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Monitoring and Analysis of Domestic Sewage Treatment Facilities in Ningbo Port, China

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Abstract : Ningbo Port is a well-known deep-water port on the Chinese mainland and one of the densest ports in the world. One of the pollution concerns at the port is the marine domestic sewage, especially those coming from ships discharged into the water. Therefore, the goal of this work is to macro-evaluate the current situation of marine domestic sewage from ships at Ningbo Port, China, according to China GB 3552-2018: Water Pollution Emission Control Standard and put forward suggestions for the improvement of the treatment facilities. Samples of domestic sewage from ships were collected between July 2020 and June 2021 and then analyzed according to their pH, suspension, chemical oxygen demand (COD), biochemical oxygen demand (BOD), heat resistance of coliform, and total chlorine. The results show that 104 batches of ships using membrane bioreactor (MBR) devices have a qualification rate of only 47.1% for domestic sewage and a 5-day biochemical oxygen demand (BOD5) of only 69.2%, a BOD5 of 25 mg/L, and a COD of 125 mg/L, which is below the limits of the GB 3552-2018 Standard. One of the proposed treatments is to use an anaerobic-aerobic mobile bed biofilm reactor (A/O MBBR) to treat the simulated marine domestic sewage. When 34 batches of simulated marine domestic sewage were treated with A/O MBBR, the removal rate of the daily domestic sewage capacity of a 1.5-ton device for total nitrogen, ammonia nitrogen, COD, and BOD reached 87.12%, 93.96%, 96.79%, and 94.89%, respectively. While the removal rate of the daily domestic sewage capacity of a 7-ton device reached 87.40%, 92.40%, 96.88%, and 93.59%, respectively, The study emphasized that the A/O MBBR combination process not only has a strong ability to resist the impact load, but also improves the daily treatment volume of sewage and effectively reduces the pollutant concentration of wastewater. This shows that it has good development potential and improves the quality of domestic sewage for ships in Ningbo Port, China.

Keywords: Domestic Sewage Treatment， Real Marine wastewater, MBR,MBBR, Ships

Introduction

Ningbo Port is located in eastern Zhejiang, the southern wing of the Yangtze River Delta, with a moderate geographical location. It is a well-known deep-water port on the Chinese mainland and one of the densest ports in the world. The prosperous port trade not only drives the economic development of Zhejiang Province and even the Yangtze River Delta region but also brings challenges to the port ecological environment.[1-2] One of the difficulties is dealing with marine domestic sewage, which consists of bacteria, viruses, and parasite eggs, as well as nitrogen, phosphorus, and other eutrophication. [3]Once it is discharged into the ocean, untreated or poorly treated domestic waste will cause disruption to the marine natural ecosystem. [4-7]

In order to protect the environment, prevent pollution control, promote the progress of ship water pollution emission control technology, promote the construction of ship pollutant reception and treatment facilities, and promote the green development of ship and related device manufacturing industry, the former Water Environmental Management Department and Science and Technology Standards Department of the Ministry of Environmental Protection has developed the GB 3552-2018: Marine Water Pollution Emission Control Standard. which is higher than the International Convention for the Prevention of Pollution from Ships (MARPOL Convention), which is a great challenge to the purification performance of existing ship sewage treatment devices. In order to make a smooth transition to the new national standard and reduce its impact on the shipping industry, the Ministry of Transport issued the Notice on the Implementation of the Ship Water Pollution Emission Control Standard (No. 2018) on July 5, 2018. This decision has clearly delayed the completion of the ship transformation required by the end of 2020. Furthermore, the Technical Rules for Legal Inspection of Domestic Navigation Marine Ships (2020) (hereinafter referred to as the "2020 Edition of Marine Regulations" or "New Sea Regulations") also stipulate that vessels already put into operation should meet relevant requirements no later than December 31, 2020, and should be inspected to prevent domestic sewage pollution.

As an important piece of equipment for ship pollution prevention, the ship domestic sewage treatment device is related to the discharge of ship pollutants and water environment quality. [8-10] Internationally, real-ship sampling surveys have also been carried out. For example, IMO PPR 6/14 Draft Amendments to MEPC 227(64) mentioned that the Netherlands sampled 127 real-ship ships, but only 4 of them met the emission standards. At present, the ship domestic sewage treatment process [11–13] includes biological methods, materialized methods, and electrochemical methods. From the treatment processes, the biofilm method is the most prominent to show a significant effect. In comparison to conventional activated sludge and fixed biofilm processes, a mobile bed biofilm reactor (MBBR) [14, 15] is preferred because it has strong tolerance, a high biological load, high nitrogen removal efficiency, no back flushing, and a small biofilm footprint. [16-17]

At the same time, in the context of global carbon neutrality, how the shipping industry can reduce carbon emissions has also become a hot topic. The moving-bed biofilm reactor MBBR has the advantage of low operating energy efficiency [18]. Based on the above background, from July 2020 to June 2021, Ningbo Port ships were selected as the research object, and 104 batches of domestic sewage from ships treated with a membrane bioreactor (MBR) [19]were sampled and analyzed. The results are in accordance with GB3552-2018 "Marine Water Pollution Discharge Control" Standards. Limit values are compared, the standards are statistically analyzed, and the overall standards are macro-evaluated. Secondly, we treated 34 batches of simulated ship domestic sewage with A/O MBBR (Figure 1) from July to September 2021. Four parameters, which include total nitrogen, ammonia nitrogen, COD, and BOD5, will be analyzed. [20-22] An evaluation of the effects before and after treatment will be done in order to put forward treatment suggestions from various perspectives to improve the existing situation.The actual ship wastewater and treated data obtained in this study make it possible to treat ship wastewater under low-carbon conditions [23-25].

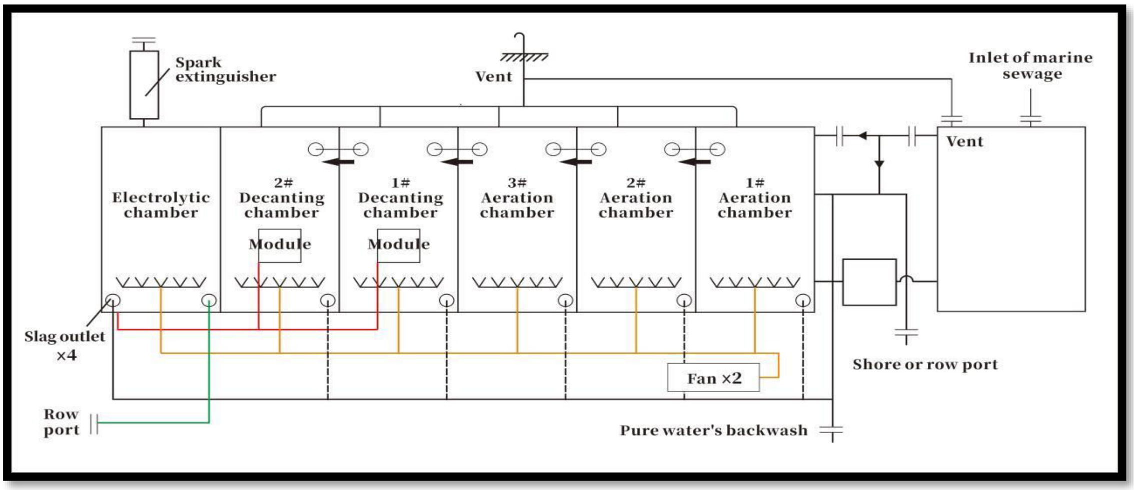

Figure 1: Schematic diagram of A/O MBBR

Experimental

Study Subjects

Ningbo Port is composed of Beilun Port District, Town Port District, Ningbo Port District, Daxie Port Area, and Chuanshan Port Area. It is a multi-functional and comprehensive modern deep-water port, integrating an inland river port, an estuary port, and a sea port. This study covers the ships in the above 5 port areas, which can provide a relatively comprehensive grasp of the current situation of ship domestic sewage treatment in the Ningbo port area.

Experimental Instrument

The main instruments and equipment used in this study are as follows: Type PHB-1 type portable pH meter (Shanghai Sanxin Instrument Plant); Milli-Q Element Ultra Pure Water Treatment System (Millipore, USA); SOH-72C oven (smartlab, Taiwan); 5ml microtitration tube (Beijing Pomeric Glass has New Company); Type SX736 type dissolved oxygen detector (Shanghai Sanxin Instrument Factory); Temperature temperature and constant humidity incubator (MMM, Germany);5B-3Ctype Chemical oxygen demand rapid tester(Beijing Lianhua Yongxing Technology Development Co., Ltd.) ;LH-3BNtype Total nitrogen analyzer (Beijing Lianhua Yongxing Technology Development Co., Ltd.).All instruments are entrusted by a qualified third-party measurement institution to conduct measurement in accordance with the relevant measurement procedures, To ensure volume and value stability and traceability.

Sample Collection

During July 2020 to June 2021,104 batches of treated domestic sewage samples were collected at Ningbo port. The sampling steps are as follows: from the discharge of the domestic sewage treatment device. After the sewage treatment device reaches a stable working state, open the drainage valve and let the natural outflow for 3~5 minutes, take the sampling container and sample the same container (not less than 5 times) to get mixed samples. Water sample containers, sample quantity and storage conditions are shown in Table 1.

Table 1: Information on the collection and preservation of ship domestic sewage samples

Sample name	Testing items	Sampling container	Sampling quantity (mL)	Save conditions
Domestic sewage of ships	pH value	Disposable sterile plastic bottles	250	Field determination
	Suspension	Disposable sterile plastic bottles	500	1~5℃ Dark refrigerated
	Chemical oxygen demand	Glass bottle	500	With the superior grade pure H_2SO_4Adjust the pH, to enable pH≤ 2
	The biochemical oxygen demand for five days (BOD_5)	Dissolution oxygen bottle	1000	1~5℃ Dark refrigerated
	Heat-resistant Escherichia coli populations	Burnout glass bottle	500	0.4ml 10% (m / m) of sodium thiosulfate was added and refrigerated at 1~5℃
	Total chlorine	Brown glass bottle	500	A 5ml 2.0mol/L NaOH solution was added in advance
	ammonia nitrogen	polyethylene bottles or glass bottle	500	With H_2SO_4Adjust the pH, to enable

				pH≤ 2
	Total nitrogen	polyethylene bottles or glass bottle	500	With H_2SO_4Adjust the pH value to 1~2

Sample Transport and Analysis Method

All samples were collected in sealed sample boxes for light avoidance, refrigerated in biological ice bags, and sent to the laboratory for testing within 2 hours. The pH items were measured using portable pH meters, while the remaining pollutant items were analyzed in the laboratory. The testing methods for each pollutant project are the methods specified in GB 3552-2018: Marine Water Pollution Emission Control Standard. All testing methods are recognized by CNAS, as detailed in Table 2.

Table 2: Monitoring methods for marine domestic sewage pollutants

Testing items	Standard name of the monitoring method	Standard No
pH value	Determination of water quality pH by the glass electrode method	GB/T 6920-1986
Suspension	Determination of suspended water quality	GB/T 11901-1989
Chemical oxygen demand	Determination of water quality and chemical oxygen demand by dichromate method	HJ 828-2017
The biochemical oxygen demand for five days	Water quality is five-day biochemical oxygen demand (BOD5) Determination dilution and inoculation method	HJ 505-2009
Heat-resistant Escherichia coli populations	Determination of fecal coliform by tubular fermentation	HJ 347.2-2018
Total chlorine	Determination of water quality free chlorine and total chlorine by N,N-diethyl-1,4-phenylenediamine titration	HJ 585-2010
ammonia nitrogen	Determination of ammonia nitrogen by spectrophotometry of nano reagent	HJ 535-2009

Total nitrogen	Determination of total nitrogen by UV spectroscopy by alkaline potassium persulfate photometry	HJ 636-2012

Result and Discussion

Results Statistics

According to Article 5.2 of GB 3552-2018: Marine Water Pollution Emission Control Standard, the time of ship installation (including replacement) of domestic sewage treatment devices is different, and its pollutant monitoring items and limits are different. BOD is required for ships installed (including replacement) with domestic sewage treatment devices after January 1, 2012. For suspended substances, heat-resistant coli flora, pH value, chemical oxygen demand, and total chlorine, Table 3 shows the statistical results of the installation of the treatment device after January 1, 2012.

Table 3: Statistics of test results of ship domestic sewage samples

Installation time of the domestic sewage treatment device	Test batch	Testing items	Limits	Qualified batch	Qualified Rate: (%)
After January 1,2012	104	pH value	6~8.5 (dimensionless)	84	80.8
		Suspension	35 mg/L	95	92.3
		Chemical oxygen requirement is COD	125 mg/L	79	76.0
		Five-day biochemical oxygen demand (BOD_5)	25 mg/L	72	69.2
		Heat-resistant Escherichia coli populations	1,000 / L	95	92.3
		Total chlorine	<0.5 mg/L	99	95.2

		All the qualified batches of the above 6 pollutant projects are 49 batches, and the qualified rate is 47.1%.

In addition, the treatment of 34 batches of simulated ship domestic sewage using two anaerobic-aerobic mobile bed biofilm reactors A/O MBBR (CD1.5-MBBR: daily water capacity of 1.5 tons and CD7-MBBR:daily water capacity of 7 tons) showed that the two devices had excellent removal of total nitrogen, ammonia nitrogen and COD, BOD, with a removal rate of more than 95%, as shown in the figure below:

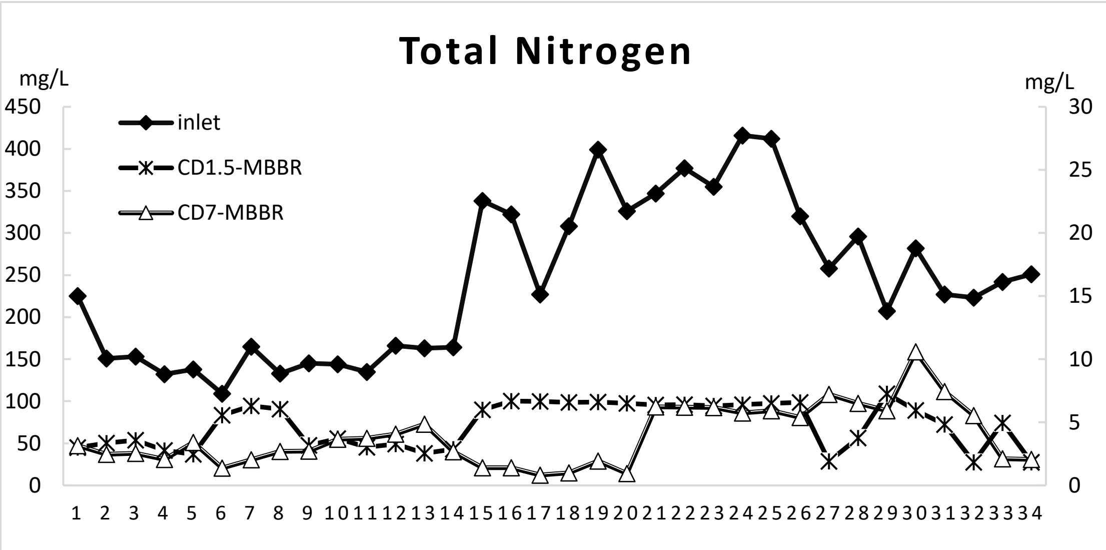

Figure 2: The values of total nitrogen at inlet,CD-1.5MBBR(Min 1.91,Max 9.63,Mean 4.75) and CD7-MBBR(Min 0.82,Max 18.2,Mean 3.88).

As shown in the Figure 2TN profile, the influent of shipborne domestic wastewater exhibited strong nitrogen fluctuation, with TN concentrations varying from approximately 110 to over 400 mg/L. Such variation reflects the intermittent discharge pattern and highly concentrated nature of shipboard wastewater. After treatment by the A/O-MBBR system, both CD1-MBBR and CD7-MBBR achieved substantial TN reduction, and the effluent TN remained much lower than the influent throughout most sampling points. This indicates that the attached biofilm in the MBBR provided effective nitrification and denitrification capacity. However, temporary increases in effluent TN were observed during the high-loading period, suggesting that nitrogen removal was affected by shock loading, limited biodegradable carbon availability, and possible imbalance between the anoxic and aerobic zones. Overall, the A/O-MBBR process showed good potential for nitrogen control in shipborne domestic sewage, although further optimization of hydraulic retention time, dissolved oxygen, internal reflux, and carbon-to-nitrogen ratio would be necessary to improve effluent stability under fluctuating marine wastewater conditions.Figure 2:Total nitrogen, referred to as TN, or the total nitrogen content in water, is one of the important indicators for measuring water quality. Total nitrogen is defined as the total amount of various forms of inorganic and organic nitrogen in water. Including inorganic nitrogen such as NO3-, NO2-, and NH4+ and organic nitrogen such as protein, amino acids, and organic amines, calculated in milligrams of nitrogen per liter of water. It is often used to indicate the degree of nutrient pollution in water bodies. The content in raw sewage is about 100-200mg/L, and the total nitrogen in domestic sewage is basically in the form of ammonia nitrogen. The treated water quality meets the standards: In the biochemical process, the nitrification reaction of nitrifying bacteria is used to degrade ammonia nitrogen into nitrate nitrogen, and then the denitrification reaction is used in an anoxic environment to decompose the nitrate nitrogen into nitrogen volatilization. Compliance with total nitrogen standards is the most difficult of all indicators. If the total nitrogen standards can be achieved in the biochemical process, the system will operate well. Only on the basis of BOD, COD, and ammonia nitrogen standards can total nitrogen standards be ensured in the biochemical process.

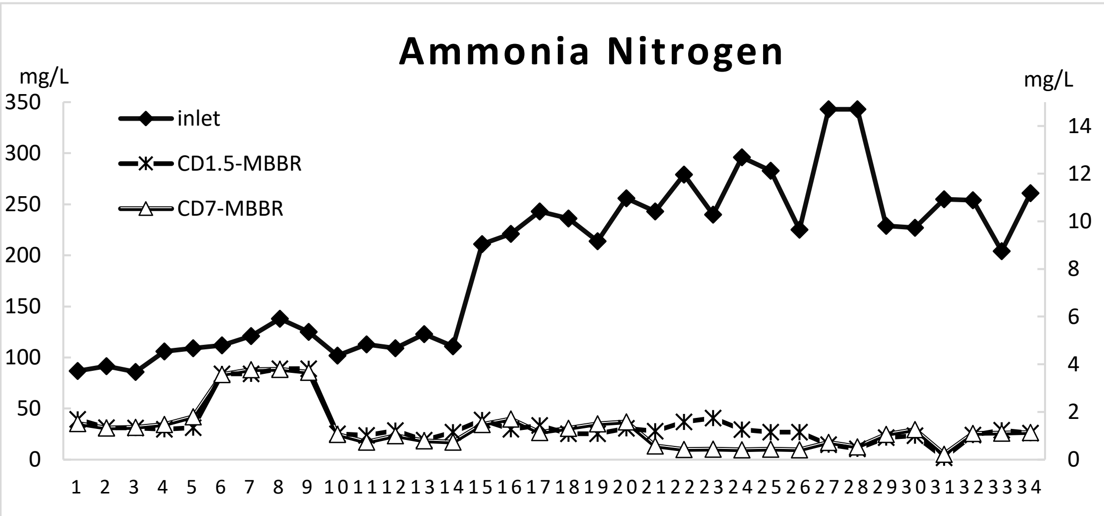

Figure 3: The values of ammonia nitrogen at inlet,CD1.5-MBBR(Min 0.08,Max 3.82,Mean 1.46) and CD7-MBBR(Min 0.23,Max 3.79,Mean 1.33).

As shown Figure 3 in the ammonia nitrogen profile, the influent of shipborne domestic wastewater exhibited substantial fluctuation, increasing from approximately 90 mg/L in the early stage to more than 300 mg/L during the high-loading period. After treatment by the A/O-MBBR system, both CD1-MBBR and CD7-MBBR maintained much lower effluent ammonia nitrogen concentrations, mostly within the range of 1–4 mg/L. This indicates that the attached biofilm in the MBBR system provided effective nitrification capacity and strong resistance to ammonia shock loading. Although slight increases in effluent ammonia nitrogen were observed at several sampling points, the overall removal performance remained stable. Compared with the TN profile, the low ammonia nitrogen concentration in the effluent suggests that nitrification was not the main limiting step; instead, incomplete denitrification or nitrate accumulation may have contributed to the remaining TN in the effluent.Figure 3:Ammonia nitrogen refers to compound nitrogen that exists in the form of ammonia or ammonium ions, that is, nitrogen that exists in the form of free ammonia (NH3) and ammonium ions (NH4+) in water. The content of raw sewage is about 150 mg/L. Post-treatment water quality compliance: The treatment system of the biochemical reaction treatment mechanism can use nitrifying bacteria to significantly reduce the relevant values after the nitrifying bacteria take effect. The electrolytic degradation requirements are equivalent to the total nitrogen removal requirements.

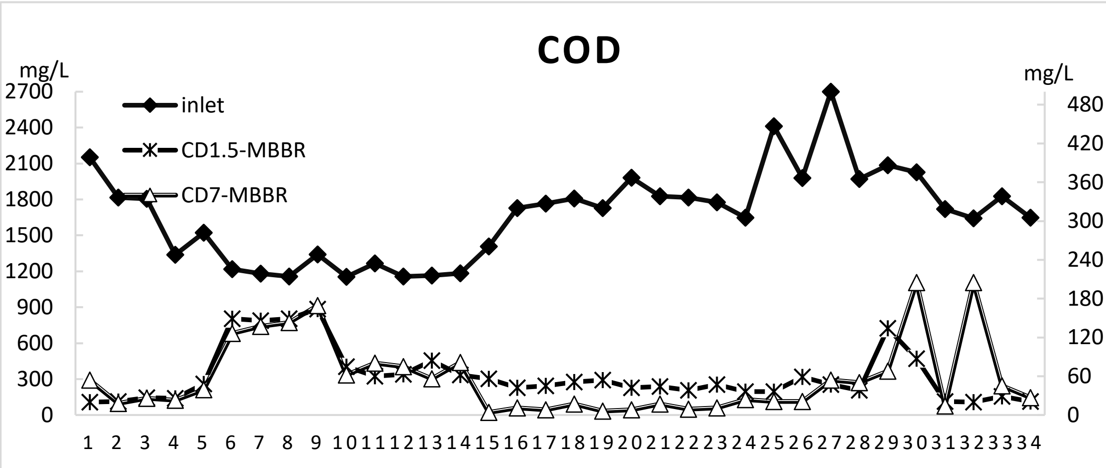

Figure 4: The values of COD at inlet,CD1.5-MBBR (Min 20,Max 164,Mean 60.03)and CD7-MBBR(Min 4,Max 205,Mean 56.29).

As shown in Figure 4 the COD profile, the influent shipborne domestic wastewater exhibited high and fluctuating organic loading, with COD concentrations ranging approximately from 1150 to 2700 mg/L. After treatment by the A/O-MBBR system, the effluent COD of both CD1-MBBR and CD7-MBBR was substantially reduced, indicating effective biodegradation of organic matter by the attached biofilm. Most effluent COD values remained within a much lower range compared with the influent, corresponding to an overall removal efficiency of approximately 90% or higher. However, several temporary increases in effluent COD were observed, particularly in the later sampling period for CD7-MBBR, suggesting that the system was affected by organic shock loading, hydraulic fluctuation, or biofilm instability. Compared with CD7-MBBR, CD1-MBBR showed slightly more stable COD removal performance. Overall, the A/O-MBBR process demonstrated strong potential for organic matter removal from shipborne wastewater, but further optimization of hydraulic retention time, dissolved oxygen control, biofilm management, and influent equalization would be necessary to improve long-term effluent stability .Figure 4:The COD content in raw sewage is approximately below 1500 mg/L. When the treated water quality reaches the standard, there is a positive correlation between the COD index and the BOD_5 effluent index. The ratio of treated water quality is generally between 1:4 and 1:10 (the better the effluent quality is). The greater the difference in the ratio, because BOD_5 can be degraded to less than 5. However, due to the biochemical method, the organic nutrients decrease after the BOD_5 decreases, and the bacteria cannot further reduce the COD. When the effluent becomes better, the greater the ratio of BOD_5 to COD. The requirements for passenger ships in the Yangtze River in GB3552 are: The effluent requirement of 60mg/L and the conventional COD effluent requirement of 125mg/L are difficult to achieve by traditional biochemical methods and electrolysis methods. It can be achieved under excellent conditions of use (such as excellent bacterial culture and good electrolytic materials). Water quality index requirements, but the 60 mg/L standard must use MBBR's biochemical process and a good environment. Pure electrolysis is almost impossible to meet the standard.

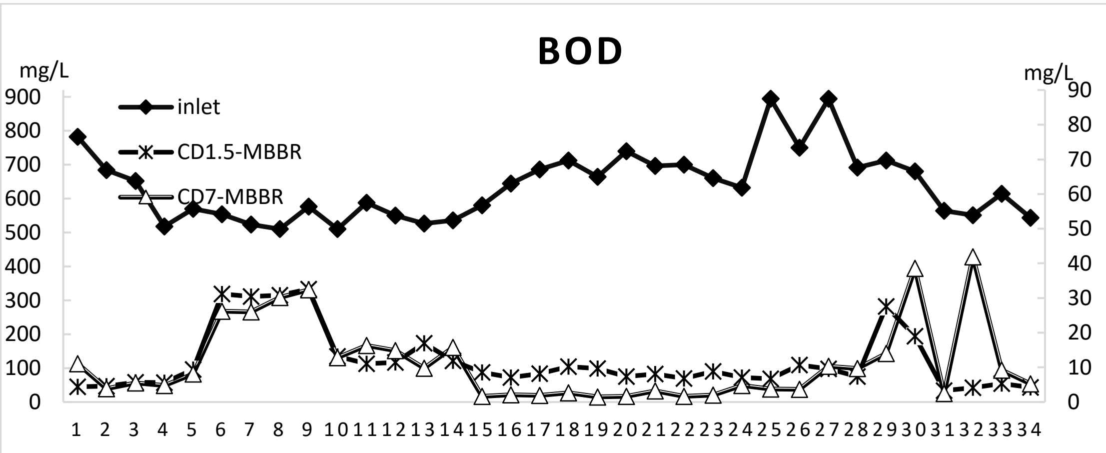

Figure 5: The values of BOD at inlet,CD1.5-MBBR(Min 3.3,Max 32.6,Mean 11.74) and CD7-MBBR(Min 1.5,Max 38.6,Mean 11.16).

Figure 5:The black water of ships, that is, domestic sewage, mainly consists of four types:.1 discharges and other wastes from any type of toilets and urinals;.2 basins, bath basins, and drainage from these places in medical offices (pharmacies, wards, etc.) discharges from holes;.3 discharges from spaces containing live livestock and poultry cargo; or.4 other wastewater mixed with the above discharges. Ship gray water mainly consists of the following aspects: laundry water, bathing water, cleaning water, and kitchen water. Different sources of gray water will lead to different compositions of gray water, and different ship types, such as cruise ships, passenger ships, cargo ships, etc., will also lead to different compositions and ingredients of the gray water they produce. If gray water needs to be treated at the same time during the peak period, it is more likely to exceed the standard: gray water is concentrated at night, and gray water in bathing, laundry, and the kitchen is discharged at the same time. In traditional processes, a large amount of sewage will enter the aeration cabinet. Compared with urban and municipal sewage treatment, ship domestic sewage is used as a A special kind of domestic sewage, whose production and discharge are restricted by the dual environmental conditions of ships and oceans. The main difference between the two is that the discharge cycle of ship domestic sewage is shorter and fresher (less decomposed), the pollution load is higher, and ship toilets Sanitary appliances are often flushed directly with seawater, so their COD, total suspended solids, and salt content are greater than municipal sewage. The hydraulic load and discharge volume are also more volatile, and the flow rate is unstable. Rapidly flowing into the sedimentation cabinet, the entire residence time is not enough to meet the residence time requirements of the treatment. As a result, the sewage that has not yet completed the biochemical process directly enters the disinfection cabinet and is finally discharged. Biochemical oxygen demand (often recorded as BOD5) refers to the amount of dissolved oxygen consumed during the biochemical reactions of microorganisms decomposing biodegradable organic matter present in water under certain conditions. Expressed in mg/L or percentage, ppm. It is a comprehensive indicator reflecting the content of organic pollutants in water. If the biological oxidation time is five days, it is called the five-day biochemical oxygen demand (BOD5). The BOD5 content in the raw sewage without gray water is between 500 and 700. If there is a case where gray water is processed together, the BOD5 of the incoming water is generally between 300 and 450. The treated water quality meets the standards: The biochemical method reduces the relevant indicators by biodegrading the organic components in the water. When the biochemical method is not good at

producing bacteria, the traditional process method generally produces water with an effluent content of around 50 mg/L. After using the MBBR process, the standard can basically be reached, and the general data for exceeding the standard in time is also below 35. There is little difference in the difficulty of meeting the standard of 20mg/L for special ships and 25mg/L for ordinary ships.

Conclusion:

At present, although most ships are equipped with domestic sewage treatment devices according to the requirements, based on the survey and the sampling results, the treatment effect of domestic sewage treatment devices is not ideal, and their discharge is generally not up to standard. The A/O MBBR combination process not only has a strong ability to resist the impact load but also can improve the daily treatment volume of sewage and effectively reduce the pollutant concentration of wastewater, which shows that it has good development potential.

For the current management of ship domestic sewage, the following suggestions are put forward: 1) local governments should increase the management and improve the treatment capacity; 2) regulatory authorities should improve laws and regulations and strengthen law enforcement supervision; 3) enterprises should strengthen the operation management according to the new standards; 4) strengthen the inspection of ship domestic sewage treatment equipment and pollution discharge supervision; 5) study a better sewage treatment process to lay the foundation for social and economic development.

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