Research status and prospect of microplastics in ship grey water

Qianchi Ma[1a], Desheng Li[2b], Hongyan Wang[1c], Zheng Wang[1d], Rongchang Chen[1e], Dong Lu[1f*]

[1] China Waterborne Transport Research Institute, Beijing, 100088, China
[2] Qinhuangdao Port Co., Ltd., Qinhuangdao, 066000, China

Abstract: This paper deeply discusses the microplastic pollution of ship gray water which is getting more and more attention at present. This paper begins with an overview of the potential sources of microplastics and the current management measures. Then, the research progress on the qualitative and quantitative analysis techniques of Marine gray water microplastics, Marine input estimation and type distribution of microplastics in domestic and foreign literature is reviewed in detail. On this basis, the paper puts forward suggestions for future research directions, including establishing the analysis method of gray water composition based on actual ships, strengthening the research on the basic data of microplastics, formulating the inventory of gray water microplastics discharge from ships, and promoting the improvement and development of the control policy of gray water discharge from ships. These suggestions aim to provide scientific basis and strategic guidance for the treatment of ships' grey water microplastics pollution.

1. Ship sources of Marine microplastics

The plastic pollution is recognized as a growing environmental problem in coastal and Marine ecosystems worldwide. In 2015, it was estimated that 407 million tons of plastic were produced worldwide, of which about 8.82 million tons of waste plastic were discharged from land into the ocean, accounting for about 85 percent of Marine litter[1], and it is predicted that the world's oceans will contain 32 million tons of plastic waste by 2050[2]. This discarded plastic enters aquatic ecosystems, where it degrades through physical, chemical and biological processes into microplastics with a smaller range of sizes[3]. In 2004, Thompson et al. first defined synthetic or semi-synthetic plastic particles consisting of polymers and additives larger than 1 μm in diameter and smaller than 5 mm as microplastics[4]. The distribution of microplastics in the ocean varies depending on their density, with polypropylene (PP) and polyethylene (PE) floating in the water due to their lower density, while denser polystyrene (PS), polyvinyl chloride (PVC), polyamide (PA) and polyethylene terephthalate (PET) sinking to the seafloor, Resulting in different types of microplastics at different nutrient levels throughout the water[5]. Terrestrial and Marine pollution sources are the main sources of microplastics entering the ocean. Land-based sources of microplastics, including wastewater, runoff and rivers, account for about 70 percent of Marine microplastics sources[6]. Due to their large contribution, current research on Marine microplastics has focused more on land-based microplastics[7-9].

In recent years, the relevant international maritime departments and governments have paid more and more attention to the way of Marine microplastics. Through literature research, the common Marine sources of microplastics usually include cargo damage accidents, aquaculture and ship sources[10], among which ship sources are mainly from ship paint layers and hull scrapings and ship garbage and wastewater[11]. Although the Marine microplastics brought by ships account for a relatively small proportion, China's shipping area is rich in ecological and fishery resources, and it is also a densely populated area for ship navigation. According to statistics, in 2022, China's coastal ocean cargo turnover will be close to 10 trillion tons kilometers, and the number of ships entering and leaving coastal ports will exceed 10 million times[12]. Therefore, in the context of a huge base, the impact of ship-derived microplastics can still not be underestimated.

2. Ship grey water is a potential sink and source of ship-derived microplastics

The concept of ship grey water was first introduced in 2006 in resolution MEPC.159(55) by the Marine Environment Protection Committee (MEPC), an agency of the International Maritime Organization (IMO)[13]. In this resolution, the concept of ship grey water is defined as the discharge of washing water, shower water, laundry water, bath water and face water from ships. Land-based data show that households contribute to the discharge of microfibres released from synthetic textiles during laundry, microbeads from personal care and cosmetic products to

[a] maqianchi@wti.ac.cn; [b] lidesheng1@portqhd.com; [c] wanghy@wti.ac.cn;
[d] wangzh@wti.ac.cn; [e] chenrongchang@wti.ac.cn; [*f] ludong @wti.ac.cn

wastewaters, as well as microplastics derived from house dust, and microplastics usually represent a major proportion of all contaminants in influent wastewaters[14, 15]. Considering the source of ship's grey water is very similar to the household discharge routes mentioned above, so there is reason to believe that the ship's grey water may also contain some amount of microplastics.

Grey water production is closely related to the number of people on board, with some merchant ships carrying more grey water than oily sewage. On cruise ships, for example, grey water can account for up to 90% of the total liquid waste. The EPA once studied four cruise ships and concluded that gray water is the largest contributor to wastewater discharge, with each ship producing an average of 170,000 gallons (1,418 tons) of gray water per day, or 67 gallons (253.6 liters) per person per day[16]. Gray water emissions from shipping also vary by ship type. In the Baltic Sea, for example, 5.5 million tons of gray water are emitted annually from all shipping. The largest contributors to gray water emissions are cargo/vehicle carriers (i.e., passenger-rolling vessels, with annual emissions of 4.25 million cubic meters), followed by cruise ships with annual emissions of 650,000 cubic meters[17].

The International Maritime Organization (IMO) recently noted that greywater emissions from ships can be a source of microplastics at sea[18]. The microplastic component of ships' grey water comes mainly from synthetic chemical fibrous microplastics in laundry water and microplastic particles added to personal toiletry products, which account for 34.8% and 2% of global sources of primary microplastics released into the ocean, respectively[9]. Microplastics are present in textiles in the form of microfibers and are separated at every step of the textile life cycle, especially during the laundry process[9]. Evidence show that a person can release about 2.98×10^8 polyester microfibers into the water by washing, or about 1.03×10^9 polyester microfibers into the air by wearing polyester clothing every year[19]. Despite the fact that personal care products release only a small fraction (2%) of microplastics into the ocean, there have been studies that estimate the average annual release of 209.7 trillion microbeads (approximately 306.9 tons) into aquatic environments in mainland China through the average density of facial scrubs, population data, scrub usage rates, wastewater treatment rates, and some conservative assumptions[20].

Although the dumping of plastic waste is prohibited in Annex V of the *MARPOL Pollution Prevention Convention*, and Annex IV of the *MARPOL Pollution Prevention Convention* only regulates the discharge of ship sewage (black water), there is no strict control on the discharge of grey water globally. Therefore, according to the current international regulations, gray water in coastal territorial waters sailing international ships can be untreated ship gray water directly discharged into the sea[21] unless the ship is in a no-discharge zone (e.g. the Great Lakes or Alaska)[21, 22]. Domestic ships sailing within China's territorial sea can discharge ship gray water that may contain microplastics at a certain speed and discharge rate according to different distances from the land after meeting the relevant discharge standards of the "Discharge Control Standard for Ship Water Pollutants" (GB 3552-2018)[23]. However, the "Ship water Pollutant Discharge Control Standard" (GB 3552-2018) does not make clear regulations on the discharge requirements of microplastics, which shows that the impact of microplastics may be caused by the discharge of gray water from ships has not been paid enough attention, and the loose discharge policy of gray water will also cause Marine microplastics pollution.

Although the current international conventions and domestic regulations have no restrictions on the gray water discharge from ships, some countries and individual regions in China have put forward higher requirements for the gray water discharge from ships, and it will be the trend of The Times to gradually control the gray water from ships both internationally and domestically.

3. Research on microplastic components of ship gray water

At present, the source control of ship-derived microplastics mainly focuses on the plastic packaging of ship transportation, the loss and abandonment of ship facilities, and the particles of ship paint and coating[24]. However, the risk of Marine microplastic pollution in ships' grey water has been largely ignored[25]. Compared with other Marine source pollution sources, due to the challenges in sample collection and quantification of gray water emissions, qualitative and quantitative research on Marine gray water microplastics has just started, and only a few research reports have been published.

Based on the characteristics of the cruise industry, Folbert et al.[26] adopted a novel approach to identify potential sources of microplastics in cruise ship wastewater and release pathways from source to ocean. The researchers first compiled an inventory of sources of microplastics in the Marine environment based on the general scientific literature, identifying all sources and mechanisms that contribute to the release of microplastics into wastewater. Further, sources from the list that are relevant to cruise operations were selected for analysis to clarify the linkages between different wastewater streams and ultimately to identify source categories and release pathways based on the characteristics of cruise operations and facilities. While this paper fills a number of knowledge gaps regarding grey water microplastics from ships, it does not quantify microplastics in wastewater.

Mikkola et al.[27] selected five cruise ships from Finland as their research targets to construct a microplastic emission estimation model and estimate the use/production of microplastics in scenarios such as microplastic beads in personal care products, house dust and microplastic particles in synthetic textiles. The estimated results show that the abundance of microplastics in ship gray water is 2×10^6-5×10^7 /m^3, and each liter of untreated ship gray water contains 0.2-6 mg of microplastics, and 30-2000 mg of microplastics per person per day can be discharged into the sea due to gray water discharge.

Kalnina et al.[28] revealed the occurrence characteristics of gray water microplastics by using the real ship test data in their study of gray water microplastics on ships. In this study, the average content of microplastic particles in untreated and treated ship gray water was 72 per liter and 51 per liter, respectively. The identification results showed that the most common type of microplastic was fiber, accounting for about 46.4 percent of the total number of microplastics, while other hard and soft particles accounted for 36.8 percent and 16.8 percent, respectively. Through the qualitative results using attenuated total reflection Fourier transform infrared spectroscopy, it was found that the main composition types of ship grey water microplastics were polyethylene, polypropylene, polyester, polyamide and acrylic fiber.

Peng et al.[25] used statistical data to make a preliminary estimate that 323 cruise ships worldwide release 100,000 tons of microplastics into the ocean each year via gray water. Meanwhile, by monitoring seawater samples before and during the COVID-19 pandemic, the researchers further demonstrated that gray water emissions from ships contribute significantly to microfibers in the ocean, and demonstrated causality using a path model between microfibers, gray water, shipping and non-freight activities[29].

Real ship tests conducted by Jang et al.[30] on a research ship showed the highest average abundance of microplastics in the grey water of the laundry room (177,667 n/m^3), followed by the grey water of the cabin living area (133,833 n/m^3) and the kitchen grey water (75,000 n/m^3). In terms of the shape of the samples tested, fiber type microplastics accounted for 66% of the total abundance, and fragment type accounted for 34% of the total abundance. In terms of microplastic size, the content of microplastics ranging from 100 to 200 μm was the highest. The main polymer identified in all gray water samples was polyester (53%), followed by polypropylene (23%).

Some domestic scholars have also carried out exploratory research on the detection of microplastics in the gray water of ships. Li et al.[31] sampled the gray water of two tugboats and tested the pollutant content in the gray water according to the "Marine Water Pollution Discharge Control Standard" (GB3552-2018). It is estimated that more than 4.17 million microplastics are discharged by ships entering and leaving the waters of Shanghai Port every day, and 3.81 tons of microplastics are discharged into the waters of Shanghai every year.

4. Research Prospects

Under the current background of Marine environmental protection and sustainable development, Marine gray water microplastics pose a potential threat to Marine ecosystems and human health due to their small size, difficulty in degradation and easy adsorption of toxic substances. The pollution of Marine gray water microplastics has also begun to receive extensive attention from the international community. The research and control of Marine gray water microplastics is a systematic project, which requires multi-disciplinary and multi-departmental cooperation. By establishing scientific analysis methods, strengthening basic data research, compiling discharge lists, promoting policy improvement and other measures, the problem of ship gray water microplastics pollution can be effectively addressed, the Marine environment can be protected, and sustainable development can be promoted. Therefore, the research on ship grey water microplastics has important practical significance and far-reaching strategic value.

1. Build the analysis method of ship grey water composition based on real ship to ensure the accuracy and scientificity of the research.

At present, the qualitative and quantitative research on ship grey water microplastics is in its infancy, and considering the high salt working environment and special working nature of the crew, the composition of ship grey water samples is very different from that of microplastics in pure environmental media, so the traditional microplastics detection method may not be fully applicable. It is necessary to develop a set of microplastics collection and detection technology specifically for ship gray water, including sample collection, preservation, pre-treatment and analysis. This can not only improve the efficiency and accuracy of microplastics detection, but also help standardize the research process, and provide technical support for the follow-up research on the source contribution, occurrence characteristics and emission characteristics of microplastics in ship gray water in China.

2. Strengthen the research on the basic data of ship grey water microplastics, and deeply understand the characteristics of microplastics pollution.

The physical and chemical properties and microplastics content of ship gray water are affected by many factors, such as navigation characteristics, ship type, navigation area, etc. Therefore, it is necessary to establish a comprehensive and systematic microplastic factor base and composition spectrum of ship gray water by increasing the number and types of ships tested. This will help reveal the distribution law of microplastics under different ship types and sailing conditions, and provide scientific basis for risk assessment and pollution control.

3. Compile an inventory of gray water microplastics emissions from ships and assess the emission flux within shipping areas across the country.

By collecting and analyzing the dynamic and static information of different types of ships, accounting for different types of microplastics discharged from gray water by different types of coastal ships, an estimation method of gray water microplastics emissions based on the activity level of ships can be constructed, and then a national inventory of gray water microplastics emissions from ships can be compiled. This can not only provide data support for the formulation of ship gray water microplastics emission standards and control strategies, but also help to identify high-risk areas and emission sources, realize pollution source control, and support the quantified and refined management and control of ship-derived microplastics.

4. Promoting and improving relevant policies for the control of ship gray water discharge is an important guarantee for achieving Marine environmental protection

goals.

Strictly implementing the Amendment to Annex V 2016 of the *MARPOL Convention* of the International Maritime Organization (IMO) and strengthening the management of shipboard waste classification is an effective way to reduce the discharge of microplastics from ships' gray water. At the same time, it is also of positive significance to promote the amendment of Annex IV to the *MARPOL Convention* and strengthen the management of the discharge and disposal of grey water from ships. In addition, improving the domestic standards and requirements for the storage and discharge of gray water microplastics from ships, promoting legislation and supervision on the control of gray water emission from ships, and establishing a gray water emission control area as soon as possible with reference to the sulfur emission control area and nitrogen emission control area are all effective measures to achieve the control of gray water microplastics pollution from ships.

Acknowledgments

This work was supported by the Prospective Basic Project of China Waterborne Transport Research Institute (grant number 62309), and Ph. D Science and Technology Innovation Project of China Waterborne Transport Research Institute (grant number 62408).

Reference

1. Zhang, Z. Q.; Gao, S. H.; Luo, G. Y., et al., The contamination of microplastics in China's aquatic environment: Occurrence, detection and implications for ecological risk[J]. *Environ. Pollut.* **2022,** *296*.
2. Forum, W. E., *The New Plastics Economy: Rethinking the Future of Plastics.* Available at: http://www3.weforum.org/docs/WEF_The_New_Plastics_Economy.pdf. (Accessed 5 Jan. 2023).
3. Chen, C. F.; Ju, Y. R.; Lim, Y. C., et al., Microplastics and their affiliated PAHs in the sea surface connected to the southwest coast of Taiwan[J]. *Chemosphere* **2020,** *254*.
4. Thompson, R. C.; Olsen, Y.; Mitchell, R. P., et al., Lost at sea: Where is all the plastic?[J]. *Science* **2004,** *304*, (5672), 838-838.
5. Thushari, G. G. N.; Senevirathna, J. D. M., Plastic pollution in the marine environment[J]. *Heliyon* **2020,** *6*, (8), e04709.
6. Yu, J.; Tang, D. L.; Wang, S. F., et al., Spatial Distribution and Composition of Surface Microplastics in the Southwestern South China Sea[J]. *Frontiers in Marine Science* **2022,** *9*.
7. Climo, J. D.; Oswald, S. B.; Buschman, F. A., et al., Inland Navigation Contributes to the Remobilization of Land-Based Plastics Into Riverine Systems[J]. *Frontiers in Water* **2022,** *4*.
8. Huang, Y.; Chen, M. L.; Wang, Z., et al., Impacts of terrestrial input on the distribution characteristics of microplastics in the East China Sea characterized by chromophoric dissolved organic matter (CDOM) analysis[J]. *Sci. Total Environ.* **2022,** *838*.
9. Boucher, J.; Friot, D., Primary Microplastics in the Oceans: A Global Evaluation of Sources[B]. **2017**.
10. Liu, A.; Han, J.; Zhang, A., Ship Microplastic Pollution and Prevention Countermeasures (in Chinese)[J]. *China Maritime Safety* **2020**, (11), 36-38.
11. Xue, Q.; Chen, R., Research on the Problems and Countermeasures of Marine Pollution from Ship-sourced Microplastics (in Chinese)[J]. *Energy Conservation & Environmental Protection in Transportation* **2021,** *17*, (86), 33-36.
12. Ministry of Transport, Statistical Bulletin on Development of Transport Industry in 2022 (in Chinese). **2023**.
13. MEPC, Resolution MEPC.159(55) revised guidelines on implementation of effluent standards and performance tests for sewage treatment plants. **2006**.
14. Lv, X.; Dong, Q.; Zuo, Z., et al., Microplastics in a municipal wastewater treatment plant: Fate, dynamic distribution, removal efficiencies, and control strategies[J]. *J. Clean. Prod.* **2019**.
15. Prata; Correia, J., Microplastics in wastewater: State of the knowledge on sources, fate and solutions[J]. *Mar. Pollut. Bull.* **2018,** *129*, (APR.), 262-265.
16. U.S. EPA, Cruise ship discharge assessment report[R]. **2008**.
17. Ytreberg, E.; Eriksson, M.; Maljutenko, I., et al., Environmental impacts of grey water discharge from ships in the Baltic Sea[J]. *Mar. Pollut. Bull.* **2020,** *152*.
18. GESAMP, Sea-based sources of marine litter[R]. **2021**.http://www.gesamp.org/work/groups/wg-43-on-sea-based-sources-of-marine-litter.
19. Belzagui, F.; Crespi, M.; Alvarez, A., et al., Microplastics' emissions: Microfibers' detachment from textile garments[J]. *Environ. Pollut.* **2019,** *248*, 1028-1035.
20. Cheung, P. K.; Fok, L., Characterisation of plastic microbeads in facial scrubs and their estimated emissions in Mainland China[J]. *Water Res.* **2017,** *122*, 53-61.
21. International Maritime Organization, *International Convention for the prevention of pollution from ships (MARPOL 73/78). (London: International Maritime Organization).* **1978**.
22. USEPA, Graywater discharges from vessels. https://nepis.epa.gov/Exe/ZyPDF.cgi/P100ZVHG.PDF?Dockey=P100ZVHG.PDF.
23. Ministry of Environmental Protection of China ＆ China General Administration of Quality Supervision, Standard for Control of Discharge of Water Pollutants from Ships (in Chinese). **2018**.

24. International Maritime Organization, *Progress report of the GESAMP Working Group on Sea-based Sources of Marine Litter Note by the Secretariat. MEPC 75/8. 2020.* **2020**.
25. Peng, G. Y.; Xu, B. L.; Li, D. J., Gray water from ships: A significant sea-based source of microplastics?[J]. *Environ. Sci. Technol.* **2022,** *56*, (1), 4-7.
26. Folbert, M. E. F.; Corbin, C.; Lohr, A. J., Sources and Leakages of Microplastics in Cruise Ship Wastewater[J]. *Frontiers in Marine Science* **2022,** *9*.
27. Mikkola, O. Estimating microplastic concentrations and loads in cruise ship grey waters. Master's thesis. Aalto University, **2020**.
28. Kalnina, R.; Demjanenko, I.; Smilgainis, K., et al., Microplastics in ship sewage and solutions to limit their spread: A case study[J]. *Water* **2022,** *14*, (22).
29. Peng, G.; Mengeot, C.; Jiang, C., et al., Microfiber Hotspots' Association with Ships in a Remote Port before and during Covid-19[J]. *ACS Es&t Water* **2023,** *3*, (5), 1275-1285.
30. Jang, Y. L.; Jeong, J.; Shim, H. W. J., Occurrence and characteristics of microplastics in grey water from a research vessel[J]. *Environ. Pollut.* **2024,** *341*, (Jan.), 122941.1-122941.8.
31. Li, Y.; Li, J.; Li, S., Study on the control of microplastics in ship grey water and grey water (in Chinese)[J]. *China Ship Survey* **2023**, (05), 60-65.