

Introduction

The rise in global warming is increasing sea surface temperatures and changing the properties of seawater. Due to the changes in the marine ecosystem, the biological structure of the seas has changed. With increasing seawater temperature, insufficient treatment of domestic and industrial wastes, and excessive fishing, sea algae in the area grows extremely and causes mucilage (Ozdelice et al., 2021). Mucilage, marine snow, or sea snot is a mucosal organic substance that can be found in the sea and is a product of sea algae (Precali et al., 2005). Recently, this phenomenon occurred in the Sea of Marmara, and mucilage concentration increased. An excessive amount of mucilage crippled the marine environment and also clogged fishers' nets (Hekimoğlu & Gazioğlu, 2021).

According to Topçu & Öztürk (2021), the latest mucilage outbreak occurred in the 2020 autumn and lasted until the summer of 2021. After the mucilage pandemic in the Marmara Sea in 2020, several studies were undertaken. A study is made by Hekimoğlu & Gazioğlu (2021) about mucilage issues in closed seas and the Sea of Marmara. In the study, the impact of mucilage on industries, the environment, fishing, and tourism is investigated. In addition, intense mucilage production in the Sea of Marmara is investigated. According to the authors, the marine ecosystem has altered as a result of the mucilage outbreak, and previously unknown species have taken over. Also, Acarlı et al. (2021), Özalp (2021) and Ozdelice et al. (2021) made similar studies on changing ecosystems due to mucilage outbreaks. Mucilage outbreaks in the Dardanelles impact surface organisms and endanger the coral ecosystem, which is located 39-51 meters down in the water (Özalp, 2021).

Tas et al. (2021) stated that mucilage has been a big concern in the Sea of Marmara since 2004, and it has gotten much worse since then. Mucilage events and potentially hazardous species in the Marmara Sea were investigated as part of the analysis. The study looked at phytoplankton composition and physicochemical factors from January 2004 to December 2007. In addition, another research on mucilage events and their consequences on cyanobacteria habitat was made in 2008 by obtaining seawater samples from the Sea of Marmara. According to their findings, cyanobacteria development peaked in November 2007 in both the Gulf of Bandırma and the Erdek (Alicli et al., 2020). However, cyanobacteria formation was the lowest in the Gulf of Bandırma in February 2008 and Erdek in May 2007. Furthermore, cyanobacteria abundance rose in the top layers of the water, but it was limited in the deeper levels because the density of mucilage changes with depth,

temperature, and pollution of the water (Tüfekçi et al., 2010). Also, in a study made by Yentur et al. (2013), it was reported that precipitation, wind speed, and sudden temperature changes affect mucilage formation.

Considering the intended use of seawater for ships, it plays an important role in the ship's cooling system. Another drawback mucilage brought into our lives is its negative effects on marine vessels, which are highlighted by Uflaz et al. (2021). A large amount of mucilage clogs the sea chest filters by preventing the liquid entry of the cooling system used to cool the ship machinery groups. It causes inefficiency by affecting the cooling system components and getting the ship machinery to operate with low performance. Thus, fuel oil consumption and exhaust emissions increase. Considering the International Maritime Organization's (IMO) recent targets of reducing Greenhouse gases (GHG), inefficient ship operation is not desired.

Material and Methods

Various studies were made about mucilage incidents in the Sea of Marmara, especially on its ecological effects, tourism, and fishing. However, there is a vast gap in the effect of mucilage on shipping. In this paper, a short review of the impact of mucilage on pumps, filters, and heat exchangers is examined. Furthermore, the malfunction of the ship's main engine and auxiliary systems due to lack of cooling is investigated.

General Overview of Cooling Systems on Ships

Due to the working principles of the machinery systems functioning on the ships, they need cooling to reduce the heat generated. The section where seawater is used for cooling water systems is supplied is defined as sea chests. Sea chests are designed as both high and low sea chests. According to the level of the water in which the ship is cruising, one sea chest is kept open, and the other is kept ready to be used as clean. Thus, when marine pollution or living organisms contaminate the filters in the sea chests, the cooling process is continued by using the spare. Conventional or central cooling systems are widely used in the maritime industry.

Conventional cooling water systems

In the conventional seawater system, seawater is preferred as the coolant in the main engine (M.E.) jacket water coolers, air coolers, lube oil (L.O.) coolers, auxiliary engines (A.E.) coolers, air condition (A.C.), and refrigeration. The types of coolers in the system are generally tubular-type coolers.

Seawater pumps on the cooling water system provide water circulation.

Central cooling water systems

The central cooling water system includes low-temperature freshwater (LTFW) coolers and a high-temperature freshwater (HTFW) cooler. Due to the system principle, seawater is only used for cooling in the LTFW cooler. However apart from cooling, seawater is used for freshwater production, ballast operations, and fire system. Cooling of engine room system components such as M.E. air coolers, L.O. coolers, A.E. coolers, A.C., refrigeration, and HTFW coolers is carried out with low-temperature freshwater from LTFW coolers. The central cooling water system and its components are demonstrated in Figure 1 briefly.

According to the circuit diagram in Figure 1, there are LTFW pumps in the system. The task of these pumps is to circulate the low-temperature fresh water in the system and feed the other coolers. In addition, an expansion tank is placed in the system to eliminate water leaks that may occur in the system and prevent the water from expanding due to the increase in temperature and damaging the system components. The main purpose of the LTFW coolers, which are the main components of the central system and perform the cooling of all coolers, is to keep the system temperatures at the optimum levels determined by the manufacturers. Another vital piece of equipment in the system is the HTFW coolers. HTFW's task is to provide cooling of the main engine jacket water. HTFW pumps supply water circulation to keep the cooling efficiency of the main engine at maximum. Together with the pre-heating system placed on the HTFW coolers, the main engine keeps the jacket waters warm at the standby position of the vessel and ensures that it is ready for operation. To get maximum efficiency from the system's features, freshwater is produced from seawater in the fresh water generator by using the waste heat of the HTFW that completes the cooling process in the main engine.

Engine Room Simulator

The purpose of the engine room simulator (ERS), including actual ship features, is to make realistic analyses of the main engine and other systems in maritime training processes. ERS is also often preferred for examining and testing targeted situations used in academic studies (Rubio et al., 2018; Stavinuk et al., 2021). ERS was used for a fuel-water emulsion operating system to reduce exhaust gas emissions for a ship engine (Laskowski et al., 2015). In addition, another study examined

the effect of shaft generators on ship energy efficiency using ERS (Yutuc, 2020). Furthermore, ERS systems are widely preferred in academic studies in the field of education as well as technical studies (Shen et al., 2017; Ivanov et al., 2020; Dere et al., 2022).

Case Study

In this study, the impact levels of cooling water and other mechanical systems due to mucilage of a ship using narrow waterways were simulated using ERS developed by Kongsberg. The Kongsberg ERS used in the study was approved by Det Norske Veritas (DNV), which is a classification society. Specifications of the ship used in the Kongsberg ERS can be seen in Table 1.

Table 1. Specifications of the ship

Ship Type	Container
Cylinder bore	840 mm
Piston stroke	2,400 mm
Cylinders	12 pcs
Maximum continuous rating	48,600 kW
Corresponding speed	102 RPM
Mean indicated pressure	17.9 bar
Scavenge air pressure	2.4 bar
Turbocharger speed	9,500 RPM
Specific fuel oil consumption	171 g/kW
Draught	12.6 m
Deadweight	55,000 tonnes
Design Speed	25 knots

During the case study, four scenarios are observed using the ERS. The four scenarios are 0% (no pollution), 30%, 45%, and 60% pollution in the filter of the seawater pump. The percentages represent the clogging of the filter in terms of flow rate. In the base case, the scenario flow rate is 2130.16 ton/h and decreased to 871.58 ton/h and 609.28 ton/h at 30% and 45%, respectively.

First, the pressure and temperature values of the engine systems (pumps and other equipment) are observed in the case of 0% pollution. In the next stage, the pollution level is increased by 30%. Thus, changing values under different conditions can be analyzed when contamination starts and progresses. In another scenario, the pollution has increased to 45%. Critical temperature and pressure values are obtained for the ship with this pollution rate, and its effects can be monitored. Finally, 60% of pollution, which is the highest point, is applied, and system efficiency is examined.

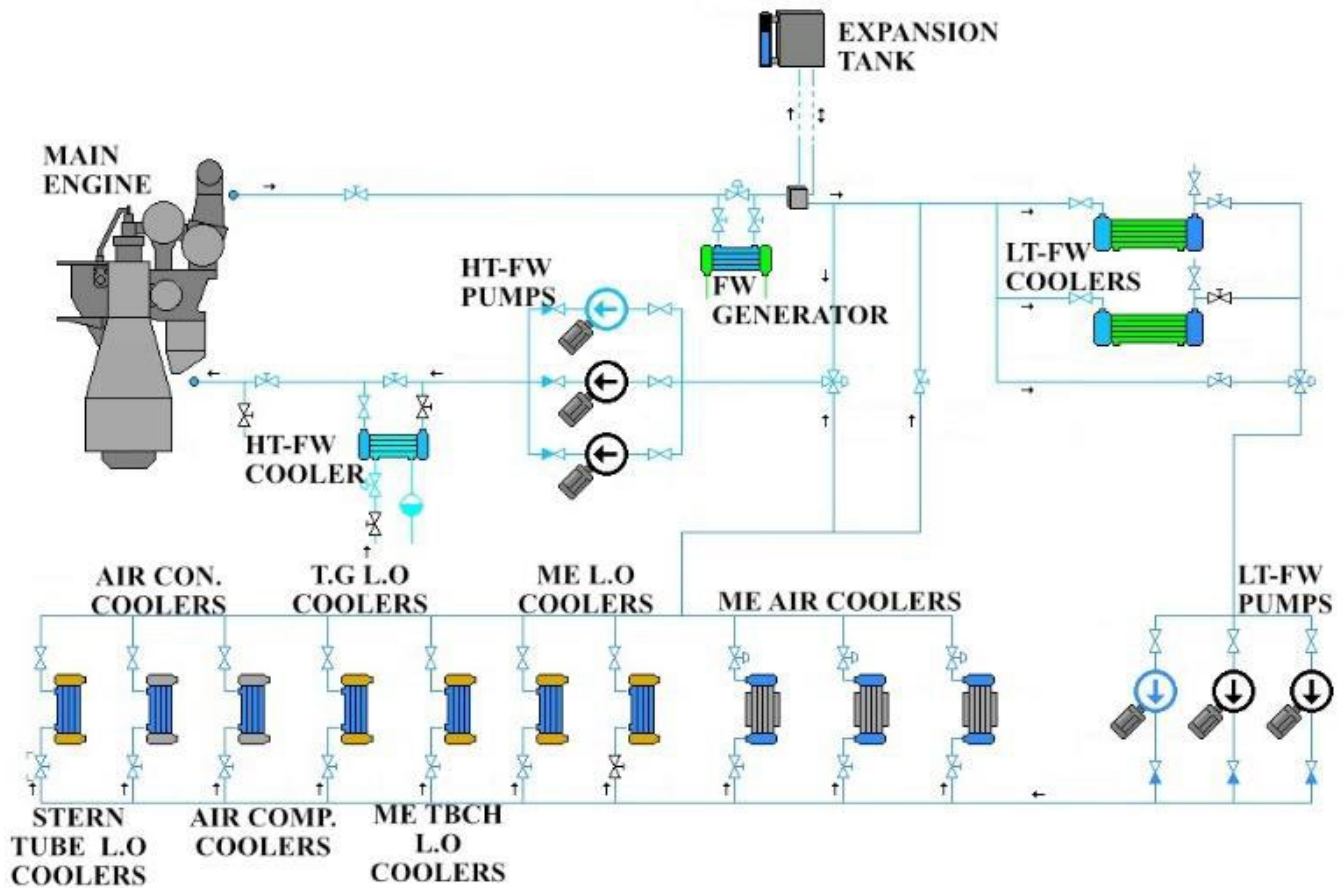


Figure 1. Central cooling water system

Results and Discussion

The data gathered from the simulator are shown in Figures 2-4. The results indicate that the ship has been affected by the increased mucilage formation in the Sea of Marmara. 60% of pollution scenarios are not included in the figures. That is because seconds after the scenario was created and clogging occurred, the main engine automatically slowed down itself due to high freshwater temperatures leaving the LTFW cooler.

The first remarkable change occurred in the high suction sea chest filter, as can be seen in Figure 2. The pressure difference in the filter has increased by a quiet margin, which indicates that the filter is partially clogged. Low suction sea chest filter pressure was zero since the high suction sea chest valve was open and the low suction sea chest valve was closed. Even though the seawater temperature has not changed, LTFW cooler seawater outlet temperature is increased because of insufficient seawater flow due to a clogged filter, which also demonstrates the reason for increased freshwater temperature leaving the LTFW cooler. Another indicator of a clogged filter is lower seawater pump discharge pressure and main seawater supply pressure. Although the 30% and 45% cases pressure are

barely changed, a change between the base and 30% cases can be seen in Figure 2.

As shown in Figure 3, the clogged filters directly increase the freshwater outlet temperature of the LTFW cooler and affect the M.E. air cooler, M.E. L.O. cooler, M.E. turbocharger (TBCH) L.O. cooler, air compressor cooler, and stern tube L.O. cooler. M.E. air cooler freshwater outlet temperature is 38.22°C in the base scenario, 43.47°C in 30%, and 52.08°C in the 45% scenario. This increase also affected the M.E. air cooler air outlet temperature and the M.E. scavenge temperature. The same principle applies to the M.E. L.O. cooler; the freshwater temperature of the cooler increases and the L.O. outlet temperature is increased from 40.10°C to 46.67°C and 53.99°C, for 30% and 45%, respectively. Another affected component is the M.E. TBCH L.O. cooler. As shown in Figure 3, M.E. TBCH L.O. cooler freshwater, both inlet, and outlet temperature are increased. Moreover, the freshwater temperature of the air compressor rises from 32.56°C to 38.47°C and 46.96°C for 30% and 45% scenarios. The final component affected by the freshwater leaving the LTFW cooler is the stern tube L.O. cooler. In the base case scenario, the L.O. in the stern tube L.O. cooler is 32.78°C, while in 30% and 45%, it increases to 38.56°C and 46.54°C, respectively.

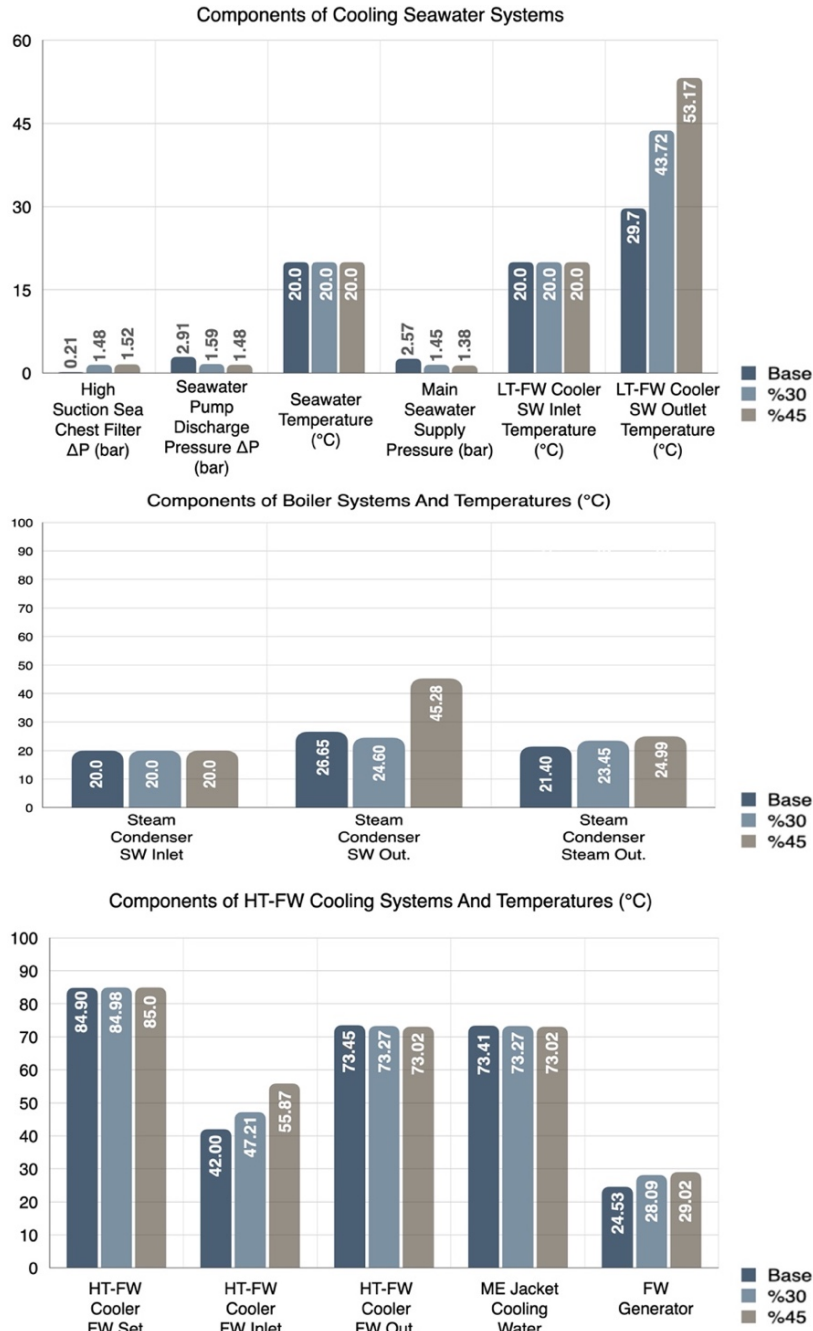


Figure 2. Effects of different pollution scenarios on ship machinery systems

HTFW is another affected cooling system. As shown in Figure 2, only the HTFW cooler inlet temperature and freshwater generator temperature are changed. However, HTFW cooler freshwater temperature and M.E. jacket water are not changed. The reason for the unchanged temperature is a mixture of LTFW and fresh water, leaving the freshwater generator mixed with a three-way valve, and then the mixture is heated in a preheater. By decreasing the load of the preheater, HTFW temperature can be decreased. On the other hand, HTFW cooler inlet temperature increases as the LTFW temperature increases.

In Figure 4, diesel generator (DG) shaft power for each scenario can be seen. In the base case, power output is 1501.4 kW, and in %30 and %45 it is decreased to 1454.18 kW and 1440.86 kW, respectively. It indicates that to generate the same power higher fuel consumption is needed.

Conclusion

A simulator study has been made about the effects of clogged seawater filters and pumps on a ship's energy efficiency and cooling system. Even though the temperature of the seawater used for cooling has not changed, the freshwater temperature

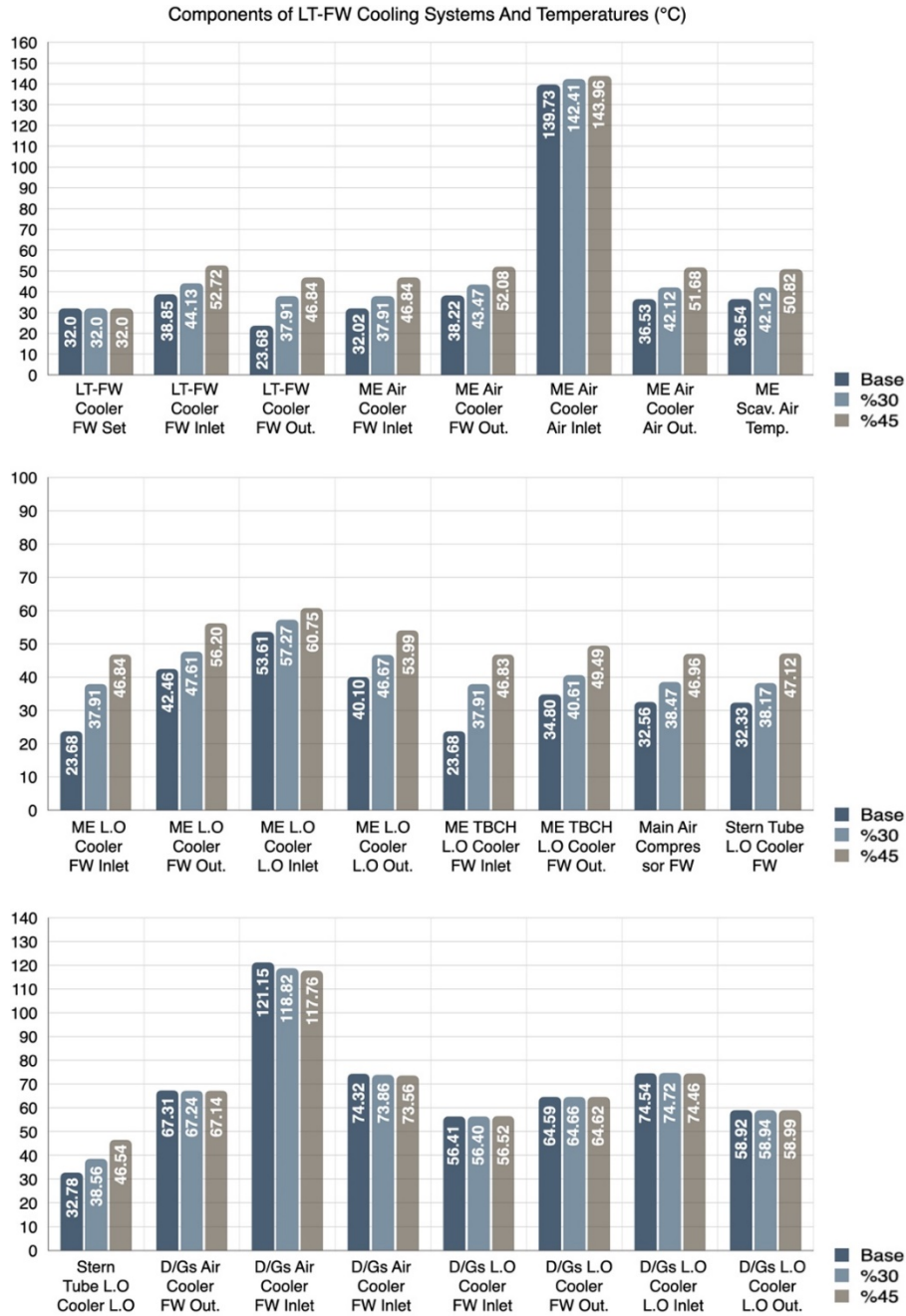


Figure 3. Effects of different pollution scenarios on ship machinery systems

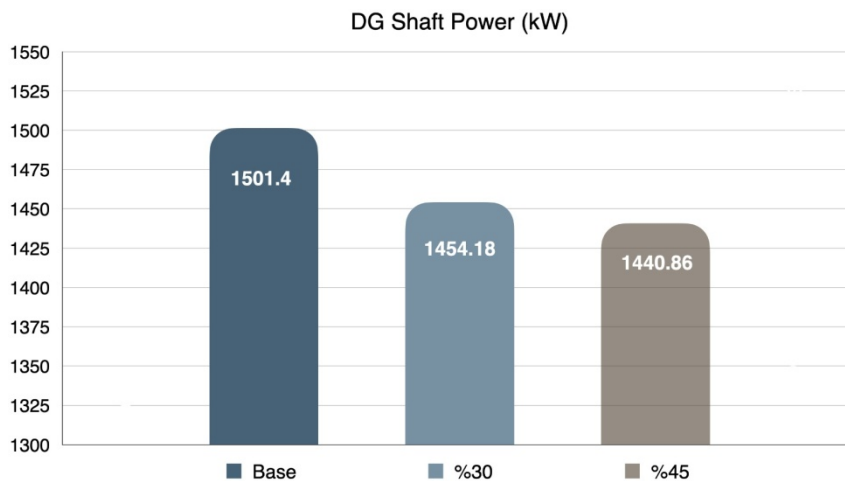


Figure 4. Diesel generator shaft power output

increased due to the decrease in the flow rate. Consequently, the increased freshwater temperature harms cooling systems and machinery. After the clogging in the sea chest filter reaches 60%, the main engine slows down itself, which can be defined as the critical point. Deficiencies in the cooling system result in inefficient operation and higher fuel oil consumption. A notable finding from the study is that high M.E. scavenge air temperature. High M.E. scavenge air temperature increases the fuel oil consumption since the combustion in the cylinder is not optimal. Besides that, seawater pump load is increased to compensate for the low seawater flow, and freshwater pumps also increase the load to compensate for the temperature difference. Thus, electrical consumption by the pumps is increased. Considering the latest regulations regarding the ship-based emissions, ship machinery should not operate at low efficiency. Current effects of the mucilage formation are mainly on the cooling system, but the further analysis should be made on the ships passing through the Sea of Marmara to investigate the other effects of the mucilage. The limitation of the study is the effect of mucilage on the cooling system, but its effect on the boiler and fresh water generator is excluded.

Compliance With Ethical Standards

Authors' Contributions

Author HBU and YA designed the study, BAZ wrote the first draft of the manuscript, EE performed and managed statistical analyses. All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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