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RESEARCH ARTICLE

Effect of contamination in cooling water line on emissions and equipment of vessels

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ABSTRACT

Emission is a threat to all living things. Despite all the conferences on climate change, emissions could not be reduced. On the contrary, its effect continues to increase. Ships use fossil-based energy and they are widely used vehicles in transportation. This paper provides an analysis of emission in ship main engine and auxiliary machinery. In addition, the effect of contamination on safety valve of ship and funnel is illustrated clearly. All data used in this study were taken from the ship during the 79-day cruise. When the pollution factor was eliminated, the average NO_x and SO_x and total emissions from the cylinder jackets, seawater circuit, scavenger circuit, freshwater circuit decreased significantly. The average revolution of main engine increased by 20% after cleaning. The results of vibration due to contamination were found to be collapse and broke up of the cylinder safety valve of main engine, and insulation layer of funnel of ship was collapsed. Only due to the contamination of the jackets and cylinders of main engine, the amount of energy losses before the ship goes aground increased by 37.48%. But this decreased by 20.83% just after the cleaning procedures were carried out. In addition, the sea circuit of main engine was contaminated at different rates on ship simulator. The actual data is in consistence with the data obtained from the ship simulator.

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Introduction

Emission is a huge problem for all living creatures. As a result of the emission, important consequences such as drought and extinction of many species occur. Ships, which provide a very important part of transportation in the world, use fossil energy sources and these gigantic vehicles have a significant share in emissions.

Since energy resources are limited, energy efficiency must be high, however energy efficiency in ships is considerably low. Thermal and mechanical energy losses in ships are quite high and this must be minimized especially in the significant parts such as circuits, main engine and auxiliary machines. One of the most important reasons of energy lose is pollution that causes an increase in friction losses and prevents heat transfer in cooling and heating systems. As a result, more energy and fuel consumption occur and this increases the emissions to the environment. As it is known, emissions are harmful to all living organisms and sometimes it may get into chemical reactions with the air in the atmosphere which may be the reason of dangerous results. However, appropriate precautions are not taken. Emissions from fuel oil and diesel are high. Even a small increase in the efficiency of ship systems is important in reducing emissions. Fuel consumption reduction can be achieved by using the waste heat recovery system (Larsen et al., 2015). Engine maintenance can be taken as an uncertainty factor in emissions and energy consumption from ships (Moreno-Gutiérrez et al., 2015). The most significant issues in mechanic systems are component life and using them with high efficiency. However, despite all the intensive researches and development, energy efficiency is still very low, and safety of systems is vital. Effects of contamination often encountered in engines are the primary negative factors within this scope. The materials used in the construction of fluid systems such as piping systems, filters, pumps, valves, ship's hull should be able to resist wear and corrosion in order to decrease fouling, which will consequently help to reduce the effect of friction and lead to less energy consumption. Mechanical systems, operators and operation methods are as important as ship design and they are the factors resulting in energy losses on vessels. The quality and nature of the materials that are used in ships is very important for system efficiency and they all affect the energy loss. Erosion of ship materials leads to contamination and causes blockages in the system circuit. Sea organisms grow up on pipe surfaces, and filters in time cause a fall in pressure in the circuit in time. In places where there is fluid at high temperatures, in contact with sea water and in places where electrical failures appear, corrosion takes place due to contamination. One of the main reasons for energy loss is turbulence which is quite common problem in ships and in the various circuits of ships. Contamination with the turbulence increases losses due to coefficiency of friction. Turbulence not only causes energy losses, but also creates vibration which can give rise to corrosion and fatigue. Long-term results of vibration on the whole system are breaks due to fatigue which will result in unusable components in some systems. When wear and corrosion increase, they lead to clogged circuits even in operative piping systems. In addition, the pump inlet and outlet valves can lead to cavitation causing excessive loss of pressure.

The concept of energy efficiency in maritime transportation may be classified under several headings and subheadings such as speed optimization, setting the course of the vessel according to the weather conditions, maintenance of the boat and machinery equipment. Turbulence, corrosion, contamination and vibration are some of the principal factors which affect the flow of substances, turning them into major factors which influence energy efficiency. Although each of them causes different effects at various levels, they are occasionally observed to occur simultaneously and they are therefore likely to affect efficiency in different ways.

The sea water cooling system is a system that takes sea water at 20°C and cools the fresh water in the central heating system. The main engine cooling system is the system in which fresh water is cooled with sea water at the center of the cooling system. The main engine cooling system consists of cooling device, oil cooling device, turbine oil cylinder, main engine piston cooling, main engine jacket water system.

When the literature is searched, many studies such as pollution Mechanism (Kuruneru et al., 2016) pollution effect (Kuosa et al., 2007; Wu & Xiao, 2011; D'Amico et al., 2015; Qureshi et al., 2016; Pan et al., 2016; Suner & Yildiz, 2017), heat transfer (Karakasli et al., 2016; Wang & Wu, 2017), emission (Corbet et al., 2009; Kontovas et al., 2011; Khondaker et al., 2016; Giannopoulos, 2017; Dere et al., 2020), cooling system (Trujillo et al., 2011; Fontanesi et al., 2013; Badak et al., 2016), Fatigue (Nielsen et, 2011), vibration (Lin et al., 2009; Gravalos et al., 2013), system collapse, corrosion (Hattori & Kitagawa, 2010), energy efficiency (Jafarzadeh & Utne, 2014; Dimitrios et al., 2016; Yalcin et al., 2016; Inal et al., 2020; Dere et al., 2022), wastewater from shipbuilding (Akanlar et al., 2011) will be seen.

As can be seen from the literature, there is no such study on the effects of contamination on emissions, engine efficiency, vibration, safety valve and the funnel of vessel. These topics need to be investigated to make up for the deficiency in the literature. In this study analyzed the effects of contamination on the emission, on the main engine revolution, heat transfer through the cylinder jackets of main engine, safety valve, funnel of vessel and it has been displayed by real data have been verified through simulator. The observation is performed using more than 400 real data by the author. All data and photographs have been taken from M/V Infinity in 2014 and operated by Makro Maritime Lines.

Material and Methods

In this study, the effect of impurities in cooling water on the safety valve and funnel of the ship has been investigated by taking the actual data (6 times per day basis) on the ship for three months. The daily average values of the main engine cooling sea water temperature values, fresh water temperature, the main engine cylinder jackets temperature values, and daily variations based on these calculations were shown graphically. Following, average values for before agrounding, after agrounding and after cleaning cooler were determined. The heat transfer variations were tabulated. Considering these average values, temperature changes in cylinder jackets cycle were determined. Finally, these results were examined by increasing the contamination rates on ITU KONGSBERG NORCONTROL SIMULATOR, whose model is Sulzer RTA84C and it is a Full-Mission Engine Room Simulator.

In this study, to what extent the safety valve is influenced by impurities in the cooling water of the main engine was measured based on actual data recorded six times on a daily basis by the author from the ship. It has been demonstrated how the heat transfer is diminished by increase of the contamination. The temperature rising in cylinder jackets after decreasing in heat transfer and consequently the fall of the revolution number in the first cylinder of the main engine to dramatical levels have been shown on graphics depending on actual data. The heat changes after cooler cleaning have also been indicated graphically. Changes in levels during vibration resulting from the increase of contamination on the first cylinder of the main engine and finally collapse of the safety valve due to vibration were analyzed. Subsequently, possible results of the same affects were compared in the simulator. In addition, the problems in funnel due to contamination caused by the waste coming out from the funnel were put forward. The accuracy of these were explained in the simulator.

As it is known, the vibrations on vessels originate from those unbalanced forces and momentum. Those local vibrations and global vibrations which occur all over the vessels cause various problems. The most significant one of those problems is dynamic fatigue. Dynamic fatigue occurs on machines and their equipment exposed to vibration for a long period of time causes various incidents which are likely to pave the way to failures and malfunctions such as fractures and disjuncture.

Contamination can be defined as the case of material being scattered around or keeping material in improper places rather than the places where they belong to and it plays a primary role which hinders the efficient management. If those problematic areas and factors are considered thoroughly, it can be seen that it results in energy losses, malfunctions and shortened life of materials.

The engine room, the freight, cargo, exhaust gases leakage from the working engines, sea water, oil, grease and fuel and similar substances as well as many other sources may create contamination. It may also lead to a variety of problems such as blockage of the cycles, blockage of heat transfer surfaces, mechanical, pneumatic or hydraulic components and seizure of a machine. Although it is possible to decrease the effects of some of these contamination problems, it is impossible to avoid contamination and its negative effects completely.

Results and Discussion

All data used and related photographs were taken from the M/V Infinity ship from 2013 to April 2014. Contamination effect will be examined in the following sections with photographs and data. The rates and values affecting the heat of the cylinder jacket for the duration of 79 days, sailing of 79 days, sailing of the M/V Infinity were used including rotation speed of the main engine (revolutions/per minute), the temperatures of the jacket cooling water before and after the towers (Celsius). These rates and values were obtained by taking the arithmetical averages of rates and values recorded every day on the basis of six shifts. The general rates and values were recorded as follows; from 10/22/ 2013 to 11/24/2013 (case1), from 11/24/2013 to-01/03/2014 (case2), 01/03/2014 to 04/04/2014 (case3). The average rate values of the Main Engine Jacket Water of the four cylinders were obtained from three different situations. According to these findings, the required heat transfer increased significantly just before and after the ship ran aground, and decreased significantly just after the final cleaning process was completed.

The M/V Infinity is stranded offshore Hudeidah – Yemen Republic on 11/24/ 2013. Although the vessel did not face any serious damage, due to the sandy bottom of the sea, extreme amounts of contamination was observed within the sea water cycles after a short while. Because both the shallow water and the deep water sea chests were opened during the maritime accident and as a result there was a rise in temperatures of the main engine jacket. Consequently, the number of revolutions of the main engine had to be decreased, so duration of sailing was extended. Furthermore, their exposure to the negative effects of contamination and high heat shortened the life span of the machines and their parts which were being used for a long time. The towers of the main engine cooling water system were cleaned on January 3rd, 2014. The serpentines were stabbed with iron bars, therefore the obstructions were removed and opened. All of the average daily rates of temperature of the jacket of cylinder 1 are illustrated in the Figure 1, which were observed from 11/22/2013 to 4/6/2014. The percentages of the increases in the rates seen at various two cylinders are as follows: cylinder one 6.324%, cylinder two 3.754%. A considerable amount of decrease is observed at average rates of temperatures for two cylinders when the values taken before and after the cleaning operation was fulfilled. The average values for each cylinder are estimated to be as follows: cylinder one 1.446%, cylinder two - 2.638%. The contamination prevents heat transfer.

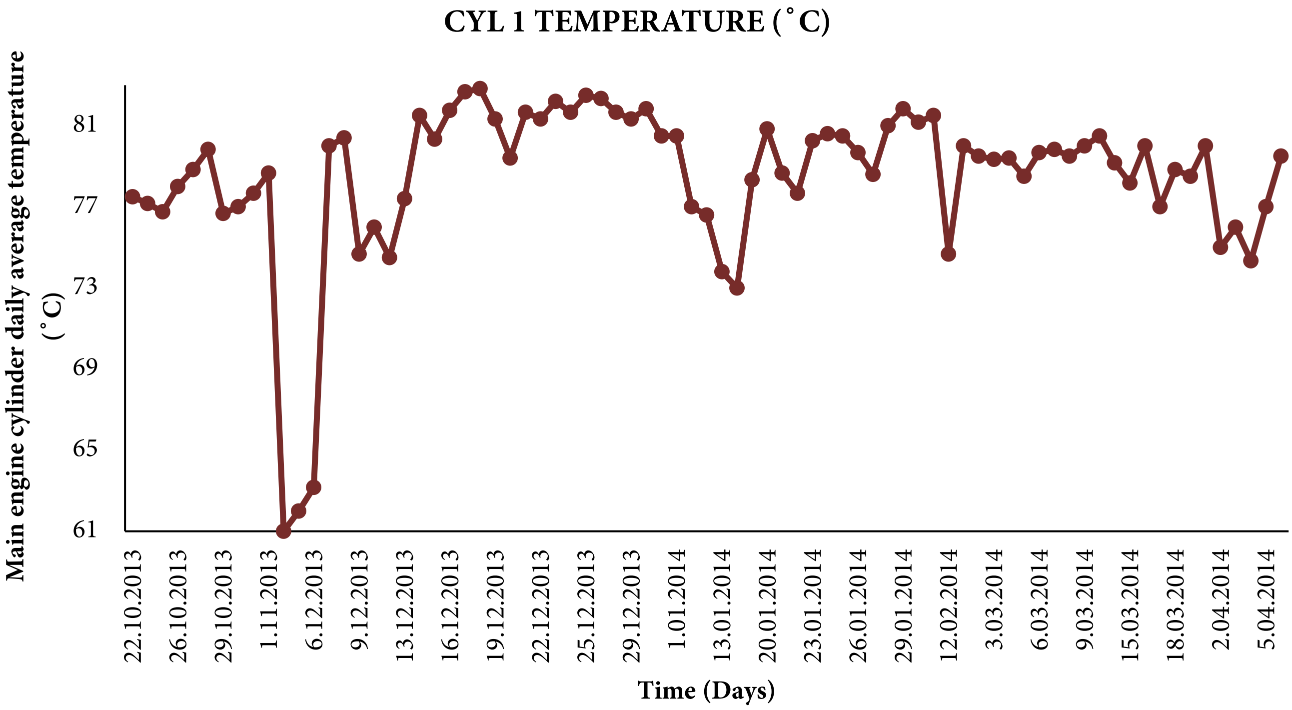

Figure 1. The daily average temperature of the jacket water of cylinder 1 of main engine.

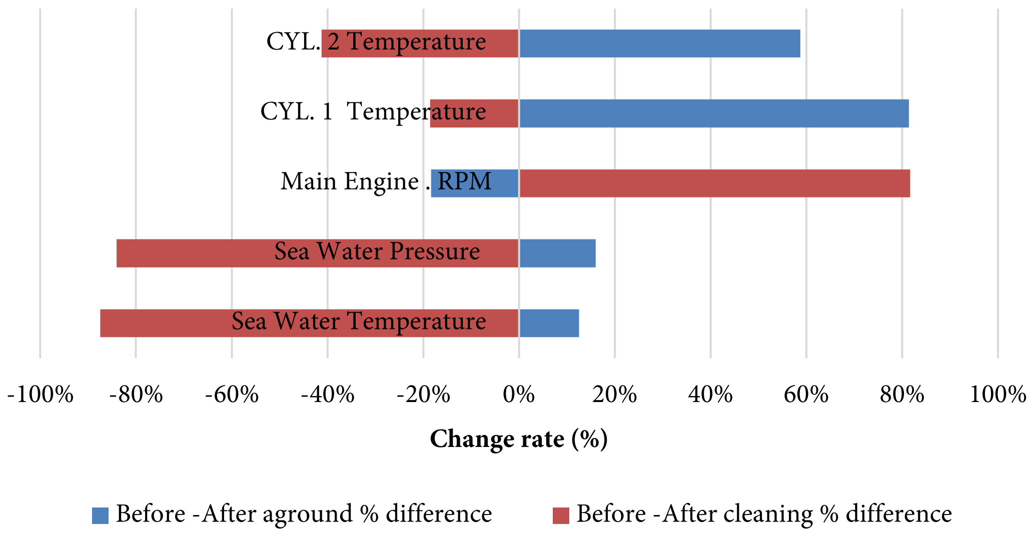

Figure 2. Average changes in the factors affecting the main engine revolution

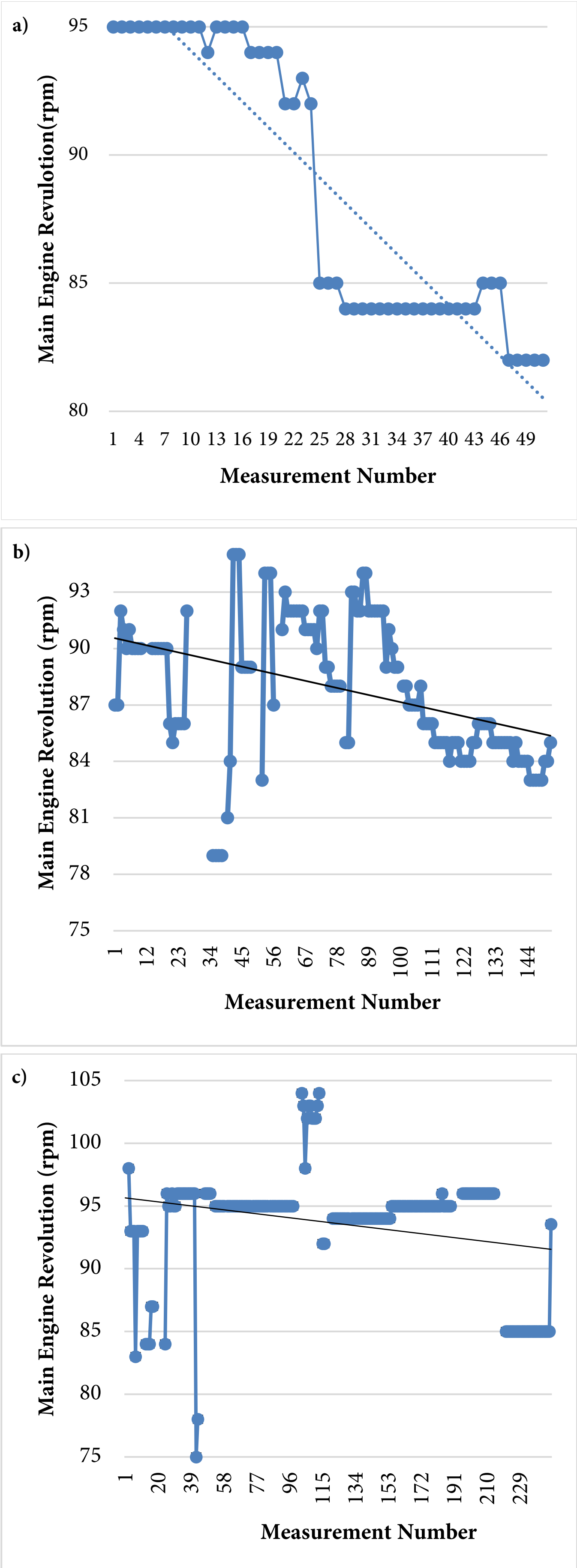

Figure 3. Revolution of main engine; a) Before aground, b) After aground, c) After cleaning 22 October to April 6

The general average rates of those three cases are illustrated in Figure 2. The first case occurred on October 22, 2013 before the ship went aground. The second case was after the ship went aground until the cleaning procedure. The third case was after the cleaning until April 6.

Average temperature of the sea water circuit increased by the average rate of 2.217% before and just after aground. Before and after cleaning, it decreased by rate of 15.470%. This circuit average pressure increased by the average rate of 8.653% before and just after aground. Before and after cleaning, it decreased by rate of 45.475%. The reason of this change is impurities in sea water circuit. In addition, it has led to significant changes in heat transfer and pressure losses.

The revolutionary change of main engine of the vessel for three cases is shown in Figure 3. As it is shown in Figure 3a before aground, Figure 3b after aground and Figure 3c after cleaning, the revolution of main engine decreased to critical numbers both before aground and just after aground. The effects of contamination and vibration on main engine revolution have been determined and illustrated. The revolution of main engine average decreased by the average rate of 1.451% before and just after aground. However, before and after cleaning, it increased by rate of 4.668%.

It is known, the safety valve mechanism which runs on the pressure of spring is utilized to provide pressure relief in such cases in order to avoid excessive and dangerous increase of pressure power which occurs in the cylinders during fuel combustion. While the M/V Infinity was going through the Suez Canal on the date of October 26th, 2013, the safety valves of the number 1 and 2 cylinders remained open due to being exposed to contamination for a long period of time and a very serious accident was hardly avoided. While going through the Suez Canal, the safety valve of main engine started to open as soon as the vessel started sailing. At the beginning of the incident, a slight gas leakage was observed at the safety valves between the compression and exhaust periods. The captain continued sailing thinking that they could deal with the problem when they arrived at the anchorage place approximately in two hours' time. One hour later, a considerable amount of increase was noticed at the leakage when the engine revolution decreased by about 22%. On the other hand, as the fuel-oil used had not been separated regularly, that seemed to be a usual condition but the opened safety valve did not close this time. However, we had to go on sailing as we were in the canal. On the other hand, it would be dangerous to sail as the safety valve remained open. The second captain kept on sailing thinking that it would close soon, but as the revolutions increased, the safety valve started to blow out smoke due to ingenerated flames and as a result of the combustion inside the valve, it started to break into pieces and scatter these glowing metal pieces around. Upon the vessel started sailing by the command of the captain, first pressurized exhaust gases, afterwards flames which ingenerated during combustion began to blow out from the safety valves belonging to the cylinder number 1. Finally, those glowing pieces metals which were broken from the safety valve were scattered around as seen in Figure 4. Thanks to various lucky and narrow escapes, there were not any serious injuries and accidents as a result of having to stop the vessel urgently in the middle of the Suez Canal. The vessel might have gone aground. Fortunately, this incident was avoided by the coil users who were on board by coincidence. They secured the vessels punctually by using the ship's tackles and running rigging. Luckily, there was nobody around the engine during the incident, therefore nobody was injured. And again, while those broken pieces were being scattered, none of them fell on risky areas such as electrical equipment. However, the authorities fined the vessel for 30.000 $. Additionally, some extra charges had to be paid for those coil users and tugboats. Although contamination seems to be a simple concept at the first sight, consequences of neglecting the contamination proves clearly what a significant issue it is as understood from the incident.

Figure 4. The safety valve of the cylinder number 1

The other major factor that led the valve to remain opened was undoubtedly impurities in the fuel. The fuel was separated only once, then the service tank was directly fueled up. As the fuel was not clean, it caused the valve jamming. Other reasons for that incident could be heat and pressures generated during combustion and vibrations occurred while sailing.

The most important damage of the vibration on ships is that vibration causes dynamic fatigue. Those vessel engines and parts which are exposed to vibration for a long period of time are likely to be broken and come off. Moreover, this may cause serious deficiencies in the performance of machines as well as some serious accidents and problems. Then, the number of revolutions of the main engine of the M/V Infinity was not able to exceed certain numbers due to the increase in the jacket temperatures and the fact that the vessel had to sail at some critical revolutions to maintain satisfactory performance. The critical revolution is related to the construction of the vessel, being independent from the manufacturer of the engine, and the values regarding the revolutions of engine are determined by some special tests. Briefly, critical revolution is the number of revolutions as the engine is working at the frequency when vibrations on the ship are at their maximum levels.

Figure 5. The funnel loop some parts of which fell of and uncovered for repairs

Figure 6. The parts which fell off funnel loop

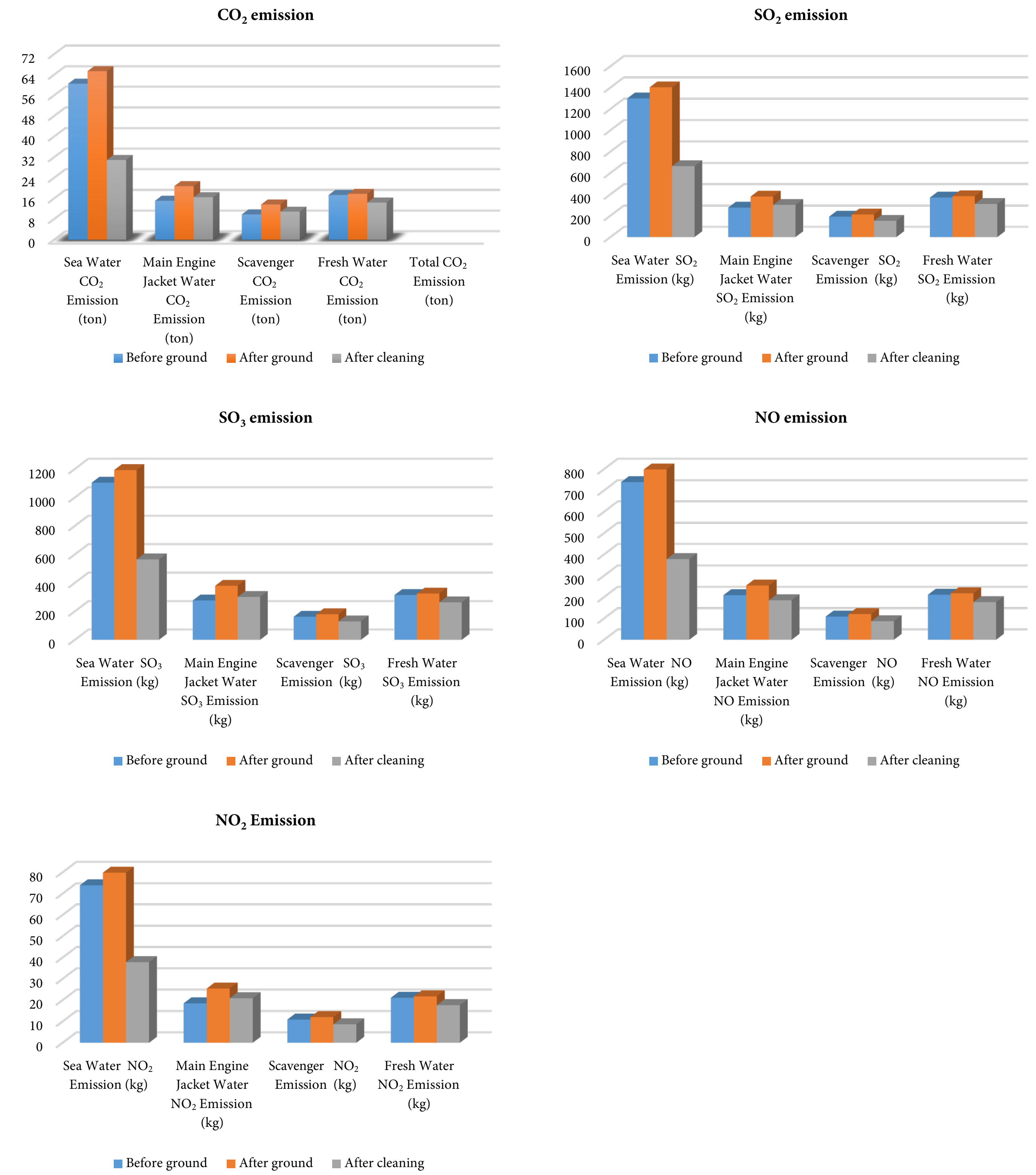

Figure 7. Emission change; a) CO_2 emissions, b) SO_2 emissions, c) SO_3 emissions, d) NO emissions, e) NO_2 emissions

As result of M/V Infinity's engine operating at critical revolutions for a long time while sailing, some damages such as fractures, dents and collapses occurred on the outer covering of the funnel loop, which caused heat insulation. In Figure 5, the funnel, some parts of which were dented and collapsed due to being exposed to excessive vibration and the funnel loop uncovered to get repaired are shown. Figure 6 shows some of those pieces of fractures.

Casualties regarding seafarers as well as the possibility of ship equipment damages were among the most common risks in accidents. Several precautions may be taken to avoid such risks and accidents. For instance, the vessel should not sail while her engines are working at critical maintenance of the dynamic absorbers of vibration dampers should be performed regularly and all sorts of preventive measures should be taken by means of visual inspections of those engines and their equipment which are likely to be affected negatively and damaged.

Table 1. Changes in systems of vessel

Systems	Difference before - after agrounding (1-2%)	Difference after agrounding- after cleaning process (2-3%)
Sea Water Temp. (°C)	+2.21	-15.47
Sea Water Pressure (bar)	+8.65	-45.47
Main Engine Revolution (RPM)	-1.45	+6.44
Cylinder 1 Temp. (°C)	+6.32	-1.44
Cylinder 2 Temp. (°C)	+3.75	-2.63
Cylinders of Jacket Heat (kw)	-37.48	+20.83

The sea circuit of main engine was contaminated with debris in simulator by amounts of 10%, 20%, 30% and 50%. Before sea water circuit was polluted, sea water flow rate was 1038.300 ton/h, and heat transfer was 22 823 kw. When the contamination amount is 10%, seawater heat transfer circuit increases to 23100 kwh and valve openings rise from amount of 44.100% to amount of 45.250%. When the sea water circuit contamination rate is 20%, flow rate is 23.050 ton/h, and heat transfer is 12600 kwh respectively. Also, at this rate of contamination, the jackets of main engine start heating and at the amount of 30%, the jackets of main engine go over heating. When the sea water circuit contamination is 50%, heat transfer is 22600 kwh, and flow rate is 1438 ton/h. These results illustrate to us the actual measured data, that, if the system temperature exceeds a certain value, there will be expansion in the cylinder, blocking, the cylinder oil burning and deadlock occur. Thus, the cylinder temperature change must remain between 70ºC and 80ºC. In the system, the cooling water flow rate and so the heat transfer increases, therefore, revolutions of the main engine are reduced automatically or manually. The effect of contamination was examined in the simulator. As the impact of contamination increases, the circuit pressure losses increase, the alarm rings, the main engine revolution undergoes heavy running position. This resulted in all freshwater cooling not being sufficiently cooled by the cooler. When the lower temperatures rise to higher temperatures, it cannot be cooled and the temperature of jacket rises. Thus, the main engine revolution has to be reduced manually.

Contamination Effect on Emission

The changes in CO_2, SO_2, SO_3, NO and NO_2 emission emissions occurring in the circuits of the main engine cooling system on the ship due to pollution are shown in Figure 7. As can be seen from the graphics, after the circuit cleaning in all circuits, emissions have decreased due to pollution. The increase in emissions due to pollution in the seawater circuit of the main engine cooling system is higher than the increase in all other circuits.

Conclusion

The results show that the main engine seawater circuit is seen as the place where the impact of pollution is the greatest. The fuel consumption caused by the increase in pollution in all circuits and the emissions emitted by the ship increased accordingly. Especially carbon dioxide and nitrogen monoxide emissions are quite high. After cleaning the main engine cooling circuit, emissions were significantly reduced. Changes in the systems of vessel due to contamination are shown in Table 1. Due to effect of contamination, the average revolution of main engine was decreased by 1.45% before and just after aground. Before and after cleaning, it increased by rate of 4.67%, and just after aground, it increased by 6.44%. Cylinder jackets temperature increased due to impurities. Only due to the contamination of the jackets and cylinders of main engine, the amount of energy losses before the ship went aground increased by 37.48%, but decreased by 20.83% just after the cleaning procedures are carried out. The average temperature of jacket cylinder one increased by 6.32%, that of cylinder two was by 3.75%. When the values taken before and after the cleaning operation was fulfilled, the change in average values for each cylinder were estimated to be as follows: cylinder one 1.44%, cylinder two as 2.638%. The contamination prevents heat transfer. The sea water circuit average temperature increased by 2.21% before and just after aground. Before and after cleaning, it decreased by 15.47%. This circuit average pressure increased by 8.65% before and just after aground, and before and after cleaning, it decreased by 45.47%. Revolution of main engine decreased to critical numbers and kept working for a long time. In addition, the effect of contamination on the main engine, revolution of main engine, and the other effect are in consistence with the data obtained from the ship simulator. The results clearly show that contamination not only affects the performance of the system and emission, but also leads to the collapse of the systems and danger.

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Compliance With Ethical Standards

Authors' Contributions

Both authors have contributed equally to this paper.

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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