou Bay decreases from value \( a \) at Point A to value \( b \) at Point B, the distance between Point A and Point B is \( L \), and the horizontal absolute loss velocity of material content is \( V_{asp} \). Then, the horizontal absolute loss velocity model of material content is obtained:

\[
V_{asp} = \frac{(a-b)}{L}
\]

Then, to assume that the horizontal relative loss velocity of material content is \( V_{rph} \), the horizontal relative loss velocity model of material content is obtained:

\[
V_{rsp} = \frac{(a-b)}{aL} = \frac{(a-b)}{aL}
\]

From the Point of spatial scale, this model reveals the loss amount of material content in per unit distance in horizontal migration, horizontal absolute loss velocity of material content indicates the absolute loss amount in per unit distance, while horizontal relative loss velocity of material content indicates the relative loss amount in per unit distance.

### 3.4 Simplification of Units

Horizontal loss velocity and horizontal relative loss velocity of oil level are complex units and need to be simplified. So the author defines \( \times 10^{-5} \) (mg/L)/m as Yang Dongfang Number, which can also be used in English and marked as ydf.

For horizontal absolute loss velocity value of PHC content, it is referred as \( V_{asp} \) and can be obtained through the equation \( V_{asp} = 30.84 \times 10^{-5} (\text{mg/L})/\text{m} \). It can be called 30.84 Yang Dongfang absolute number or 30.84 ydf.

For horizontal relative loss velocity value of PHC content, it is referred as \( V_{rph} \) and can be obtained through the equation \( V_{rph} = 7.78 \times 10^{-7} (\text{mg/L})/\text{m} \). It can be called 7.78 Yang Dongfang relative number or 7.78 ydf.

Therefore, in any waterbody, horizontal loss amount of any material content can be measured with Yang Dongfang absolute number(ydf) and Yang Dongfang relative number (ydf).
3.5 Horizontal Loss Velocity between the Eastern Center and Bay Center
In August, a high PHC content area formed at the central Point 2106 in the eastern Jiaozhou Bay, which indicated that the source of PHC was the oil spill at sea and the PHC content was 0.056 mg/L. The PHC content in the surface water between Point 2106 and Point 55 in the central bay was 0.024 mg/L.

According to the horizontal loss velocity model of Yang Dongfang material content, the horizontal absolute loss velocity and horizontal relative loss velocity of PHC content were calculated.

In August, the PHC content in the surface water decreased from 0.056 mg/L at Point 2106 to 0.024 mg/L at Point 55. 

\[ V_{asp} = \frac{(0.056-0.024)}{7075.05} = 0.45 \times 10^{-5} \text{(mg/L)/m} = 0.45 \text{ ydfr.} \]

\[ V_{rsp} = 8.03 \times 10^{-5} \text{(mg/L)/m} = 8.03 \text{ ydfr.} \]

Then, in August, the source of PHC was the oil spill at sea. In the central bay, the horizontal absolute loss velocity of PHC content in the surface water between Point 2106 and Point 55 was 0.45 Yang Dongfang absolute number, and the horizontal relative loss velocity was 8.03 Yang Dongfang relative number.

3.6 Horizontal Loss Velocity between the Eastern Center and the Northwest Bay
In August, a high PHC content area formed at the central Point 2106 in the eastern Jiaozhou Bay, which indicated that the source of PHC was the oil spill at sea and the PHC content was 0.056 mg/L. The PHC content in the surface water between Point 2106 and Point 57 in the northwest bay was 0.027 mg/L.

According to the horizontal loss velocity model of Yang Dongfang material content, the horizontal absolute loss velocity and horizontal relative loss velocity of PHC content were calculated.

In August, the PHC content in the surface water decreased from 0.056 mg/L at Point 2106 to 0.027 mg/L at Point 57.

\[ V_{asp} = \frac{(0.056-0.027)}{6803.93} = 0.42 \times 10^{-5} \text{(mg/L)/m} = 0.42 \text{ ydfr.} \]

\[ V_{rsp} = 7.50 \times 10^{-5} \text{(mg/L)/m} = 7.50 \text{ ydfr.} \]

Then, in August, the source of PHC was the oil spill at sea. In the northwest bay, the horizontal absolute loss velocity of PHC content in the surface water between Point 2106 and Point 57 was 0.42 Yang Dongfang absolute number, and the horizontal relative loss velocity was 7.50 Yang Dongfang relative number.

3.7 Horizontal Loss Velocity between the Eastern Center and the Northeast Bay
In August, a high PHC content area formed at the central Point 2106 in the eastern Jiaozhou Bay, which indicated that the source of PHC was the oil spill at sea and the PHC content was 0.056 mg/L. The PHC content in the surface water between Point 2106 and Point 2105 in the northeast bay was 0.041 mg/L.

According to the horizontal loss velocity model of Yang Dongfang material content, the horizontal absolute loss velocity and horizontal relative loss velocity of PHC content were calculated.

In August, the PHC content in the surface water decreased from 0.056 mg/L at Point 2106 to 0.041 mg/L at Point 2105.

\[ V_{asp} = \frac{(0.056-0.041)}{4154.61} = 0.36 \times 10^{-5} \text{(mg/L)/m} = 0.36 \text{ ydfr.} \]

\[ V_{rsp} = 6.42 \times 10^{-5} \text{(mg/L)/m} = 6.42 \text{ ydfr.} \]

Then, in August, the source of PHC was the oil spill at sea. In the northeast bay, the horizontal absolute loss velocity of PHC content in the surface water between Point 2106 and Point 2105 was 0.36 Yang Dongfang absolute number, and the horizontal relative loss velocity was 6.42 Yang Dongfang relative number.

3.8 Horizontal Loss Velocity between the Eastern Center and the Southeast Bay
In August, a high PHC content area formed at the central Point 2106 in the eastern Jiaozhou Bay, which indicated that the source of PHC was the oil spill at sea and the PHC content was 0.056 mg/L. The PHC content in the surface water between Point 2106 and Point 59 in the southeast bay was 0.048 mg/L.

According to the horizontal loss velocity model of Yang Dongfang material content, the horizontal
absolute loss velocity and horizontal relative loss velocity of PHC content were calculated.

In August, the PHC content in the surface water decreased from 0.056 mg/L at Point 2106 to 0.048 mg/L at Point 59. $V_{wp} = (0.056-0.048)/2686.07 = 0.29 \times 10^{-5} (mg/L)/m=0.29 yd/ft$. $V_{wp}=5.17 \times 10^{-5} (mg/L)/m=5.17 yd/ft$.

Then, in August, the source of PHC was the oil spill at sea. In the southeast bay, the horizontal absolute loss velocity of PHC content in the surface water between Point 2106 and Point 59 was 0.29 Yang Dongfang absolute number, and the horizontal relative loss velocity was 5.17 Yang Dongfang relative number.

4. Discussion

4.1 Horizontal Content Changes under the Same Source

In August, Station 2106 at the eastern central Point of Jiaozhou Bay was taken as the source of offshore oil spill, and its PHC content was 0.056 mg/L. A series of concentric circles with different gradients formed around there, and there was a descended distribution trend from the center to the periphery along the gradient. The content of PHC decreased from 0.056 mg/L at the center to 0.024 mg/L in the central water, 0.027 mg/L in the northwest water, 0.041 mg/L in the northeast water and 0.048 mg/L in the southeast water (Fig. 2).

Results in Table 2 were calculated with the horizontal absolute loss velocity model of material content. In August, the horizontal absolute loss velocity of PHC content in the surface waters from the eastern center to the central bay was 0.45 Yang Dongfang absolute number, and it decreased to 0.42 in the northwest water, 0.36 in the northeast water, and 0.29 in the southeast water. Therefore, with Station 2106 in the eastern central Point of Jiaozhou Bay as the source of offshore oil spill, there was a descended PHC content distribution trend from the center to the periphery with the horizontal absolute loss velocity of 0.29-0.45 Yang Dongfang absolute number.

Results in Table 2 were calculated with the horizontal relative loss velocity model of material content. In August, the horizontal relative loss velocity of PHC content in the surface waters from the eastern center to the central bay was 8.03 Yang Dongfang absolute number, and it decreased to 7.50 in the northwest water, 6.42 in the northeast water, and 5.17 in the southeast water. Therefore, with Station 2106 in the eastern central Point of Jiaozhou Bay as the source of offshore oil spill, there was a descended PHC content distribution trend from the center to the periphery with the horizontal relative loss velocity of 5.17-8.13 Yang Dongfang relative number.

| Table 2 PHC content velocity values of the central water in the southern bay |
|------------------------|-------|-------|-------|-------|
| Month                  | August| August| August| August|
| the central water in the Eastern bay | 2106-55 | 2106-57 | 2106-2105 | 2106-59 |
| variation range of PHC content | 0.024-0.056 | 0.027-0.056 | 0.041-0.056 | 0.048-0.056 |
| the horizontal absolute loss velocity of PHC content  | 0.45 | 0.42 | 0.36 | 0.29 |
| the horizontal relative loss velocity of PHC content | 8.03 | 7.50 | 6.42 | 5.17 |
| characteristics value of PHC content  | same time, same source, different distances |

4.2 Characteristics of Calculation Values under the Same Source

Under the condition of same time, same starting point and different endpoints, the absolute loss amount in per unit distance was different. In August, the PHC content of the central water in southern bay was 0.056 mg/L, and there was a descended distribution trend toward the periphery along the gradient. The content of PHC decreased from 0.056 mg/L at the center to 0.024 mg/L in the central water, 0.027 mg/L in the northwest water, 0.041 mg/L in the northeast water and 0.048 mg/L in the southeast water. Therefore, the PHC content distribution order was: that of the central water < that of the northwest water < that of the northeast water < that of the southeast waters. According to the
horizontal absolute loss velocity model of material content, it was calculated that the order of the horizontal absolute loss velocity of PHC content was: that of the central water < that of the northwest water < that of the northeast water < that of the southeast waters. According to the order of the horizontal relative loss velocity model of material content, it was calculated that the order of horizontal relative loss velocity of PHC content was: that of the central water < that of the northwest water < that of the northeast water < that of the southeast waters.

The order of the horizontal absolute loss velocity of PHC content was consistent with that of the horizontal relative horizontal loss velocity of PHC content, also that of PHC content decreasing from the center toward the periphery along the gradient.

Therefore, a series of concentric circles with different gradients formed around the center of the eastern Bay, the source of offshore oil spill with a PHC level of 0.056 mg/L. Then, the order of PHC content distribution was consistent with that of the horizontal absolute (relative) loss velocity of PHC content: that of the central water < that of the northwest water < that of the northeast water < that of the southeast water. PHC content indicates the variation amount from the source to certain water, namely terminal value. The horizontal absolute (relative) loss velocity of PHC content indicates the variation process from the source to certain water, namely process value, which revealed that both the terminal value and the process value of PHC content present the migration process of PHC content in waterbody.

4.3 Quantitative Migration Process
A series of concentric circles with different gradients formed around the center of the eastern bay, the source of offshore oil spill with a PHC level of 0.056 mg/L. Then, the PHC content ranged between 0.024 mg/L to 0.056 mg/L along the gradient among the central bay, the northwest bay, the northeast bay and the southeast bay. Through the horizontal loss velocity model of Yang Dongfang material content, it was calculated that the horizontal absolute loss velocity of PHC content ranged between 0.29 ydfr-0.45 ydfr, and the horizontal relative loss velocity of PHC content ranged between 5.17 ydfr - 8.03 ydfr. After the migration of certain distance, the final value and process value of PHC content from the same source were same. That is, the PHC content from the same source was consistent with its horizontal absolute (relative) loss velocity. Therefore, according to the horizontal loss velocity model of Yang Dongfang material content, the migration and deceasing process of PHC content toward the periphery along the gradient can be calculated and quantified.

5. Conclusion
In August, Station 2106 at the eastern central Point of Jiaozhou Bay was taken as the source of offshore oil spill, and its PHC content was 0.056 mg/L. A series of concentric circles with different gradients formed around there, and there was a descended distribution trend from the center to the periphery along the gradient. The content of PHC decreased from 0.056 mg/L at the center to 0.024 mg/L in the central water, 0.027 mg/L in the northwest water, 0.041 mg/L in the northeast water and 0.048 mg/L in the southeast water (Fig. 2).

According to the horizontal absolute loss velocity model of material content, it was calculated that the horizontal absolute loss velocity of PHC content in the surface waters from the eastern central water to the central water of eastern Jiaozhou Bay in August was 0.45 Yang Dongfang absolute number, and it decreased to 0.42 in the northwest water, 0.36 in the northeast water, and 0.29 in the southeast water. Therefore, with Station 2106 in the eastern central Point of Jiaozhou Bay as the source of offshore oil spill, there was a descended PHC content distribution trend from the center to the periphery with the horizontal absolute loss velocity of 0.29-0.45 Yang Dongfang absolute number.

According to the horizontal relative loss velocity model of material content, it was calculated that the horizontal relative loss velocity of PHC content in the surface waters from the eastern central water to the central water of eastern Jiaozhou Bay in August was 8.03 Yang Dongfang absolute number, and it decreased to 7.50 in the northwest water, 6.42 in the northeast water, and 5.17 in the southeast water. Therefore, with Station 2106 in the eastern central Point of Jiaozhou Bay as the source of offshore oil
spill, there was a descended PHC content distribution trend from the center to the periphery with the horizontal relative loss velocity of 5.17-8.13 Yang Dongfang relative number.

A series of concentric circles with different gradients formed around the center of the eastern bay, the source of offshore oil spill with a PHC level of 0.056 mg/L. The order of PHC content distribution was consistent with that of the horizontal absolute (relative) loss velocity of PHC content: that of the central water < that of the northwest water < that of the northeast water < that of the southeast water. PHC content indicates the variation amount from the source to certain water, namely terminal value. The horizontal absolute (relative) loss velocity of PHC content indicates the variation process from the source to certain water, namely process value. This reveals that both the terminal value and the process value of PHC content present the migration process of PHC content in waterbody.

According to the horizontal loss velocity model of Yang Dongfang material content, the decreasing and migration process of PHC content toward the periphery along the gradient can be calculated and quantified. Through the horizontal loss velocity model of Yang Dongfang material content, the horizontal absolute (relative) loss velocity of material content can be calculated. Then with the horizontal loss velocity model of Yang Dongfang material content, the horizontal absolute (relative) loss velocity of material content and the distances between two points, the material content of certain water can be calculated.

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