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# MEDIUM SIZE LNG TANKER LUBRICATING SYSTEM HEAT EXCHANGER (COOLER) ANALYSIS

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***Abstract:*** As part of the project, the necessary steps are taken to carry out a calculation of a main engine lubrication system fitted on board an LNG tank vessel with a capacity of 45,000 dwt. The validation of the system is achieved by using a calculation program based on finite element theory (CFD). This is a new ship with a series of innovations regarding the construction of the cargo tanks, which was built in 2018. For sure, this engine is a dual fuel type, powered by marine fuel and natural gas. A general description of the naval lubrication system is made, then a specific calculation is performed for the essentials, such as: the main oil pump, the oil storage tanks, the oil separator, the oil filters and the oil cooler. Next, the focus is on the oil cooler, which is considered an essential part of the installation. In the first part of chapter five it is described in detail, from a constructive and functional point of view, then, using the Ansys program, the corresponding calculation is performed to verify it. A model is made according to the geometrical characteristics, then a series of specific simulations are performed. The main purpose of the simulation is to determine de operational behaviour of this heat exchanger from a temperature point of view and to establish its optimal operational status. This cand be done by establishing a proper simulation model and by conducting a precise simulation stage focused and key parameters. As noted in the final part of this study the temperature contour in the heat exchanger for cooled oil flows form minimum 291 0K to maximum 363 0K, this being its optima operational limit.
***Key words:*** lubrication, LNG tanker, simulation, dual-fuel engine, cooler.

## 1. INTRODUCTION

•Small and medium-sized LNG carriers (tankers) are required when LNG is to be distributed farther from the large import terminal, either farther from an intermediate terminal or to a ship. There are two categories of small and medium-sized LNG carriers, namely bunker LNG and feeder LNG. Moreover, LNG can be transported by barges that can be self-propelled or have no propulsion of their own. There is only one ship in the world today that can be considered a bunker ship, this being *Pioneer Knutsen*. However, it is essentially used as a feeder vessel, being used to supply intermediate terminals located along the Norwegian coast. LNG bunker ships will become an essential part of filling stations in the infrastructure of Northern Europe. It should be noted that there are currently no orders for this type of ship, but there are projects drawn up for them. The lack of LNG bunker vessels is an obstacle to the storage/bunkering process in areas such as Nynashamn/Stockholm (Sweden) and will be an obstacle to the LNG bunkering process at other terminals and other small quays that follow. to be commissioned in the next 3-4 years.

•The purpose of feeder vessels is to ensure the distribution of LNG and the bunkering of LNG from very large vessels. LNG is loaded from very large import terminals or from liquefaction stations to receiving facilities located along the coastal area. In the Netherlands, the development of an infrastructure for LNG propulsion of inland waterway barges is a priority [1].

•The main LNG receiver is the intermediate terminal for ships of different sizes, or for larger ships that require a large amount of LNG as bunkering fuel. The size and size of feeder vessels may vary drastically, depending on the need of the market, the depth or other geographical limitations of the ports and the places where the bunkering areas are installed. The typical cargo capacity for a feeder vessel can be about 7,000 to 20,000 cubic meters.

•There are just over 20 small LNG feeder vessels worldwide. The fleet existence is quite underdeveloped. However, the number of ships is constantly growing. In particular, the Norgas fleet can be seen as a vital acquisition for the fleet of small and medium-sized ships in the Northern Europe area.

•All LNG bunkering solutions have all sorts of technological, operational or legislative constraints. There are other critical parameters that are related to different hazards. The lack of specific guidelines, regulations and standards for the LNG boiler is an issue that has been raised at many seminars and conferences in recent years. However, in the current absence of specific bunkering rules, there are some regulations that can be used in particular and which provide a method of indicating how future regulations and rules should be formulated [2]. Some examples of operational regulations for LNG bunkering, which present an overview, are normally addressed in these plans. Changes to ISO standards are currently underway to achieve new standards and technical specifications that will specifically address LNG bunkering procedures.

•Among the existing regulations and those to be developed regarding LNG bunkering, the IGF Code can be considered the most important regulation and must be followed. While the IGF Code does not specifically provide for operational bunkering procedures, it is most likely that the technical aspects for bunkering ports will also be discussed, which in turn will lead to changes in operational solutions that may be applicable.

For the study on the lubrication system using programs based on the finite element theory, the 45,000 dwt *Saga Dawn* LNG tanker is chosen. The ship is part of the LNT80 range developed especially for the company Saga LNG Shipping, the development program of the project being LNT A-BOX, a generation of LNG tankers with a new concept of cargo tank construction. This cargo storage system is classified as class A in accordance with IMO regulations for such ships. This type of vessel has a capacity reduced by half, compared to conventional LNG tankers, and the draft varies around 9 meters, being designed as a "workhorse" for the segment of medium-sized LNG tanks.

The vessel is large enough to dock at conventional LNG terminals and small enough to dock at terminals subject to significant draft restrictions. The loading capacity is optimized so that the transhipment and reloading operation of the goods can be carried out quickly, regardless of the size of the terminal.

The main technical features of the 45,000 dwt LNG tanker, shown in Figure 1 are the following:

•IMO number: 9769855;

•MMSI: 563070400;

•Pavilion: Singapore;

•Year of construction: 2018;

•Total length: 229.9 meters;

•Length between perpendiculars: 226.4;

•Construction width: 36.6 meters;

•Construction draft: 9 meters;

•Summer draft: 9.5 meters;

•Deadweight: 42,500 tons;

•Service speed: 16.5 knots;

•Fuel consumption, in gas supply mode: 36 mt/day.

Fig. 1. The medium-size LNG tanker *Saga Dawn* [2]

•The propulsion system is provided by a two-stroke engine, slow, dual fuel type (which also consumes gaseous fuel). The main motor is mechanically connected to a single axial line that drives a fixed pitch propeller. Auxiliary engines are also designed to use gaseous fuel (they are also dual fuel). The primary characteristics of the engines are the following:

•Main engine power: 14,300 kW;

•Auxiliary engine power: 3,000 kW.


Fig. 2. The medium-size LNG tanker *Saga Dawn* [2]

•As mentioned above, the main advantage of this type of ship is the new type of tanks in the *LNT45-3* range and how they are arranged during shipbuilding. Thus, the main characteristics of the tanks shown in Figure 2 and the cargo system are the following:

•Number of cargo tanks: 4;

•IMO Class: A;

•Total loading capacity: 80,000 $m^3$;

•MARVS: 0.4 bar;

•Project density: 0.6 tons/$m^3$;

•Boill-of rate (evaporation of goods): approximately 0.09% of the total loading capacity;

•Minimum temperature at which the temperature of the goods must be maintained: - 165 ˚C.

In the maritime industry, both shipbuilding and propeller manufacturers offer products that fall into ranges that have incremental characteristics. Therefore, based on the resistance calculations, the engines with the characteristics closest to the necessary ones will be searched in the available offer, in order to achieve a construction with functional parameters as close as possible to the optimal ones. Thus, from the *MAN B&W* company product rang it can be choosed a two-stroke engine, of dual fuel type, from the *MAN 6S70ME-GI* series, [3]. This engine meets the power requirements set out in the first chapter of the project. The rudder and propeller assembly are presented in Figure 3.

Fig. 3. *Wartsila Cunial* propeller fitted on *Saga Dawn*[2]

Fig. 4. MAN 6S70ME-GI main engine, 6-cylinder in-line configuration [2]

The engine presented in Figure 4 develops the required power (14,300 kW) at 90% M.C.R. and at a speed of about 97 rpm. It is immediately noticeable that the characteristic parameters of the adopted engine are very close to the previously calculated optimal parameters (the calculated running speed is even higher than initially intended and the relatively high percentage of M.C.R. does not seem to be a rarity in the context of more recent achievements). Therefore, by reducing the speed, speed and percentage of the M.C.R. they will be within the desired limits, so no further adjustments or optimizations are needed at this stage.

In addition, the engines in the *MAN ME-GI* series also have the ability to run on gas. Thus, instead of burning and eliminating gas vapours resulting from the phenomenon of evaporation and temperature variations (BOG), they are directed to power the main engine, significantly reducing the costs of fuel consumption, but also the costs of losing a certain quantity of the goods transported. The *ME-GI* engine is equipped with an additional high-pressure injection system that allows the introduction of gas vapours into the combustion chamber [3]. It is ignited by a quantity of pilot fuel, facilitating continuous operation on the gas. Further details about the chosen main engine will be presented in the next chapter, the emphasis being on its lubrication system.

The main engine lubrication system is directly integrated into the engine construction. Most components are connected to the engine block without the use of external piping systems, which are provided only for:

- Lubrication pump with pressure control valve and non-return valve;
- Pre-pump;
- Lubrication module with cooler, filter and thermostatic valves;
- Centrifugal filters;
- Sampling valves;
- Purge for venting the crankshaft lubrication system.

The lubricating oil is sucked out of the oil tank via the connection by the oil pump and is forcibly pushed to the oil module where it is cooled and brought to the correct temperature, then filtered. From here the lubricating oil is discharged into the discharge connection and is directed on two routes, to the intake manifold and to the intake valve. The intake manifold is integrated in the crankcase and provides lubrication for the following components: crankshaft bearings, bearing bolts, pistons, and for the drive wheels of the pumps at the free end (which is not visible). The intake is integrated in the engine block and provides lubrication for the following elements:

- Camshaft bearings, fuel pump supports with the gears of this pump; exhaust valves, cylinder head and injectors (for injectors the oil has only a cooling role);
- Camshaft driven by gear wheels;
- Gear of the drive device;
- Turbocharger bearings.

**Bearing lubrication** - the suction lubricating oil enters the bearing through the holes in the lubrication bolt and through the bearing caps on the bearing. This oil flows through the lubrication channel provided in the engine block. The upper bearing of the bearing is rounded through the holes provided in it, and from it flows back on the bearing and on the camshaft of the short shaft.

**Lubrication of the connecting rod bolt** - Through the lubrication channel in the camshaft, the oil flows from the short shaft of the bearing to the connecting rod spindle and to the large end of the bearings.

Through a large hole, the oil flows into the large circumferential lubrication channel, into the bearing housing cover and partially passes into the upper part of the connecting bolt at the large end. The oil is conducted through a vertical channel in this bolt to the bearing cap of the bearing bolt, [4].

**Piston lubrication** - Through the holes made in the middle of the bolt the oil enters a distribution space and exits through the holes at both ends, as shown in the figure below. The oil is led to four vertical channels to the piston skirt, and at the end of the vertical channels the lubricating oil is distributed through the holes in order to control the amount of oil that reaches the piston crown, having the role of cooling this component. Four horizontal spray holes are also used to lubricate the cylinder liner, piston skirt and piston rings during engine operation. The oil flow during all this time is controlled by these holes mentioned above. The amount of excess oil on the cylinder liner is cleaned by a scraper segment and drained through a channel at the base, below the cleaning segment, through the holes in the cylinder liner, directly to the crankshaft. After passing the transient area at the top of the piston, the oil reaches the outer space of the piston crown. This outer space is separated from the central space by an outer area with two channels at different heights. Due to these channels, the outer space of the crown is always partially filled with oil. During the translational movements of the piston, the lubricating oil is mixed and has an increased speed, while at the same time intensely cooling the piston crown. The collected oil flows into the central area of the piston crown. At this point, a second mixing action begins, thus cooling the central area of the piston crown. After the oil cools the piston, it flows back into the crankcase.

**Gearbox lubrication** - Part of the camshaft lubrication oil is intended for lubricating the intermediate gear and intermediate bearings. Both intermediate drive wheels are provided with radial holes for lubricating the drive wheel teeth.

**Turbocharger Lubrication** - The turbocharger is lubricated directly by the main pump of the lubrication system which is fed to the specially provided connection and is then drained to the crankcase of the main engine. A sensor is mounted so that it can detect the process of bending the turbocharger before starting the engine.[4]

**Camshaft lubrication** - For this system, the lubricating oil is sent to the high-pressure fuel pump and to the valve driven by the dowels. To send the oil to the cylinder head, install an additional connection oil line and connection. Some of this oil is used to cool the nozzle tip of the injector. Thus the lubricated components are the following: shaft and rocker arms, pivots and end pieces, valve torsion shafts, valves and valve guides.

The main lubrication pump is driven directly by the main engine, only if it has sufficient rated capacity to maintain the rated lubricating oil pressure under normal main engine operating conditions. During the process of starting the main engine, the motor oil pump driven by the engine must be supported by a lubricating oil pump until a minimum value of the main engine speed is obtained. The junction box, built on the discharge of the main lubrication pump, is equipped with a non-return valve to prevent oil from flowing in the opposite direction if the lubrication pump is blocked or even if the main lubrication pump is blocked. The pressure control unit is provided directly on the pump housing.

In order to calculate the parameters of the lubrication oil heat exchanger, a series of functional parameters must be established that define its working environment:

- Oil temperature at the inlet to the cooler: $T_{io} = 60\ ^\circ C$;
- Current oil temperature: $T_{co} = 65^\circ C$;
- Salt water temperature at the inlet to the cooler: $T_{swi} = 20^\circ C$;
- Salt water temperature at the outlet of the cooler: $T_{swo} = 28^\circ C$;

The oil remains the main thermal agent (the element that gives off heat)

Water is the secondary thermal agent (the element that receives heat).

The cooler is of the type with plates, these being made of brass with the thickness:

$$d_p = 0.03\ [m]$$

The total length of a plate is 2.5 meters.

The general efficiency of such coolers is equal to: $\eta = 0.98$, [5].

The global coefficient for the heat exchange process has the highest value in the temperature range 800 - 1200 [kJ/m$^2$h], the highest value being:

$$k = 800\ [kJ/m^2h\cdot grd]$$

Further, a plate heat exchanger can be used. It meets the technical requirements presented in the above description of the main engine. That is why the *Alfa Laval T35* plated-heat exchanger, is presented in Figure 5:

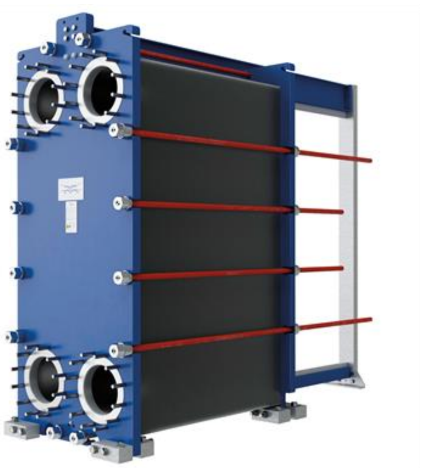

Fig 5. *Alfa Laval T35* plate heat exchanger fitted in the lubrication system for the *Saga Dawn* LNG tanker[5]

## 2. *ALFA LAVAL T35* PLATE HEAT EXCHANGER OPERATIONAL ANALYSIS

The heat transfer between the two media can be done through a solid wall, which separates them, or it can be done by mixing the media. If the mediums are in contact with the dividing wall on different sides, the heat passing through the wall, the exchanger is of the recuperative type, and if the media are in successive contact with the same face of the wall, the heat accumulating in the wall and being transferred to the other medium. it is of the regenerative type. Heat transfer always takes place, according to the second principle of thermodynamics, from the warmer to the coldest environment.

According to the heat transfer mode, the heat exchangers are divided into surface heat exchangers, in which the heat is transmitted through a partition wall, considered a separation surface, with a high thermal conductivity and variable heat exchanger, in which the heat transfer is done through the mixture. environments. Because they are simpler and more efficient, mixing exchangers are preferred in all cases where fluids can be mixed. The heat transfer can be stationary in time (continuous) or non-stationary (periodic). Those with continuous transfer are usually made with a separating surface and are called recuperators, and those with non-stationary transfer accumulate heat over a period of time and return it in another, being called regenerators. Another type of non-stationary heat exchangers are accumulators, in which heat is stored and then delivered on demand, [5].

Being a crucial part in the lubrication system, the calculation of the installation verification using calculation programs based on MEF (*Finite Element Method*) will be summarized only at the specified cooler. *ANSYS* simulation program is used to check the heat exchanger in the main engine lubrication system on board the LNG Saga Dawn tanker. This simulation software allows the assessment of the situation using several processors that can run on the same computer. This parallel processing consists of the correlation of the program, the host process and the processing set. The *Ansys Fluent* simulation program has the following modelling and calculation possibilities:

- calculation of flows on 2D flat surfaces, symmetrical with respect to a 2D axis, symmetrical and rotational with respect to a 2D, and 3D axis;
- discretization with discretization cells in the shape of a quadrilateral, triangular, hexagonal, tetrahedral prism, pyramid, polyhedron, and mixed cells;
- balanced flow or transient flows;
- flows of incompressible or compressible liquids, including all speed regimes (subsonic, transonic, supersonic, and hypersonic);
- laminar and turbulent flows;
- Newtonian or non-Newtonian flows;
- real or ideal gas;
- heat transfer by convection, conduction and radiation;
- mixing of different chemical compounds, including homogeneous and heterogeneous combustion modelling and surface deposition/reaction models;
- multiple reference frames (MRF) and discretization cell sliding options for modelling more moving frames;
- database with the properties of different materials, [6].

The first step in the simulation process is the cooler respecting the geometric parameters as it appears from its technical book, as shown in Figure 6.

With the help of the *Design Modeler* option, the geometric construction of the heat exchanger in the installation frame was realized.

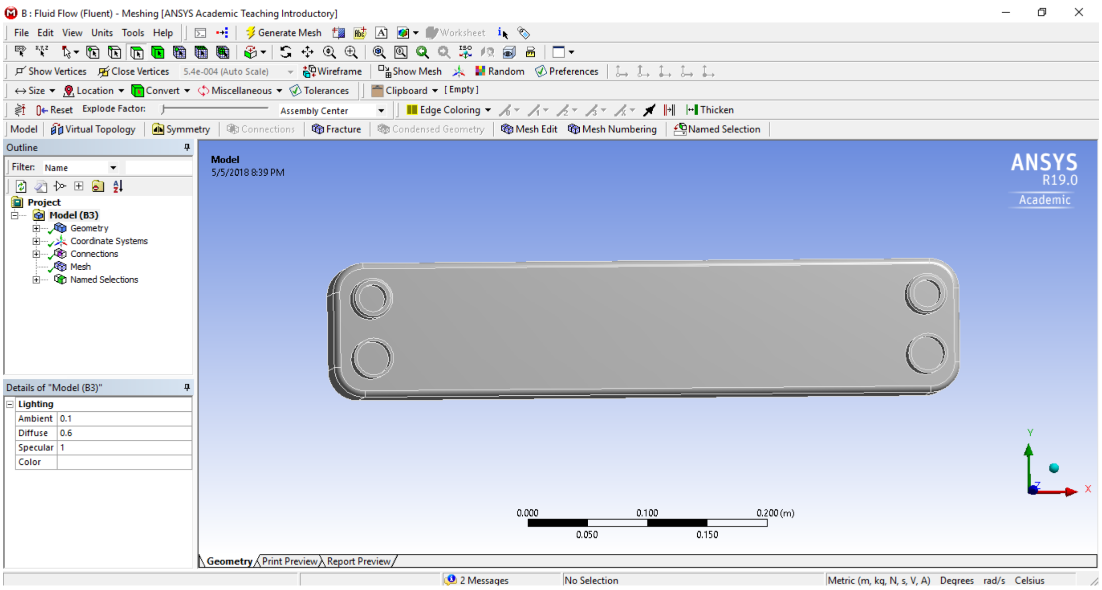


Fig. 6. Heat exchanger geometry [6]

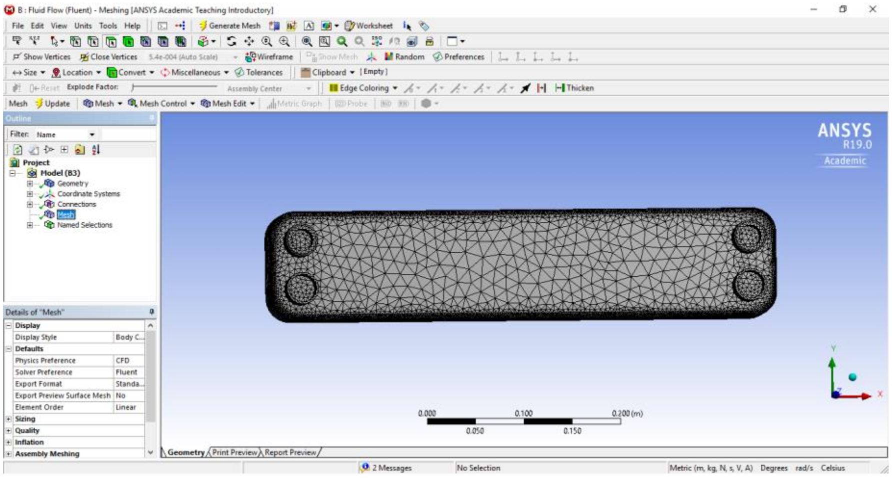


Fig. 7. Heat exchanger meshing [6]

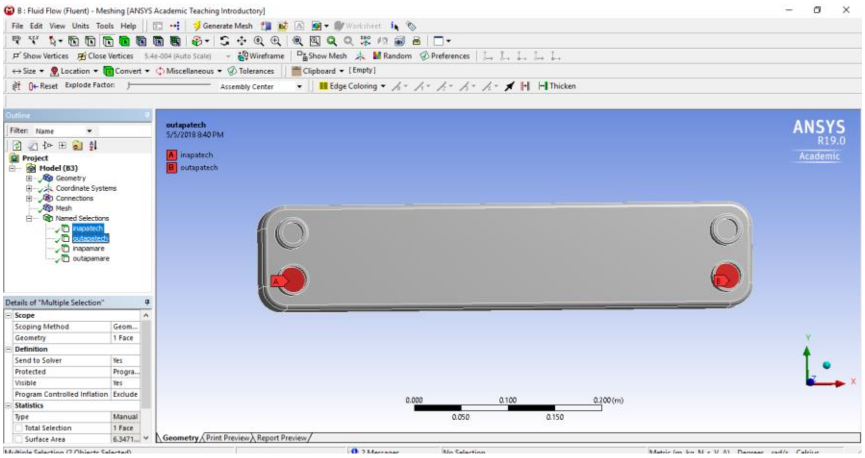


Fig. 8. Defining the chilled oil inlet points [6]

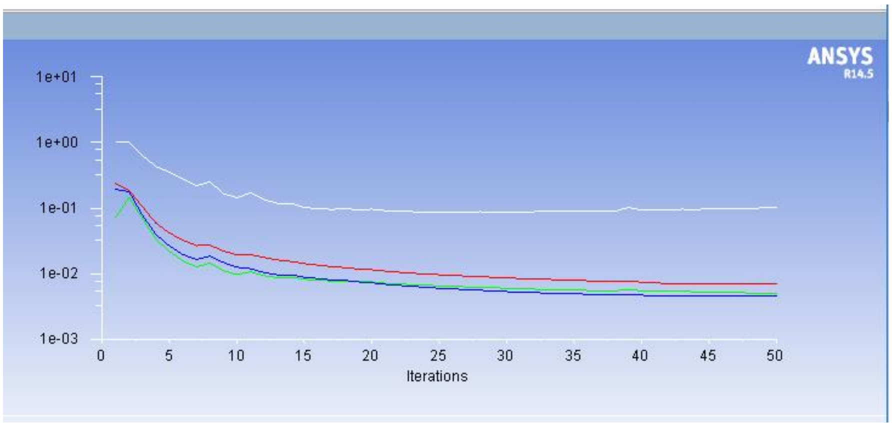


Fig. 9. Iterations of fluid (oil) flow in Ansys CFD [6]

The heat exchanger respects the geometric characteristics presented in the previous chapters. As can be seen, the following components were done:

•geometrical body of the heat exchanger;

•inner pipes;

•working fluid inlet-outlet openings, [7].

The next stage after the geometric construction is the meshing of the cooler, as it was presented in Figure 7. This process is a structural analysis of the entire heat exchanger, it being divided into a certain number of cells, in view of the possibility of further development of the calculation on each cell, determining the particular values of the walls. The discretization was performed with the help of the "Mesh" interface of the *Ansys Fluent* program. The structural analysis resulted in 1934,221 cells and 650,435 nodes.

In the first stage, the fluid inlet and outlet points are established. Were noted 5 inputs for the coolant and one inlet for the cooled fluid, as presented in Figure 8, as well as the overall iterations number, in a graphical manner, presented in Figure 9. I also noted 5 coolant outlets and one coolant outlet.

In the next stage, the type of fluid, the number of iterations for the calculation of the calculation were established and the flow of fluid through the pipes was simulated. In the same stage, the inlet and fluid parameters, both pressure and speed, were established, as shown in Figure 10 and further on detailed in Figure 11. Detailed simulation of several perspectives of the heat exchanger are presented as follows: heat exchange simulation per unit volume (upper part), in Figure 12, followed by heat exchange simulation per unit volume (upper part), in Figure 13 and finally Heat exchange simulation per unit volume (upper part) and simulation per unit volume (side part) in Figure 14:

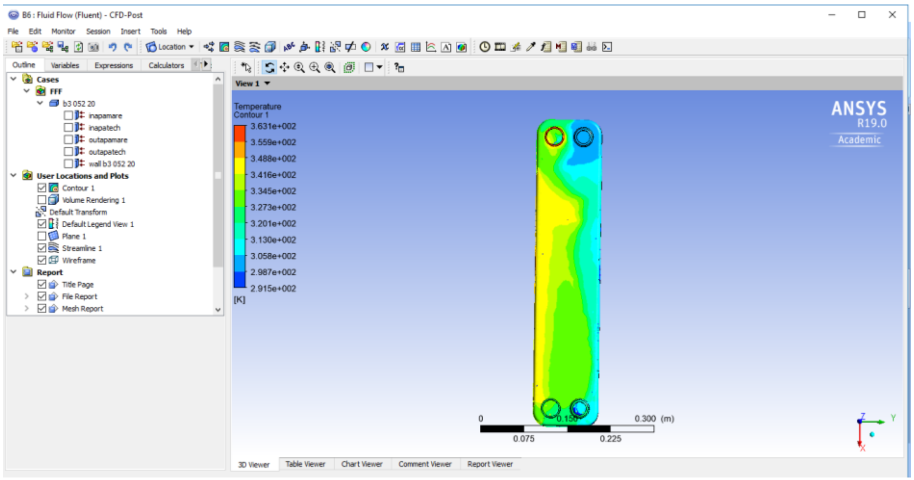


Fig. 10. Heat exchange simulation (the entire heat-exchanger surface) [6]

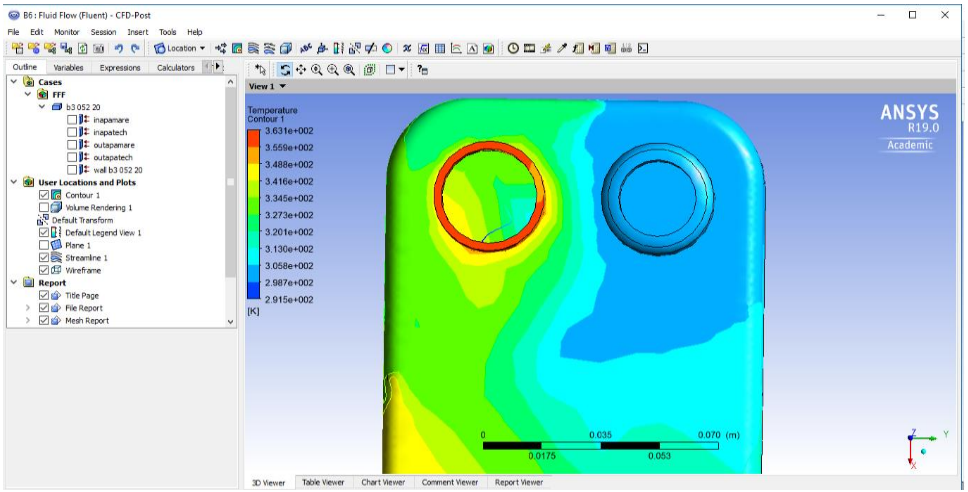


Fig. 11. Heat exchange simulation (the upper part) [6]

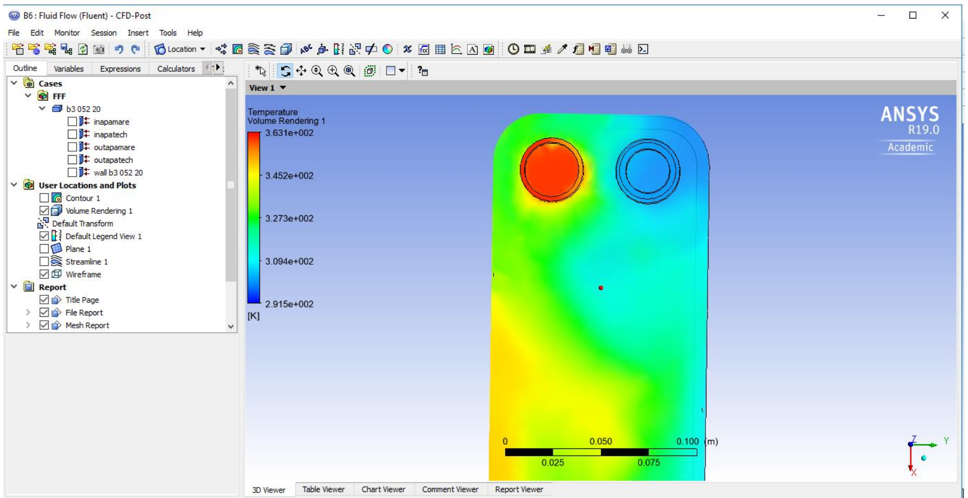


Fig. 12. Heat exchange simulation per unit volume (upper part) [6]

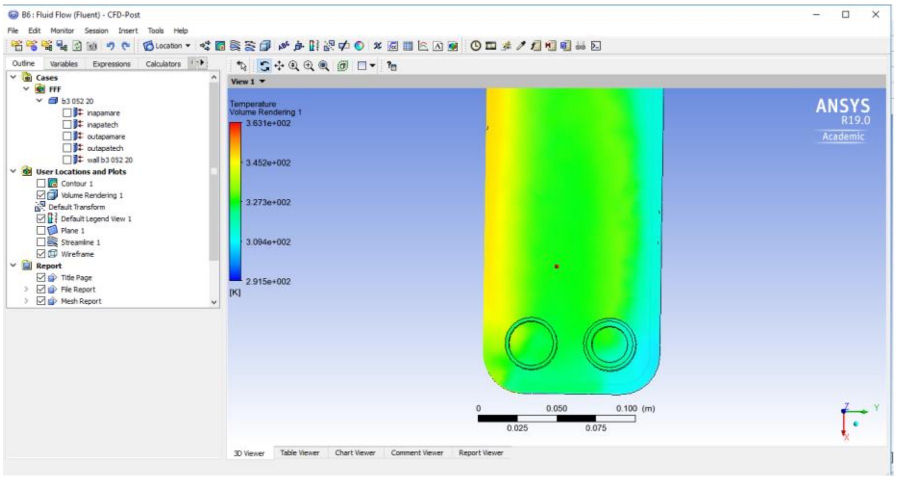

Fig. 13. Heat exchange simulation per unit volume (bottom part), [6]

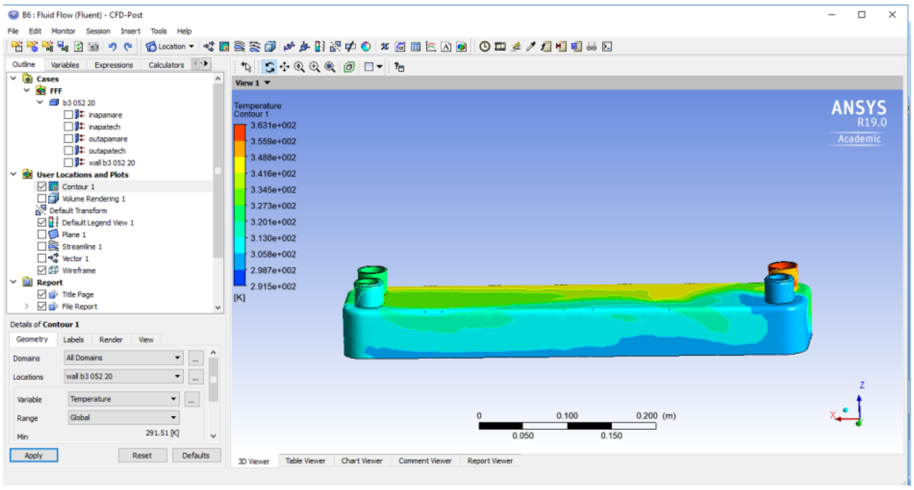

Fig. 14. Heat exchange simulation per unit volume (side part) [6]

The results obtained after the simulation conclude that the temperature contour in the heat exchanger for cooled oil flows form minimum 291˚K to maximum 363˚K.

## 3. CONCLUSIONS

•In the case of large, slow, two-stroke engines, the capacity of an oil pan can reach up to 30,000 liters. The lubrication pump has an oil filter, which can sometimes be inserted directly into the crankcase of the main engine. From there, the oil pump circulates the lubricating oil and leads it to a discharge filter with a fine sieve, with meshes with a diameter of only 25 microns. Further the oil passes through the oil cooler, whose cooling medium is sea water. The most efficient heat exchangers for main engine oil are those with plates. Generally, these coolers have a temperature control valve to supply the required temperature to the main engine. Normally the oil temperature at the engine inlet is (40 – 42)˚C. The basic function of the main engine oil is to lubricate the main bearings, the cross head and the crankshaft. At the same time, the oil is sent to the piston crown and cools this system, bringing it to the operating temperature of the main engine. The potential damage to the lubrication system can lead to major damage to the main engine components, which translates into costly repairs and operational costs, while the ship is taken out of service.

•According to a series of studies carried out by Swedish shipping companies, damage to main engines accounts for 28% of all causes of plant damage, amounting to around 38% of the total cost of repairs. The average of these costs per ship reaches the threshold of 650,000 US dollars annually. Lubrication system failures are the most common and costly type of failure that can occur in the case of a main engine, which is followed by improper maintenance and inefficient management of the main engine fuel.

•The main cause of damage to the main engine lubrication system is its poor management in combination with its contamination with abrasive metal particles. Therefore, efficient cleaning of the lubricating oil is essential to minimize the risk of premature wear of the main engine and to prevent frequent breakdowns.

•From 2020, the IMO expects that the rules on the use of naval fuels worldwide will be tightened, the main condition being that they do not have a sulfur content higher than 0.5%, and this will have a significant impact on the characteristics and requirements of lubricating oil. Reducing the sulfur content from 3.5% to 0.5% will require a reformulation of the use of lubrication plants. These types of fuel will demand more of the essential components of the main engine from the perspective of wear.

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