Dilution Diffusion Model Research of Offshore Deep-sea Discharge in Coastal Area

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Abstract. The sewage diffusion effect under deep water was carried out between different diffuser design parameters based on the hydraulic model test. According to the test of diffuser length, riser spacing, riser number, riser nozzle number, horizontal azimuth angle and jet angle, the specific parameters of diffuser need to be determined comprehensively considering the water surface sewage field, sewage diffusion degree, project cost, etc. We used a coastal marine disposal project in China as an example. The article analyzes the influence of diffuser technology on the dilution and diffusion of sewage under the condition of large water depth, and puts forward the engineering design schemes of different horizontal azimuth angle, different jet angle and different diffuser length.

1. Introduction

In the sewage discharge project, the main function of the porous diffuser in which it can discharge the sewage to the marine environment water body evenly and dispersedly [1]. Therefore, the diffuser can provide a great initial dilution of sewage. From the perspective of the sewage discharge process that has been put into operation at present, a good design of the hydraulic structure of the diffuser has become a key factor in the design of offshore deep-water discharge engineering [2]. At present, due to the actual engineering conditions, the water depth of most sewage deep sea drainage projects in China is generally no more than 10 meters [3]. Compared with the condition that the water depth is more than 20 meters, the design length of the diffuser is often smaller [4]. Because of the limitation of the water depth, it is difficult to select the jet angle under the condition of small water depth [5]. In order to prevent the discharged sewage from rising too early, and at the same time, the dilution and diffusion effect of sewage will not be weakened [6]. Under the condition of large water depth, the selection range of diffuser jet angle and horizontal direction angle is large, and the sewage outflow effect will be improved [7]. But in the big, at present, there is no in-depth study on the effect of diffuser structure on the dilution and diffusion of sewage [8].

For the whole sewage marine disposal, the terminal diffuser is an important link to improve the dilution and diffusion effect of sewage and protect the marine environment [9]. The main structure of the diffuser consists of a main pipe, a rising pipe and an outlet nozzle, and the main pipe is mainly used for the normal flow of sewage [10]. The rising pipe is generally connected to the main pipe, which is used to dredge the outflow position of sewage [11]. The terminal nozzle is used for sewage outflow [12]. From the perspective of structural design, the structure of diffusers in foreign countries is also different [13]. The
single nozzle structure of riser is adopted for the diffuser of a sea discharge project in California, USA [14]. The diameter of riser is larger than that of nozzle, the inlet is round, and elbow bend is used to guide the flow [15]. In an Australian sea drainage project, I-Type structural diffuser is adopted, which is of multi nozzle structure [16]. The spacing of 36 risers is 21 meters, and each riser has 6 nozzles on the top. Some pollution of L-shaped structure is adopted in the water and ocean disposal project, with 8 nozzles on the top of each vertical riser [17]. The hydraulic model test of Boston sewage outfall project shows that when the number of orifices on the riser is more than 8, the plume outfall forms a rising ring, thus reducing the dilution of seawater to sewage [18]. At present, most of the researches on the sewage diffusers are carried out in the area with small water depth. For the case of water depth below 20 m, there are few researches at present, and there is no systematic analysis on the dilution and diffusion effect of sewage.

2. Materials and Methods

Based on the parameters of diffuser length, riser spacing, riser number, riser nozzle number, horizontal azimuth angle and jet angle, this paper studies the dilution and diffusion near diffuser.

2.1. Engineering case

Huizhou Dayawan petrochemical industrial zone shows the comprehensive advantages of the coastal area, has superior location advantages and unique conditions for the development of petrochemical industry, and attracts many domestic and foreign petrochemical project investment businessmen park investment. At present, there are three sewage treatment plants in the area, which are respectively transported to the sea discharge pump station through a section of land pipeline, and then discharged through the only sea discharge pipeline under pressure. The total length of the pipeline is about 22km, including 2km for the onshore part and 20km for the submarine part. The deep sea outfall is located between the Delta Island and the Sangzhou Island on the west side of the Huidong Pinghai power plant. The water depth of the outfall is 23 m, and the area of the sewage mixing area is very limited. It is understood that due to the influence of rainfall during the rainy season, the actual discharge of the pipeline will reach saturation.

2.2. Diffuser parameters

According to the design requirements, the proposed diffuser design scheme is screened. See Table 1 for the basic parameters of the test diffuser, and a total of test diffuser scheme groups are selected (Note: "√" indicates the test scheme).

| Diffuser length | 54m | 58m |
|-----------------|-----|-----|
| Riser spacing   | 4.0m|     |
| Number of risers| 14  | 15  |
| Number of riser nozzles | 2 |
| Horizontal azimuth | 0° | 30° | 90° | 0° | 30° | 90° |
| Jet angle       | 0°  | √   | √   | √   | √   | √   |
|                 | 10° | √   | ×   | ×   | √   | ×   |
|                 | 15° | √   | ×   | ×   | √   | ×   |

Scheme design of diffusion string test: The experiment was carried out according to different diffuser length, horizontal azimuth and jet angle.

Test scheme of different horizontal azimuth: Study the influence of different horizontal azimuth angle of the diffuser on the dilution, and carry out 6 groups of tests. See Table 2 for the prototype parameters of the test diffuser. (At 0°, the jet is parallel to the flow direction)

Different jet angle test scheme: Study the influence of different jet angles of the diffuser on the dilution, and carry out 6 groups of tests. See Table 3 for the prototype parameters of the test diffuser.
Table 2  Test scheme of different horizontal azimuth.

| Diffuser length | 58m  | 70m  |
|-----------------|------|------|
| Number of risers| 15   | 18   |
| Jet angle       | 0°   | 0°   |
| Horizontal azimuth | 0°   | 30°  | 90°  |
| Scheme          | 1    | 2    | 3    |

Table 3  Different jet angle test scheme.

| Diffuser length | 58m  | 70m  |
|-----------------|------|------|
| Number of risers| 15   | 18   |
| Horizontal azimuth | 0°   | 0°   |
| Jet angle       | 0°   | 0°   | 10°  | 15°  |
| Scheme          | 1    | 7    | 8    | 4    | 9    | 10   |

Table 4  Different diffuser length test scheme.

| Diffuser length | 58m  | 70m  |
|-----------------|------|------|
| Number of risers| 15   | 18   |
| Horizontal azimuth | 0°   | 0°   |
| Jet angle       | 0°   | 0°   |

Test plan of different diffuser length: According to the results of Experiments 1 and 2, two groups of experiments were carried out on the basis of selecting the best horizontal azimuth and jet angle. The prototype parameters of the test diffuser are shown in Table 4.

2.3. Model overview

The model is carried out in a glass flume with a normal size (Length, width and height=70m×0.7m×0.9m). The model is designed according to the criterion, and the flow pattern in the model must be consistent with the prototype. In order to ensure the similarity of flow pattern, the Reynolds number of model nozzle should be greater than the critical Reynolds number.

\[ R_{e, min} = \frac{D_{min}}{\nu} \geq R_{e,c} \]

Where: Rejmin is the minimum nozzle Reynolds number in the model; uimin is the minimum nozzle velocity in the model, m/s; Dmin is the minimum nozzle diameter in the model, m; v is the flow viscosity coefficient; Rec is the critical Reynolds number. The model scale is selected according to the laboratory conditions, diffuser materials, sewage discharge, etc. the model scale value is geometric scale: λ1=30; flow scale: \(\lambda Q = \lambda Q \lambda (2/5) = 4929.5\); flow scale: \(\lambda v = \lambda 1^{1/2} = 5.5\); relative density scale: \(\lambda (\rho/\rho_0) = 1\).

3. Results & Discussion

3.1. Analysis of test data of different horizontal azimuth

The horizontal azimuth is 0°, and the test results are listed in Table 5. Meanwhile, the horizontal azimuth is 30°, and the test results are listed in Table 6. At the last for the 90°, and the test results are listed in Table 7.

Table 5  Test results at 0° horizontal azimuth.

| Tide | Diffuser length | Dilution multiple |
|------|----------------|-------------------|
|      | 100m           | 200m              | 500m              |
| Tide | 58m            | 102.3             | 135.8             | 207.5             |
|      | 70m            | 177.1             | 206.2             | 246.1             |
| Ebb  | 58m            | 122.9             | 144.6             | 219.5             |
Table 6  Test results at 30° horizontal azimuth.

|        | Tide | Diffuser length | Dilution multiple |
|--------|------|-----------------|-------------------|
|        |      |                 | 100m 200m 500m    |
| Tide   |      |                 |                   |
| 58m    |      | 93.7 221.3 268.8|                   |
| 70m    |      | Diffusion range: 0.039km² |
|        |      | Diffusion range: 0.043km² |

Table 7  Test results at 90° horizontal azimuth.

|        | Tide | Diffuser length | Dilution multiple |
|--------|------|-----------------|-------------------|
|        |      |                 | 100m 200m 500m    |
| Tide   |      |                 |                   |
| 58m    |      | 58.7 114.6 151.2|                   |
| 70m    |      | 119.1 143.2 231.1|
| Ebb    |      | 58.2 139.1 175.4|
| 70m    |      | 119.7 168.1 249.5|
|        |      | Diffusion range: 0.046km² |
|        |      | Diffusion range: 0.048km² |

3.2. Experimental data analysis of different jet angles
The jet angle is 15°, 10°, and 0, and the test results are listed in Table 8/9/10.

Table 8  Test results at 15° jet angle.

|        | Tide | Diffuser length | Dilution multiple |
|--------|------|-----------------|-------------------|
|        |      |                 | 100m 200m 500m    |
| Tide   |      |                 |                   |
| 58m    |      | 108.1 134.4 184.1|                   |
| 70m    |      | 121.6 165.4 194.6|
| Ebb    |      | 58.2 165.5 192.0|
| 70m    |      | 210.1 246.2 287.7|
|        |      | Diffusion range: 0.035km² |
|        |      | Diffusion range: 0.038km² |

Table 9  Test results at 10° jet angle.

|        | Tide | Diffuser length | Dilution multiple |
|--------|------|-----------------|-------------------|
|        |      |                 | 100m 200m 500m    |
| Tide   |      |                 |                   |
| 58m    |      | 90.1 122.8 169.4|
| 70m    |      | 138.6 146.2 223.7|
| Ebb    |      | 58.2 226.6 180.8|
| 70m    |      | 151.3 161.5 244.1|
|        |      | Diffusion range: 0.040km² |
|        |      | Diffusion range: 0.043km² |
Table 10 Test results at 0 ° jet angle.

| Diffuser length | Dilution multiple |
|-----------------|-------------------|
| Tide            | 100m    | 200m    | 500m    |
| Tide            | 58m     | 102.8   | 137.2   | 207.4   |
| Tide            | 70m     | 176.3   | 207.8   | 245.5   |
| Ebb             | 58m     | 124.2   | 145.6   | 219.5   |
| Ebb             | 70m     | 93.2    | 221.9   | 269.5   |
| Diverticulum    | 58m     | 0.039km²|
| Diverticulum    | 70m     | 0.042km²|

3.3. Analysis of test data of different diffuser length
The diffuser length is 58m and 70m, the horizontal azimuth angle is 0 °, and the jet angle is 0 °. The test results are listed in Table 11.

Table 11 Results of diffuser length 58m/70m, horizontal azimuth 0 °, jet angle 0 °.

| Diffuser length | Dilution multiple |
|-----------------|-------------------|
| Tide            | 100m    | 200m    | 500m    |
| Tide            | 58m     | 102.6   | 136.6   | 207.4   |
| Tide            | 70m     | 177.1   | 208.2   | 244.9   |
| Ebb             | 58m     | 124.5   | 145.4   | 219.1   |
| Ebb             | 70m     | 93.8    | 223.9   | 270.2   |
| Diverticulum    | 58m     | 0.039km²|
| Diverticulum    | 70m     | 0.044km²|

3.4. The influence of different horizontal azimuth on dilution diffusion.
The results show that the horizontal jet path and dilution diffusion are directly related to the horizontal azimuth of the nozzle. When the horizontal azimuth is 0 °, 30 ° and 90 °, the dilution can meet the design environmental protection requirements.

When the horizontal azimuth is 90 °, it means, the jet is perpendicular to the direction of the environmental water flow, the initial dilution and diffusion of sewage is the best. It is mainly due to the strong disturbance of the environmental water flow after the sewage flows out of the nozzle, which expands rapidly on the flow section, mixes rapidly with the surrounding environmental water body, and the initial dilution and diffusion effect is obvious. However, when the water depth of the sea area where the sewage outfall is located is relatively small, it is easy to form a sewage field on the water surface, which is not conducive to the re-dilution and diffusion of sewage, thus affecting the environment.

When the horizontal azimuth is 30 ° and 90 °, there are surface sewage field, but the impact of sewage field on the environment decreases with the decrease of the angle.

When the horizontal azimuth is 0 °, i.e. the jet is parallel to the direction of environmental water flow, the initial dilution and diffusion of sewage is slightly poor; however, due to the entrainment of water flow, the horizontal drift distance is long when the roof falls, so it is not easy to form a sewage field on the water surface. Therefore, in order to prevent the formation of unfavorable sewage field on the water surface. In engineering cases, the horizontal azimuth of the general diffuser is recommended to be 0 °, that is, the jet is parallel to the direction of the ambient flow.

3.5. Influence of different jet angles on dilution diffusion
The experiment shows that the jet angle is one of the important factors affecting the near zone dilution of wastewater. The longitudinal diffusion shape is related to the jet angle. The larger the angle between the jet and the vertical line is, the jet will slowly bend due to the effect of the hydraulic resistance around
the flow after the jet is launched. At the same time, the jet will slowly mix with the cross flow, and its width will be larger and larger.

When the jet angle is 0 °, due to the horizontal azimuth angle of 0 °, some sewage clouds are entrained by water flow, and the drift distance is too long, which affects their dilution and diffusion.

When the jet angle is 15 °, due to the small water depth in the engineering case sea area, the time of sewage rising to the water surface is short, so it is easy to form a sewage field on the water surface, which affects its dilution and diffusion.

When the jet angle is 10 °, under the strong disturbance of the environmental water flow, it is not easy to form a certain sewage cloud group, and has a certain drift distance, it is not easy to form a sewage field on the water surface, which can achieve better dilution and diffusion effect.

From the test results of different jet angles, it can be seen that the larger the jet angle of the nozzle is, the shorter the horizontal migration distance when the sewage reaches the water surface. Although the jet angle of the large nozzle is better than that of the small nozzle in the same distance before reaching the water surface, because the large nozzle flows through the early roof, especially for the shallow water, the sewage with the angle of 10 ° and 15 ° may not form on the surface. The dilution of the water surface is not as good as the jet angle of the small nozzle.

Moreover, the water area at the discharge outlet of the domestic sewage offshore treatment project is shallow. In order to prevent the sewage from falling off the roof too early, affect the initial dilution effect near the area, and prevent the bottom touching phenomenon, the jet angle of the nozzle should not be too large or too small. For (marine discharge), because of the buoyancy, the jet angle is generally taken as 0 °.

Considering the above factors, the nozzle angle of the diffuser used in the project is recommended to be about 0 °, that is, the angle between the jet direction and the horizontal plane is about 0 °.

3.6. Effect of different diffuser length on dilution diffusion
The results show that the length of the diffuser has an obvious effect on the initial dilution, which increases with the increase of the diffuser length. The above two diffuser lengths can meet the requirements of initial dilution. Considering the engineering economy, technology, environment and other factors, the diffuser length of 58m can meet the requirements of design initial dilution. Through the test, it is found that the sewage of each riser is basically mixed when the roof falls, which shows that the design of the number of risers can meet the requirements.

4. Conclusions
According to the test of diffuser length, riser spacing, riser number, riser nozzle number, horizontal azimuth angle and jet angle, the specific parameters of diffuser need to be determined comprehensively considering the water surface sewage field, sewage diffusion degree, project cost, etc.

Under the condition of large water depth, the better dilution and diffusion of sewage can be ensured by increasing the spray angle and horizontal angle of the diffuser. Properly increasing the horizontal azimuth and jet angle can improve the diffusion effect of sewage. But if we want to achieve the same diffusion effect under the condition of small water depth, we often need to increase the length of the diffuser, which will increase the cost of the diffuser itself and the construction difficulty and cost of the diffuser, so the economy is poor. Therefore, in the actual t-path of deep-sea sewage discharge, it is recommended to set the sewage discharge at the place where the water depth is greater than 20 m, if conditions permit.

In the actual project, under the condition of large water depth, the sewage can be fully mixed with sea water due to the relatively long time of lifting the roof. Therefore, in the design of diffuser, the length of diffuser can be reduced and the jet angle can be increased. According to the experimental results, the jet angle can be controlled within the range of 5-30 degrees, and the dilution and diffusion of sewage can achieve better results. But if there is a better water depth condition in the actual project, the jet angle and horizontal angle can be increased appropriately, so as to reduce the length of the diffuser, reduce the project cost and construction cost.
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