Effect of Mucilage Pollution on Ship Energy Efficiency

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ABSTRACT

In recent years, ecological degradation has increased and drawn many environmental problems with it. One of the outcomes is the mucilage problem, which directly affects tourism, fishing, and especially the maritime sector. The recent mucilage outbreak in the Sea of Marmara has brought attention to these environmental disaster-related studies. However, there are only a few studies about mucilage's effect on maritime transportation. In this context, the impact of mucilage on a marine vessel is examined within the scope of the study. One of the major negative effects of mucilage on a vessel is, its cooling system. Due to the mucosal formation of mucilage, it clogs the filters and reduces the cooling effect of seawater. In our paper, a case study was made, and data was obtained from a simulator. The seawater filter in front of the seawater pump was clogged by 0 %, 30 %, 45 %, and 60 % during the simulated case study. 0 % is the base condition that is not clogged by the mucilage while the other three cases are partially clogged. A comparison study was made according to the data gathered from the simulator. While the filter is clogged by 60 % main engine slowed itself down, but during 30 % and 45 % of cases, pumps tried to compensate cooling effect by increasing the seawater flow. However, this was not provided with enough cooling effects on the main engine jacket water, air cooler, lubrication oil cooler, steam condenser, and air compressor.

Moreover, the reduced cooling effect increases fuel oil consumption which leads to higher CO_2 emissions. These results show that mucilage not only affects fishing, and tourism but also affects the environment via fuel oil consumption of a vessel.

Keywords: *Mucilage; Marine pollution; Turkish Straits; Energy efficiency*

1. Introduction

The increase 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 is changing, and environmental effects are observed. With rising seawater temperature, insufficient treatment of domestic and industrial wastes, and excessive fishing, sea algae in the area grows extremely and causes mucilage [1]. Mucilage, marine snow, or sea snot is a mucosal organic substance that can be found in the sea [2]. Mucilage is the product of a certain type of sea algae. Recently, this phenomenon occurred in the Sea of Marmara and the sea filled with mucilage. An excessive amount of mucilage crippled the marine environment also, clogged fishers' networks [3].

After the 2020-2021 mucilage outbreak in the Sea of Marmara, several studies were made. One of which is made by Savun-Hekimoğlu and Gazioğlu in, 2021. They focused on mucilage problems in enclosed seas and mucilage problems in Marmara. Also, the authors studied the impact of mucilage on certain sectors such as ecology, fishing, and tourism. Moreover, intense mucilage formation in the Sea of Marmara is investigated by Balkıs-Ozdelice et al. in, 2021. Authors implied that the habitat of the sea has changed, and unobserved species has become dominant due to massive mucilage event. Also, Özalp made a research on

the ecological effects of mucilage outbreaks in Çanakkale Strait [4]. According to the author, mucilage not only affects the creatures on the surface, but also threatens the life of coral habitat, which is at a depth level of 39-51 m of the sea.

Although mucilage in the Sea of Marmara has increased dramatically, it has been a problem since 2004. A study was made by Tas et al., about on mucilage events, and potentially toxic species in the Sea of Marmara [5]. In the paper phytoplankton composition and Physico-chemical variables from January 2004 to December 2007 are investigated. Another study was made by Toklu-Alicli et al., on mucilage events, and their effect on cyanobacteria habitat [6]. The authors stated that, during the one year from August 2007 to August 2008, water samples were taken and analyzed. According to their study, cyanobacteria formation was highest in November 2007 for both Gulf of Bandırma and Erdek. However, cyanobacteria formation was the lowest in February 2008 for Gulf of Bandırma and in May 2007 for Erdek [7]. Moreover, the abundance of cyanobacteria increased in the upper layers of the sea, while it is minimal at the deeper layers. As it can be seen, the mucilage density is changed with respect to depth, temperature, and contamination of the sea.

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 effect on marine vessels. A large amount of mucilage clogs the 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 gets 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.

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.

2. Material and method

2.1. 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.

2.1.1. 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, lubrication (L.O.) coolers, and 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. In addition to the coolers, the fire pump also feeds the fire line through the ship’s seawater line.

2.1.2. 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 fresh water from LTFW coolers. The central cooling water system and its components are demonstrated in Figure 1 briefly.

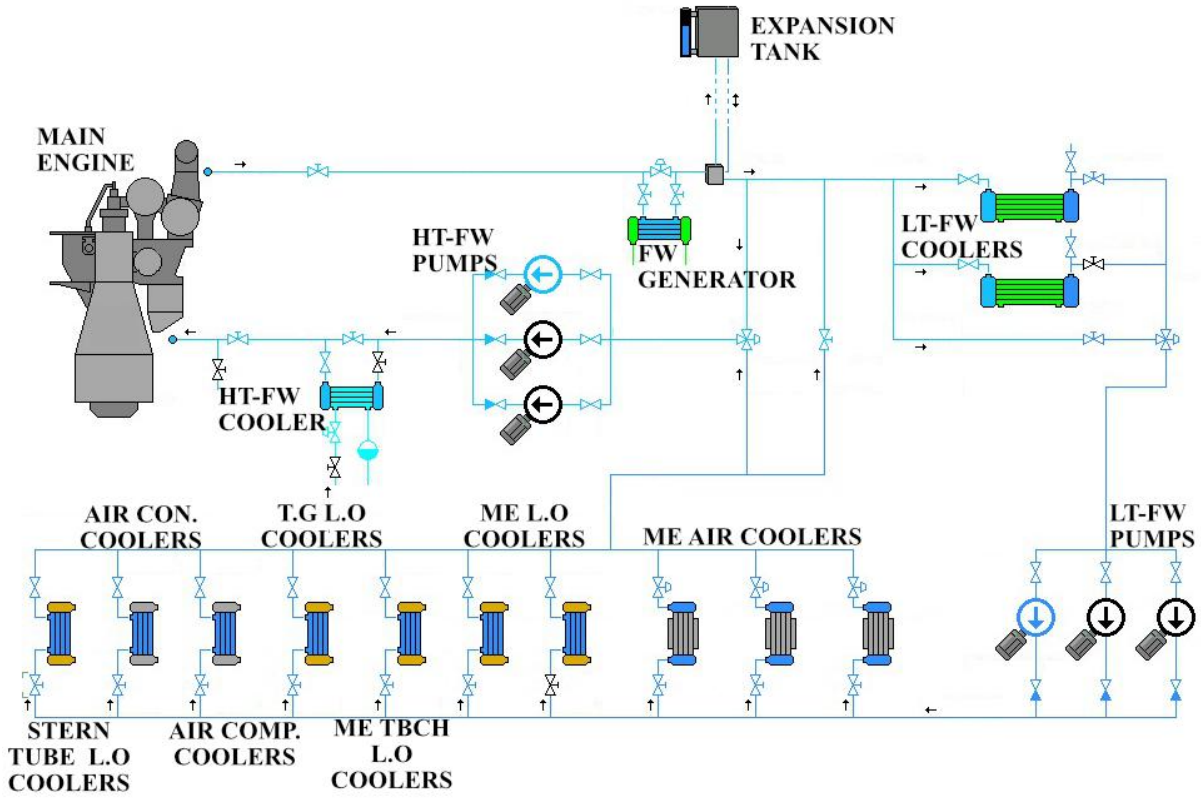


Figure 1. Central cooling water system.

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 to supply water circulation to keep the cooling efficiency of the main machine at maximum. Together with the pre-heating system placed on the HTFW coolers, the main engine keeps the jacket waters warm at the stop 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 FW generator by using the waste heat of the high-temperature water that completes the cooling process in the main engine.

2.2. engine room simulator

The purpose of the engine room simulators (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. Laskowski et al., used ERS for a fuel-water emulsion operating system used to reduce exhaust gas emissions for a ship engine [8]. Yutuc examines the effect of shaft generators on ship energy efficiency using ERS [9]. ERS systems are widely preferred in academic studies in the field of education as well as technical studies [10; 11].

3. 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. In this context, pollution scenarios were created with an engine simulator program using the ship's characteristics in Table 1.

Table 1. Specifications of the ship.

Specifications	
Ship Type	Container
Cylinder bore	840 mm
Piston stroke	2.400 mm
Cylinders	12
Air coolers	3
Turbochargers	3
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	55000 ton
Design Speed	25 knots

First, the pressure and temperature values of the engine systems (pumps and other equipment) are observed in the case of 0 % pollution (no 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 examined. The temperature and pressure values as a result of the simulation are shown in Table 2.

Table 2. Comparison of different pollution situations.

SYSTEMS	COMPONENTS	BASE	30 %	45 %
Cooling Seawater Systems	High Suction Sea Chest Filter ΔP	0,21	1,48	1,52 bar
	Low Suction Sea Chest Filter ΔP	0,00	0,00	0,00
	Seawater Pump Discharge Pressure ΔP	2,91 bar	1,59 bar	1,48 bar
	Seawater Temperature	20,0	20,0	20,0
	Main Seawater Supply Pressure	2,57 bar	1,45 bar	1,38 bar
	LT-FW Cooler SW Inlet Temp.	20,0	20,0	20,0
	LT-FW Cooler SW Out. Temp.	29,7	43,72	53,17
LT-FW Cooling Systems	LT-FW Cooler FW Set Temp.	32,0	32,0	32,0
	LT-FW Cooler FW Inlet Temp.	38,85	44,13	52,72
	LT-FW Cooler FW Out. Temp.	23,68	37,91	46,84
	ME Air Cooler FW Inlet Temp.	32,02	37,91	46,84
	ME Air Cooler FW Out. Temp.	38,22	43,47	52,08
	ME Air Cooler Air Inlet Temp.	139,73	142,41	143,96
	ME Air Cooler Air Out. Temp.	36,53	42,12	51,68
	ME Scav. Air Temp.	36,54	42,12	50,82
	ME L.O Cooler FW Inlet Temp.	23,68	37,91	46,84
	ME L.O Cooler FW Out. Temp.	42,46	47,61	56,20
	ME L.O Cooler L.O Inlet Temp.	53,61	57,27	60,75
	ME L.O Cooler L.O Out. Temp.	40,10	46,67	53,99

	ME TBCH L.O Cooler FW Inlet Temp.	23,68	37,91	46,83
	ME TBCH L.O Cooler FW Out. Temp.	34,80	40,61	49,49
	Main Air Comp. FW Temp.	32,56	38,47	46,96
	Stern Tube L.O Cooler FW Temp.	32,33	38,17	47,12
	Stern Tube L.O Cooler L.O Temp.	32,78	38,56	46,54
	D/Gs' Air Cooler FW Out. Temp.	67,31	67,24	67,14
	D/Gs' Air Cooler Air Inlet Temp.	121,15	118,82	117,76
	D/Gs' Air Cooler Air Out. Temp.	74,32	73,86	73,56
	D/Gs' L.O Cooler FW Inlet Temp.	56,41	56,40	56,52
	D/Gs' L.O Cooler FW Out. Temp.	64,59	64,66	64,62
	D/Gs' L.O Cooler L.O Inlet Temp.	74,54	74,72	74,46
	D/Gs' L.O Cooler L.O Out. Temp.	58,92	58,94	58,99
HT-FW Cooling Systems	HT-FW Cooler FW Set Temp.	84,90	84,98	85,0
	HT-FW Cooler FW Inlet Temp.	42,00	47,21	55,87
	HT-FW Cooler FW Out. Temp.	73,45	73,27	73,02
	ME Jacket Cooling Water Temp.	73,41	73,27	73,02
	FW Generator Temp.	24,53	28,09	29,02
Boiler Systems	Steam Condenser SW Inlet Temp.	20,0	20,0	20,0
	Steam Condenser SW Out. Temp.	26,65	24,60	45,28
	Steam Condenser Steam Out. Temp.	21,40	23,45	24,99

The results indicate that the ship has been affected by the increased mucilage formation in the Sea of Marmara. 60 % pollution scenarios are not included in the table. That is because seconds after the scenario was created and congestion occurred, the main engine automatically slowed down due to high freshwater temperatures leaving the LT-FW cooler. Thus, results for the 60% scenario are not healthy enough for comparison.

The first remarkable change has occurred in the high suction sea chest filter. The pressure difference in the filter has increased by a quiet margin, which means 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, LT-FW cooler seawater outlet temperature is increased because of insufficient seawater flow due to clogged filter, which also results in increased freshwater temperature leaving the LT-FW cooler. Another indicator of a clogged filter is lower seawater pump discharge pressure and main seawater supply pressure. Although the 30 % and 45 % case pressure are barely changed, a change between the base and 30 % case can be seen.

The clogging of the filters directly increases the freshwater outlet temperature of the LT-FW cooler and directly affects the ME air cooler, ME L.O cooler, ME TBCH L.O cooler, air compressor cooler, and stern tube L.O cooler via LT-FW pumps. ME 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 ME air cooler air outlet temperature and the ME scavenge temperature. The same principle applies to the ME L.O cooler, the freshwater temperature of the cooler increases, and the L.O outlet temperature for each case is 40,10 °C, 46,67 °C, and 53,99 °C, respectively. Another affected component is the ME TBCH

L.O cooler. As shown from Table 2, ME 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 LT-FW 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.

HT-FW is another affected cooling system. In the previous chapters, the role of HT-FW for ME is explained. As shown in Table 2, only the HT-FW cooler inlet temperature and FW generator temperature are changed; however, HT-FW cooler FW temperature and ME jacket water are not changed. The unchanged temperature is a mixture of LT-FW and FW, leaving the FW generator mixed with a three-way valve, and the mixture is heated in a preheater. Decreasing the load of the preheater can adjust the HT-FW temperature. On the other hand, HT-FW cooler inlet temperature is increased as the LT-FW temperature increases.

5. 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 increased due to the decrease in the flow rate. The increased freshwater temperature harms cooling systems and machinery. Deficiencies in the cooling system result in inefficient operation and higher fuel oil consumption. A notable finding from the study is that high ME scavenge air temperature. High ME scavenge air temperature increases the fuel oil consumption since the combustion in the cylinder is not optimal. Besides that, the flow of seawater and freshwater is increased in pumps to compensate for the temperature

differences. Thus, electrical consumption by the pumps increased. Considering the latest regulations regarding emissions, it is undesirable for ship machinery to operate at low efficiency, and mucilage formation can have a negative impact on the energy efficiency of ship machinery.

6. Abbreviations

AC: Air Conditioner

AE: Auxiliary engine

DG: Diesel Generator

ERS: Engine Room Simulator

FO: Fuel Oil

FW: Fresh Water

FWG: Fresh Water Generator

GHG: Greenhouse Gases

HT: High Temperature

HTFW: High-Temperature Freshwater

IMO: International Maritime Organization

LO: Lubrication Oil

LT: Low Temperature

LTFW: Low-Temperature Freshwater

ME: Main Engine

MCR: Maximum Continuous Rating

TBCH: Turbocharger

SW: Seawater

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