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Operational and Environmental Costs of a Certain Ship due to Possible Energy Loses

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Abstract — Ships are complex energy plants which are equipped with several energy producing and consuming machineries. Almost all of the ships have main and auxiliary engines consuming fossil fuels to meet the power demands of all ship operations including propulsion, heating, cooling, pumping etc.

All types of energy losses on board caused by different sources such as hull friction, air draft of ship, heat losses, pressure losses of fittings and pipes and engines energy losses are determined and additional power requirements of engines are specified to compensate these losses. The optimum design and operational criteria are discussed to decrease total energy loses. Furthermore, the costs of fuel price and environmental damages due to exhaust gas emissions are specified by reason of additional fuel consumptions.

Keywords — Ship, energy efficiency, maritime, environment, emission.

1 INTRODUCTION

Ocean-going merchant vessels transport almost 90 percent of all trade by volume to and from the 25 members of the European Community, and nearly 80 percent by weight of all goods shipped in and out of the United States. The shipping sector has grown on average by 5 percent every year over the last three decades [1].

Ships are complex energy plants which are equipped with several energy producing and consuming machineries. Almost all of the ships have main and auxiliary engines consuming fossil fuels to meet the power demands of all ship operations including propulsion, heating, cooling, pumping etc.

Ships are generally equipped with one or two numbers of main engines for propelling and a generator set consist of two or three auxiliary engines for electric generation. In addition, an auxiliary boiler is fitted to provide steam requirement of both the heating and power generation. Thus, ships consume fossil fuels in main engines, diesel generators and auxiliary boilers.

Shipping sector is governed by the International Maritime Organization (IMO). The IMO is a specialized United Nations agency responsible for improving maritime safety and preventing pollution from ships. The air pollution from ships is regulated by Annex VI of MARPOL Convention of IMO. Today, the Marpol is the only globally applicable and the most developed regulation which is a combination of two treaties adopted in 1973 and 1978 respectively. It includes the Protocol of 1997 for controlling the shipping fleet in the world in respect to various emissions to the atmosphere.

The SOx and NOx emissions (as well as PM Emission) from ships are limited according to the regulations in the Annex-VI. The convention also prohibits the deliberate release of ozone depleting substances.

In addition to these emissions, the reduction of carbon dioxide (CO_2) emissions from ships is one of the main concerns of IMO. Because the amount of emissions released to atmosphere is mainly depend on the fuel consumptions of main and auxiliary engines on board, IMO proposed some suggestions in operational, technical and market-based measures to decrease the fuel consumptions.

According to different estimation studies, global marine fuel consumption predicted over 300 million tons based on assumption methodologies. Shipping is estimated to have emitted 1,046 million tons of CO2 in 2007, which corresponds to 3.3% of the global emissions during 2007. International shipping is estimated to have emitted 870 million tons or about 2.7% of the global emissions of CO2 in 2007 [2]. The external cost of CO_2 is 32 euro per ton of emissions [9].

The energy generated by engines and the boiler are consumed in propulsion, heating, pumping, compression and some auxiliary engine operations as well as mechanical and heat losses. Each element of every ship system has certain efficiency which affects the overall energy efficiency of the ships. Thus, reducing the energy loses will improve the fuel economy and decrease harmful effects on the environment.

All types of energy losses on board caused by different sources such as hull friction, air draft of ship, heat losses, pressure losses of fittings and pipes and engines energy losses are determined and

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2 PARTICULARS OF MTA SISMIK-1

This study is carried on MTA Sismik 1 which is research ship built in 1953. Length overall (LOA) is 56.6 m., length between perpendiculars (LBP) is 51.8 m.,draft is 3.948 m., grosston is 667 m/t,deadweight ton is 353 m/t, displacement is 1196.378, breadth is 8.8 m. and draft is 3.6 m.

The service speed of the ship is 12 knot at 330 rpm of main engine. Accommodation of the ship consist of three main parts, main deck, upper deck and bridge deck.

Fig. 1. MTA Sismik 1.

The ship is equipped with a medium speed (350 rpm) four stroke main diesel engine 1050 HP (772 kW) for propulsion and three generators having 209, 150 and 50 HP. Fuel consumption of main engine is 170 kg / h at 330 rpm. Generators fuel consumptions are 20, 15 and 10 kg /h respectively.

3 ENERGY LOSSES ON BOARD

Since the ship has both the energy generating and consuming plants, it could be a good method to separate the ship operations according to the origin of energy production in engine room. Therefore, the overall efficiencies of each origin including related systems can be evaluated.

Ships generates their own energy by using fossil fuels in diesel engines and auxiliary boilers. There are loss of energy on each stage of production, distribution and consumption. These losses determine the total energy efficiency of each system and overall efficiency of ship.

General enery losses are shown in Table 1.

Table 1. General energy losses onboard.

Equipments consuming fuel	Energy type	Transmission losses	Consumption
Main Engine (thermal and mechanical losses)	Mechanical energy	Shaft, propeller	Total resistance of ship
Auxiliary generators (thermal and mechanical losses addition to alternator losses	Electrical energy	Electrical distribution	Pumping and lighting
Auxiliray Boiler	Heat energy	Pipe heat losses	Accomodation and heat exchanger

As seen in the table, marine fuels are burned in main engine, auxiliary diesel generators and auxiliary boiler, so to investigate the energy losses and efficiencies, each systems involving these equipments must be evaluated separately.

3.1 Main Engine

As for the main engine, part of the produced energy from burning of fuel in the cylinders is consumed via exhaust, lubricating oil cooler, jacket water cooler, heat radiation and air cooler. In addition, mechanical losses of the engine reduces the mechanical output power of the engine shaft.

The main engine is four stroke medium speed diesel engine which use marine diesel oil (MDO). The lower calorific value of MDO is 8217 kcal/kg (34380 kJ/kg) [3]. These type of engines consume approximately 200 gr/kWh for shaft output power which means 6876 KJ or 1.91 kWh. Thus, the engine efficiency can be assumed as 52% approximately.

Most of the power losses made from, waves, skin friction and water resistance(viscous pressure resistance). The coefficient of resistance depends on the reynolds number, geometry and viscosity, residual resistance and wave resistance. The power required for the resistance can be calculated as follows [6]:

$$P = \frac{5.\nabla^{\frac{2}{3}}(40 - 0.017.L - 400(Cs-1)^2 - 12.}{15000 - 110N\sqrt{L}}$$

where,

∇ is displacement of ship
Cs is resistance coefficient
L is length of ship
N is revolution of propeller

for N= 350 RPM, $\nabla = 901$ ton. L=56,6 m V=12knot = 6.17 m/s, P is 310 kW.

When considered the main engine power at full load is equal to 772 kW, although there is not enough information about the wet surface of the ship, power demand for the resistance of ship is logical as an assumption.

3.2 Auxiliary Diesel Generators

On a ship, there are without number of fitting pipe connections, interconnections between different systems, bends and elbows, reductions and expansions on fittings, various types of valves and very long pipelines may reach up to hundreds of meters.

Electrical energy is generated by alternators driven by four stroke diesel engines onboard. Electrical energy is transferred via circuits to final users such as pumps, heaters etc. Therefore, there energy losses in all system starting from the production of energy from burning fossil fuels in the generator engines to benefits obtained by the working fluids.

Ships are fitted with numerios pipe system for different kinds of purposes such as fire, ballast, drink and service water, lubricating oil, jacket cooling water, bilge system, fuel transfer etc. Each system need power for circulation of the working liquid in the pipe system. Pressure losses due to fitting elements such as valves, elbows, reductions as well as the length of the pipes cause undesired energy losses which are compansated by the additional needs of pumping power and fuel consumption in generators.

In sea water cooling system for main engine and auxiliary diesel generators, the sea water is inlet from the sea chest via a 5 inch pipe having 3 meters long, 1 gate valve and 1 globe valve. Then the pipe is reduced to size of 4 inch before the seawater pumps and 3 inch after the pumps. There is a gate valve and 5 elbows on 4 inch pipe which is 10 meters long. On the pipe of 3 inch which is 13 meters, there are 5 number of valves, 2 heat exchanger, 6 elbows and a filter installed. The equations regarding pressure losses on pipe system can be summarized as follows [7]:

$$\frac{\rho v_1^2}{2} + P_1 + \rho g h_1 + P_{Pump} = \frac{\rho v_2^2}{2} + P_2 + \rho g h_2 + \Delta P \quad (2)$$

$$f = \varphi(Re., \varepsilon)$$

$$Re = \frac{vD}{\gamma}$$

$$f = \frac{0.3164}{Re^{0.25}} \quad Re \geq 2320 \; and \; \varepsilon = 0$$

$$f = \frac{64}{Re} \quad 0 \leq Re < 2320$$

$$\frac{1}{f^{1/2}} = -2\log\left(\frac{\frac{\varepsilon}{D}}{3.7} + \frac{2.51}{f^{\frac{1}{2}}.Re_D}\right)$$

$$K = \varphi(Re., Geometry)$$

$$\Delta P = \frac{\rho v^2}{2}\left(\frac{L}{D}.f + K_T\right)$$

where,

K Coefficient of pressure losses in elbow, fittings
Re Reynolds Number
f Coefficient of friction
v average velocity
γ Kinematics' viscosity of fluids
ρ Fluids density
D Hydrolic diameter
ε Roughness
ΔP Pressure losses
P Statics pressure
h Hight
L Length of the pipe
φ Function

For the cooling sea water system; Q is 19 m^3/h and $\gamma\ is\ 1.10^{-6} m^2/s$. The system is consist of 3 sections. For section I, L is 3m., $v\ is\ 041\frac{m}{s}$, $\varepsilon\ is\ 1mm$, $\gamma\ is\ 1.10^{-6} m^2/s$. , D is 0.127 m., for a gate valve and a globe valve, Re is 52070 and f is 0.037 (from MOODY diagram), $\Delta P_1 is\ 677 Pa$. For section II, L is 10m., $v\ is\ 051\frac{m}{s}$, $\varepsilon\ is\ 1mm$, D is 0.1016 m., for 1 gate valve and 5 elbows, Re is 51816 and f = 0.039 (From MOODY diagram), $\Delta P_1\ is\ 702 Pa.$, for section III, L is 13m., $v\ is\ 1.15\frac{m}{s}$, $\varepsilon\ is\ 1mm$, D is 0.076 m., for five glob valves, one filter, two number of cooler and six elbows, Re is 87630 and f is 0.041 (From MOODY diagram), $\Delta P_1 is\ 15548\ Pa.$, ΔP_{total} is 16926

Pa., additional power required for the pressure losses is 89.33 watt.
Gemide bu bunun gibi bir sürü devre olduğu göz önüne alınırsa devrelerdeki basın kaybının ne kadar önemli olduğu sonuçtan görülebilir.

3.3 Auxiliary Boiler

Auxiliary boiler consumes 17 kg of MDO per hour when it is running, which means generation of 162 kW heat energy. The thermal efficiency of the boiler is assumed as %70. Therefore the 113 kW of heat is transfered to the working fluid. The working pressure of the boiler is about 5 bar which means the saturation temprature of the steam equal to aboat 150°C. The average engine room temprature is assumed as 30°C [4].

3.3.1 Steam pipe heat losses

The ships usually have heat exchangers using steam from the boiler to warm up the engines prior to run to avoid thermal stress. Nevertheless, MTA Sismik 1 is equipped with electric heaters for jacket cooling waters and system oil of engines. Thus, the steam is just used for heating of ambient air in accomodation and hot waters in cabins and mess rooms.

The ship is fitted with 10 steam pipe having diameter of 1 inch. Heat losses from the pipelines are can be calculated as follows [8]:

$$Q = \frac{2\pi L}{\frac{1}{h_i d_i} + \frac{1}{h_o d_o} + \frac{1}{2k_{iron}} \ln\left(\frac{d_1}{d_i}\right) + \frac{1}{2k_{isolation}} \ln\left(\frac{d_o}{d_1}\right)}$$

$$Re = \frac{V.d_i}{\gamma}$$

$$\overline{Nu} = Re^{0.8}.Pr^{0.4}$$

$$\overline{Nu} = \frac{\bar{h}.L}{k}$$

$$Q = \bar{h}.A_s.\ln\frac{(T_{s_i} - T_i) - (T_{s_o} - T_o)}{(T_{s_i} - T_i)/(T_{s_o} - T_o)}$$

The main steam pipe of the boiler ise about 3 meters long having diameter of 3 inches. The pipe is connected to the collector which the steam is directed to accomodation by two different pipes which are 3/8 inches and 50 meters long.

The uninsulated steam pipes having the length of 1feet and diameter of 3 inch losses the heat 246 btu per hour on average for 120°C difference between the steam and engine room temprature [5]. Thus, the uninsulated steam pipes of the ship losses 0.237 watt per meter. (1feet = 0.3048 meter, 1 btu = 1054.35 Joule). The total energy losses on steam pipes is about 12 kW. Thus, it is obvious that about 10% of heat generated in boiler is lost during delivery of the heat in pipelines. The overall loss of the system is about 40% excluding losses on condenser, hotvel and return pipes of the system.

3.3.1 Accomodation heat losses

$$Q = mc_p(T_{e-}T_i)$$

$$Q = KA(T_{i-}T_o)$$

$h_o = 20$ watt/m^2 ^{0}K

$h_i = 8$ watt/m^2 ^{0}K

$$\frac{1}{K_e} = \frac{1}{h_i} + \frac{l_{iron}}{k_i} + \frac{l_g}{k_g} + \frac{l_a}{k_a} + \frac{l_c}{k_c} + \frac{1}{h_o} \text{ (watt/m}^2\ {}^0\text{K)}$$

$$\frac{1}{K_e} = \frac{1}{h_i} + \frac{l_{iron}}{k_i} + \frac{l_g}{k_g} + \frac{l_a}{k_a} + \frac{l_c}{k_c} + \frac{1}{h_o}$$

$$\frac{1}{K_e} = \frac{1}{h_i} + \frac{l_g}{k_g} + \frac{l_a}{k_a} + \frac{1}{h_o}$$

ΔT Temprature differance (^{0}C)
Q Heat transfer (Watt)

A : Area (m^2)

K : Coefficient of heat losses (watt/m^2 K)

h: Heat transfer coefficient (watt/m^2 K)9,10,

Table 2. The conduction coefficients of the bulkheads.

Coefficients	Value (w/mK)	Length	Value (m)
k_{glass}	0.78	L_g	0.008
k_{iron}	54	L_{iron}	0.007
$k_{glass\ wool}$	0.043	$L_{glasswool}$	0.020
k_{air}	0.026	L_{air}	0.103
k_{wood}	0.2	L_{wood}	0.020

Coefficient of heat transfer for single glass is assumed as 5.45 w/m^{2}K (tickness is 10 mm) and 2.4 w/m^{2}K (tickness is 6-6-6 mm) for double glazed porthole.

$$Q_{overall} = Q_{maindeck} + Q_{upperdeck} + Q_{bridgedeck}$$

Table 3. Heat losses from accomodation part of Sismik-1 (watt).

Deck	Bulk heads	Port holes	WoodenHatches	Port holes of hatches	Total
Main deck	777	256	67	59	1159
Upper deck	497	596	67	59	722
Bridge deck	386	344	33	29	793
Total	1660	1196	167	147	2674

The ship is equipped with single glazed portholes on maindeck, upperdeck and bridgedeck of accomodation. The overal heat losses of whole accomodation is 2674 watt. If she was fitted with double glazed portholes, the total heat losses would be 1991 watt which means improvement of 26% of energy saving.

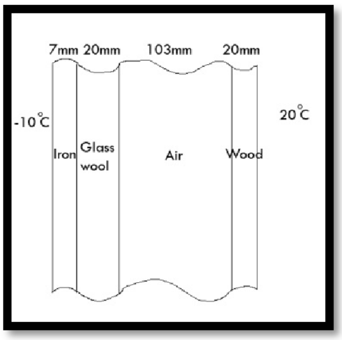

Fig. 2. Cross section of bulkhead.

The heat losses in accomodation is rather low when compared to the boiler capacity by virtue of Heat losses in passenger ships, especially the outer walls of the cams, heat exchangers and boiler room occurs.

4 CONCLUSIONS

The very simple counter-measures against the heat losses can improve the energy efficiency of the ships. As it is well known, the lowest conduction coefficient of heat transfer belongs to air pocket between two materials. Thus, for prevention of heat losses from accommodation, double glass portholes should be used.

The use of unnecessary fitting elements should be avoided to prevent both pressure and heat losses. Also the fitting lines must be very short as much as possible.

Heating pipelines should be properly insulated.

The hull of ships must be regularly cleaned in dry dock regularly against the shells of sea animals and algeas.

Since the cavitation on propeller and fittings including pumps, valves, elbows cause power losses, ship operations in engine room must be managed to minimize the risks of the cavitation.

Since there is not enough regulations on shipping, total energy efficienies of ships are lower than that of it should be. As a rough estimation, increasing the total efficiency of shipping and reduction of 10% of CO_2 from ships can globally decrease the total environmental cost of marine emissions 3.2 billion euro per year. This cost does not include the fuel cost and environmental costs occuring from the other types of emissions.

The environmental costs of other emission types will reduce either due to reduction of fuel consumption.

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