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Numerical and experimental investigation on the ballast flushing system

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ABSTRACT

The ballast sediments deposit not only provide the breeding ground for the survival organisms, but also affect the weight balance of the ship and even accelerate the corrosion of the ballast tank. In this work the performance of a ballast water flushing system for the 138,000 m^3 LNGC (Liquefied Natural Gas Carrier) double bottom cargo ship is studied. A simulation model of the ballast tank was made to conduct the numerical analysis. Besides, a scaled experimental setup was established on basis of the similarity principle. With different injecting velocities at the flushing inlet, the sediments distribution in the ballast tank is investigated and the energy consumption of the circulating pump is studied. The results show that by flushing the ballast water on the bottom, the sediments first accumulate at the far end, with the sediments volume fraction climbs up to 10–30%, before gradually getting removed over time. Further, higher inlet velocity leads to a more rapid decrease of average sediments proportion in the ballast tank over time, but the energy consumption in circulating pump significantly increases as well. The required power for this proposed ballast water flushing system is within the common range and thus applicable in the cargo ship.

1. Introduction

Negative environmental impacts made by the uptake and discharge of ballast water are great challenge for international shipping. The non-indigenous species (NIS) transported in the ballast tank may cause harm to native ecosystems (Djoghlaf; Scriven et al., 2015) and these invasive species can even contribute to animal extinctions in local area (Molnar et al., 2008; Shiganova, 1998; Pearce, 1995). In response to this challenge, the International Maritime Organization (IMO) instituted a performance standard of “Regulation D-2” for ballast water treatment management (Doblin and Dobbs, 2006; Učur, 2011; Čulin and Mustać, 2015). In this regulation, limitations on both the size and the quantity of the remained organisms in the treated ballast water are made to exclude microbes and viable microorganisms from discharged ballast water (Werschkun et al., 2014). To meet the requirement of the IMO convention, different sorts of ballast water management technologies including oxidation by chlorine/ozone and the ultraviolet radiation (UV) method are proposed by researchers.

Although dozens of shipboard treatment systems have been certified as meeting ballast water discharge standards till now, their application in eliminating invasive species is not that satisfactory (Cohen and Dobbs, 2015; Dobroski et al., 2015.). It should be noted that only the maximum amount of living organisms is restricted according to Regulation D-2, nevertheless, the remaining sediments in the ballast water is still not concerned. Studies in references (Darby, 1997; Maglić et al., 2016) pointed out that the soil sediments mainly consist of the clay, silt and sand, with the particle diameter from less than 2 μm to 2 mm. Moreover, these soil sediments are admitted with ballast water during the ballasting. Although most of the large-size organisms (> 10 μm) gets inactivated according to Regulation D-2, a tiny fraction of organisms cannot be totally removed from the loaded ballast water, and these soil sediments turn to be the perfect breeding ground for the survival organisms (Kremp and Anderson, 2000; Itakura and Yamaguchi, 2001; Figueroa et al., 2006).

In fact, providing the habitat for organisms is only part of negative impacts that the ballast water sediments could induce. On one hand, it is found that The sediments at the bottom of the ballast tanks in a double hull cargo vessel can accumulate up to 30 cm depth within only two years operation (Hamer et al., 2000). According to current Rules and Regulations of respective Classification Societies, sediments in ballast water tank can only be systematically removed during the mandatory dry docking, and the interval is usually made in every five years (Prange, 2013). With such a long period of time the sediments tend to be compacted and the sediments removing work becomes a great challenge. On the other hand, the ballast sediments also affect the weight balance of the ship. Due to non-uniform distribution in the ballast tanks, the loading and unloading of ballast have to be cautious, because the excessive stresses can potentially lead to a ship breaking

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during incorrectly unloading (Eames et al., 2008).

Furthermore, the corrosion of the ballast tank is another negative impact induced by the ballast sediments. The sulphate reducing bacteria (SRB) and acid producing bacteria (APB) that living in the sediments can bring significant microbiologically influenced corrosion (MIC) (I.A.o.C.S. (IACS), 2006; Stipaničev et al., 2013). Compared with the electrochemical oxidation process, the corrosion speed of MIC is greatly accelerated and thus unpredictable.

This paper proposed a solution for this problem. With the flushing system, the unfiltered sediments along with the regrown organisms can be removed when needed.

In this paper, a ballast water flushing system is proposed. By circulating the ballast water in the tank, the deposits of sediments can be suspended and removed before getting compacted on the tank bottom. A simulation model of the ballast tank was made; an experimental setup was established on basis of the similarity principle. Further, with four different ejecting velocities, both numerical and experimental studies were conducted to evaluate the performance of this flushing system.

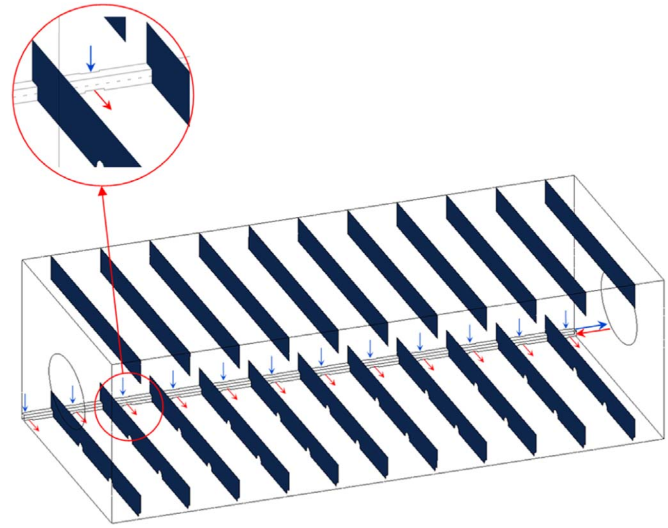

Fig. 2. Ballast tank model for simulation.

2. System description

In this work the ballast water system of the 138,000 m^3 LNGC (Liquefied Natural Gas Carrier) double bottom cargo ship (Lee et al., 2005) is investigated. The volume of cargo ballast water system takes up to 56,090 m^3 in total. Fig. 1 shows the structure of a single block of ballast tank in the cargo ship. As is shown, lines of longitudinal are arranged on the inner side of the ballast tank and drain holes are provided on the bottom longitudinal. Besides, the ballast water pipes (inlet-pipe and outlet-pipe) are arranged in the corner, on which a row of jet holes (inlets) are placed along the inflow-pipe while a row of exit holes (outlets) are placed along the outflow-pipe. Besides, a hydrocyclone (Pazouki, 2012) is introduced between the outflow-pipe and the circulating pump to separate the sediments from the ballast water. The size of a single block of ballast tank is $6700 \times 3000 \times 2000(mm)$, and the size of inlets/outlets on the ballast water pipes is $100 \times 10(mm)$.

With the assistance of the circulating pump, the ballast water is first pumped into the inflow-pipe and then ejected through the inlets, and in this way the deposits of sediments are stirred up. Further, the suspended sediments, along with the ballast water, get sucked into the outflow-pipe through the outlets. Then the mixture of water and sediments is separated in the hydrocyclone before pumped back into the ballast tank. As ballast water flows into the hydrocyclone, a cyclonic flow is produced and the centrifugal force drives the sediments toward the outer wall, so the clean water can flow through the centre of the hydrocyclone into the circulating pump. Thus the ballast water circulates around the ballast tank and the bottom sediments deposits are suspended and then removed from the ballast water.

3. Simulation setup

The numerical model for the ballast tank consists of a row of inlets along the inflow-pipe, a row of outlets along the outflow-pipe and longitudinal with drain holes on the inner side of the tank, as shown in Fig. 2.

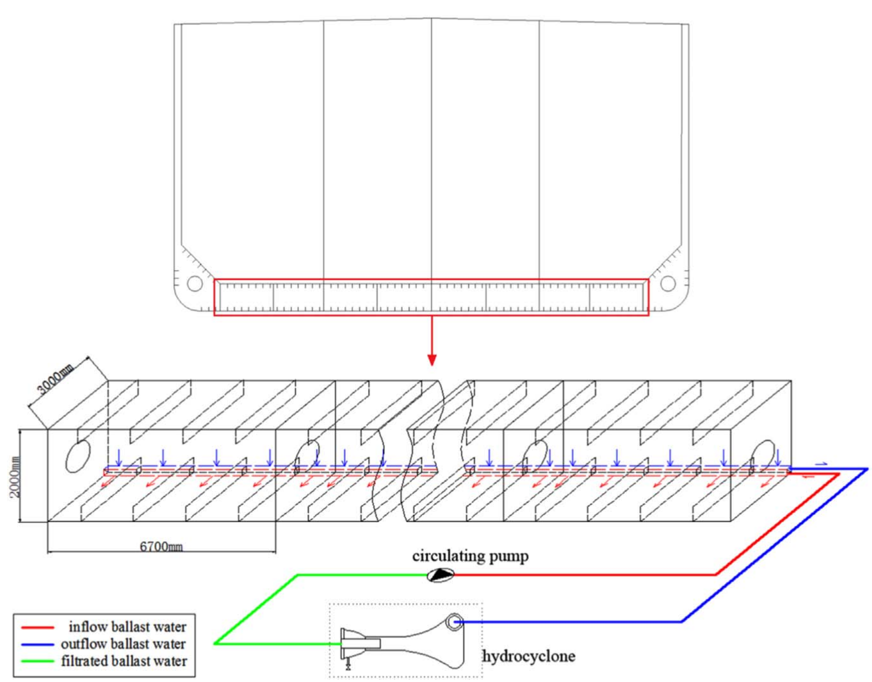

Fig. 1. Schematic of ballast water flushing system.

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