Wastewater pollution from cruise ships in coastal sea area of the Republic of Croatia

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ABSTRACT

Marine pollution from wastewater is a problem especially pronounced on large cruise ships. There is a great disproportion in quality of discharged wastewater directly related to the type of wastewater treatment system installed on cruise ships. To obtain exact empirical data case study was done which included one-year monitoring of cruise ships in the Adriatic Sea, their routes and retention times in defined navigation zones. The aim of this paper is to present data related to the coastal sea area of the Republic of Croatia and display results of marine pollution for that area. The scientific contribution of the research can be recognized in the evaluation of pollution of coastal areas in the Republic of Croatia in different scenarios of wastewater discharge and identification of gray water as a pollutant which is not recognized by the international legal regulations.

1 Introduction

Previous studies in the world have proven that sanitary wastewater has negative impact on the marine environment. The problem is particularly pronounced on large cruise ships where the number of persons on board reaches 8000. To evaluate the contamination of a specific sea area with sanitary wastewater from cruise ships two original models have been developed: a model of movement of cruise ships in the Adriatic Sea [Perić, Komadina, Račić, 2016: 430] and evaluation model of sanitary wastewater pollution from cruise ships in the Adriatic sea [Perić, 2016: 54]. The purpose of this paper is to present the results of the pollution of coastal areas of Republic of Croatia for a period of one year provided with use of above models.

2 Research analyses

Detailed research of cruise ship traffic in the Adriatic sea was done by monitoring cruise ships in the Adriatic Sea in one year period (1.8.2014 – 31.7.2015) in which empirical data on the routes of the ships in the Adriatic and their retention times in MARPOL1 Annex IV areas of limited wastewater discharges were obtained.

For the purpose of this scientific research paper empirical data on retention times in the coastal area of the Republic of Croatia was selected. Also, sanitary wastewater properties, international legal regulations and quality and quantity of generated wastewater on cruise ships were analyzed.

2.1 Wastewater on ships

Wastewater on cruise ships are generated in large quantities. Therefor, method of wastewater management on board and the quality of wastewater discharged into the sea is very important. Wastewater on ships can be divided into sanitary and bilge waste water. Sanitary wastewater, for more efficient treatment and disposal, are divided into black water and gray water. Black water may host many pathogens of concern to human health, including Salmonella, shigella, hepatitis A and E, and gastro-intestinal viruses. Sewage contamination in swimming areas and shellfish beds pose potential risks to human health and the environment by increasing the rate of waterborne illnesses [United States Environmental Protection Agency, 2008: 2–26].
Table 1 Comparison of quality of discharged sanitary wastewater due to type of wastewater treatment system and their operation mode

<table>
<thead>
<tr>
<th>Sanitary wastewater pollutants</th>
<th>MSD</th>
<th>AWT</th>
<th>Annex IV quality criteria for coastal sea area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treated black water</td>
<td>Untreated gray water</td>
<td>Treated black and gray water</td>
</tr>
<tr>
<td>Faecal Coliforms FK/100 ml</td>
<td>2,040,000</td>
<td>36,000,000</td>
<td>14.5</td>
</tr>
<tr>
<td>BOD₅ mg/l</td>
<td>133</td>
<td>1,140</td>
<td>7.99</td>
</tr>
<tr>
<td>TSS mg/l</td>
<td>627</td>
<td>704</td>
<td>4.49</td>
</tr>
<tr>
<td>Chlor residual µg/l</td>
<td>1,070</td>
<td>372</td>
<td>338</td>
</tr>
</tbody>
</table>

\* dilution compensation factor \( Q/Q_i \) is used to take account of dilution, where \( Q \) is influent, liquid containing sewage, gray water or other liquid streams and \( Q_i \) is effluent, treated wastewater produced by the sewage treatment plant.


Gray tank chemicals contain an array of pollutants from the highly chemical (bleach, strong acids from some cleaning products giving water high pH) or strong alcalis (including many detergents, phosphates, whiteners, and foaming agents giving water low pH), to oil and grease, suspended solids and organic particles. In addition, degreasers found in washing up liquids and soaps strip the natural oils from fish gills making it difficult for them to breathe [Hoskins, 2011: 1]. In addition, researches have proven that untreated graywater contains bacteria and suspended solids concentrations equal to or exceeding blackwater [Eley, Morehouse, 2003: 748].

If large quantities of wastewater and waste matter are brought to water systems, particularly semi-closed and closed water systems, the amount of nutrients (nitrogen and phosphorus) substantially increases which increases primary production (phytoplankton). However, there is no increase in consumption which may result in water system becoming eutrophic [Tušar, 2009: 30].

Regarding the criteria for discharge of sanitary wastewater, Annex IV of MARPOL Convention divides the sea into four zones:
- Port/anchorage – zone 1,
- Sea area at distance less than 3 M from the nearest land – zone 2,
- Sea area at distance 3-12 M from the nearest land – zone 3 and
- Sea area beyond 12 M from the nearest land – zone 4.

For each of these zones Annex IV defines quality criteria for discharged sanitary wastewater from ships. The are two types of sanitary wastewater treatment systems available: marine sanitation device, MSD and advanced wastewater treatment system, AWT. MSD handles only black water while in AWT systems black and gray water are collected and processed together. Table 1 shows a comparison of quality of discharged sanitary wastewater from the treatment system considering quality criteria and minimum requirements of MARPOL Convention for the coastal area of the sea.

Table 1 shows that treated black water from MSD has about 2 million faecal coliform while treated sanitary wastewater from AWT plant has 14.5 faecal coliforms. The values of other quality factors of sanitary wastewater are also several times higher at the exit of the MSD compared to the output from the AWT system. It can be concluded that there is great disproportion in quality of discharged wastewater directly related to the type of wastewater treatment system installed on cruise ships. However, it is important to emphasize that the requirements of Annex IV refer only to black water while discharge of grey water has no limitations despite the fact that quality of discharged untreated grey water exceeds quality factors of treated black water in both systems.

2.2 Case study analyses

For the purposes of this paper the coastal sea area includes internal waters and the sea area at a distance less than 3 M from the nearest land (zone 2) shown in Figure 1. The light gray area marks the sea area at a distance less than 3 M from the nearest land and the dark gray area marks sea area 3 M from the baseline that divides the internal waters and territorial sea of the Republic of Croatia.

The results of the case study gave information on the retention time of ships in ports and in areas of limited discharge of sanitary wastewater in accordance with Annex IV of MARPOL Convention.

In the year of monitoring 63 cruise ships carrying 500 or more passengers arrived in the Adriatic Sea. Out of the 34 world cruise companies (refers to cruise companies that have two or more cruisers with passenger capacity of 500 or more), mentioned ships represent 26 of them. During their stay in the Adriatic, cruisers had 21 different ports of call, of which eleven Croatian: Dubrovnik, Split, Zadar, Korčula, Hvar, Šibenik, Hvar, Trogir, Pula and Supetar. Port of call number, retention time in port/anchorage and in the corresponding zone 2 in function of wastewater treatment system installed on cruise ships is given in table 2.

From mentioned 63 cruise ships, only two did not have Croatian ports of call in their itinerary. Cruise ships
had Croatian ports as port of call 552 times and they have spent 5193 hours in Croatian ports and 1286 hours in the coastal sea area. Distribution of retention time in ports and in zone 2 is shown in Figure 2.

From the presented retention times in Croatian ports and in zone 2 and with the knowledge of the average number of people on each of the ships in the observed research year, generated black water, GCV and generated
gray water, GSV is calculated according to the following formula [Perić, 2016: 57]:

\[
GCV = \frac{K \cdot F_{CV} \cdot t}{1000} [m^3]
\]

\[
GSV = \frac{K \cdot F_{SV} \cdot t}{1000} [m^3]
\]

where:

- \(GCV\) is generated black water
- \(GSV\) is generated gray water
- \(K\) is average number of persons on the ship,
- \(F_{CV}\) is black water constant and it is 1,325 l/person/h,
- \(F_{SV}\) is black water constant and it is 10,54 l/person/h,
- \(t\) is retention time in sea area [h].

3 Results of wastewater pollution in different operational modes

Generated gray and black water can be discharged arbitrarily if minimum requirements of Annex IV are respected. It means that there is a range of various operational modes i.e. scenarios that can be used while discharging wastewater which are simulated using evaluation model of wastewater pollution [Perić, 2016: 59] and are summarized below.

In all scenarios ships with AWT plant discharge treated wastewater continuously while ships with MSD store their black water in holding tanks (treated black water with MSD does not meet Annex IV requirements for discharge). Changes in the scenarios are therefore only in discharge of untreated gray water on ships with MSD system. Following scenarios where simulated:
- Scenario 1: gray water is discharged continuously in the port/anchorage and in the zone 2
- Scenario 2: gray water is not discharged in port/anchorage while the ship is stationary and is stored in holding tanks. Discharge begins with departure of the ship in zone 2.
- Scenario 3: gray water is not discharged neither in port/anchorage nor in zone 2. It is stored in holding for discharge in zones 3 and 4.

Regarding treatment system installed on ships, AWT to MSD ratio is 54.4:46.6 in percentage of total retention time in Croatian ports. The ratio of retention time in the zone 2 is 54.2 % of the time for AWT. Regarding the amount of generated wastewater, ratio is again on the side of AWT, even in a higher percentage (55.8 % in the port and 54.3 % in zone 2) as ships with AWT generally have bigger capacity. The distribution of generated wastewater according to the area of navigation and wastewater treatment system is given in Table 3.

After calculation of generated wastewater for each scenario quantity and quality of discharged sanitary wastewater is calculated according to area of navigation and an overview is given in Figures 3 and 4.

From Figure 4, it can be concluded that the quality of discharged wastewater after treatment with AWT system which is presented in scenario 3 (since in this scenario, there are no discharges from MSD) is satisfactory and is insignificant in comparition with the quality of discharged untreated gray water from the MSD.

Previous studies have already concluded that untreated gray water has negative impact on the environment if released near the coast, and with the evaluation model application in this paper that was only confirmed.

4 Conclusion

Sanitary wastewater has negative impact on the environment. It has been shown that there is disproportion in the quality of discharged wastewater depending on the treatment system installed on cruise ships. This paper demonstrated that ships with AWT system have minimal impact on the environment regarding wastewater pollution.

Legal regulations recognize only black water as a contaminant. Research results have also proven that pollution...
Figure 3 Quantity of discharged wastewater in port and zone 2 following defined scenarios

Figure 4 Quality of discharged wastewater in port and zone 2 following defined scenarios

In ports and coastal areas, wastewater is not coming from the black water but from gray water, which is not recognized as a pollutant in the MARPOL Convention. It is therefore considered necessary to introduce legislative measures limiting the discharge of untreated gray water into the ports and sea area up to 3 M from the nearest land.

Future research on this subject should focus on establishing limits of wastewater pollutants for specific sea areas that ships should not exceed in order to protect marine environment and also on the cumulative effect of marine pollution by wastewater that includes other ship types and land-based pollution.

References


