Design and Analysis of Heat Exchange of Subsea Cooling System for Ship Protector Motor

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Abstract. The purpose of this research is to design an underwater cooling system to cool the Diesel motor, determine the performance of the Diesel motor and calculate the rate of heat exchange. This study uses an experimental method. The location for obtaining data related to the problems in this paper is located at the location of the fishermen at Lampu Satu beach, Samkakai District, Merauke Regency. The amount of heat transfer that occurs in the modified cooling system is larger, which is in the range of \( Q = 26099,6 \) W for stationary ships and \( Q = 3196,91 \) W for road ships, when compared to the original heat exchanger which is only \( Q = 3196,91 \) W for stationary ship and \( Q = 16126,2 \) W for moving ship. The occurrence of heat transfer in large quantities in the modified heat exchanger because it is also influenced by the speed of the ship, so that heat can move quickly in large quantities to the open sea. The modifications made have no effect on engine performance, because from the results of calculating engine performance as a comparison to determine engine performance, it can be seen that the calculated quantities are the same value, there is only a difference in the amount of heat lost due to other losses, namely \( Q_{oth} = 4,1 \) kW for the original heat exchanger, while the modified heat exchanger is \( Q_{oth} = 4,3 \) kW.

Keywords: Coolant, Heat, Engine.

A. INTRODUCTION

Diesel motors belong to the group of internal combustion engines, where the combustion process takes place in the cylinder. This Diesel Motor uses liquid fuel which is inserted into the combustion chamber of the motor cylinder by being injected using an injection pump. The use or application of Diesel Motors as a driving force (primover) is growing rapidly and will continue to grow. Diesel motors are widely used for transportation purposes, one of which is as the main propulsion of ships. The cooling system used on fishing vessels, especially those in Lampu Satu, Samkakai Village, Merauke Regency, is generally a closed cooling system.

This closed cooling work system is that fresh water is flowed through a pump (Fresh Water Pump) to cool the Diesel motor in a closed manner and sea water is flowed through a pump (Sea Water Pump) to cool the Diesel motor continuously as long as the Diesel motor is still working. The cooling system used is inefficient because of frequent damage to the sea water pump and strainer on the Diesel motor radiator and also damage to the Diesel motor as the main mover. Damage occurs because when sea water is flowed to cool fresh water mixed with sand and mud, it causes damage to the water seal pump and strainer in the heat exchanger. Based on this, the author tries to design the existing cooling system by no longer using a sea water pump, but fresh water is pumped under the sea by a fresh water pump through a spiral pipe to be cooled directly by sea water.

The problem here is how to find out how much the temperature changes at the inlet temperature (Ti) before cooling the Diesel motor and the outlet temperature (To) after cooling the Diesel motor.
B. LITERATURE REVIEW

Fishing vessels of the type of people's ships operate only on the coast of the Merauke Sea, while iron ships operate up to the Arafura Sea and the Banda Sea (Maluku). Iron ships operate in clear (clean) seas, while people's ships operate on the coast of the Merauke Sea where the water is cloudy, both river water and sea water are all cloudy because they are mixed with mud and fine sand also has a high salt content.

Iron ships (modern) in their operation rarely experience problems with the cooling system because they operate in clean seas, while people's ships always experience problems with the cooling system because they operate in cloudy water (Xu & Shi, 2014). In the event of damage, local fishermen suffer huge losses, because fishermen must bear all operating costs and the period of damage costs during the time the ship is not operating (Sommariva et al. 2003).

Based on the analysis of Merauke's muddy and sandy sea conditions, the authors think that there is no need to use a sea water pump to cool fresh water by modifying it, namely fresh water that has cooled the Diesel motor is directly pumped to the bottom of the sea through a flow pipe, (spiral) and from the spiral pipe back into the Diesel motor (Shin & Nam, 2015). In this case sea water is used as a heat exchanger directly without going through a sea water pump. With this modification, it is hoped that it will improve the efficiency of the Diesel motor used (Groppi & Tronconi, 2000).

The cooling system used in Diesel motors for people's ships is a closed cooling system, where seawater is pumped to cool fresh water as engine coolant (Shuqiang et al. 2015). The pumped seawater mixes with mud and fine sand so that there is repeated friction between the fluid flow and the cross section of the pump, flow pipe and strainer heat exchanger (Toro & Sciubba, 2018). This condition continues as long as the Diesel motor is still operating, resulting in frequent damage/leakages in the flow pipes, pumps and heat exchangers so that the ship cannot operate.

1. Heat Transfer

The heat transfer process occurs, when two objects are in contact, heat will flow from a medium with a high temperature to a medium with a low temperature. The mechanism of heat transfer can occur in the form of conduction, convection and radiation heat transfer. In fact, the above heat transfer process takes place simultaneously, but for temperatures that are not too high, the radiation can be ignored.

a. Conduction Heat Transfer

An object that has a gradient, the rate of flow of heat transfer without being accompanied by a movement of the substance. This process of heat transfer is called conduction or conduction. Heating a metal means activating molecular motion, while cooling means reducing molecular motion. The rate of heat transfer by conduction is proportional to the temperature gradient.

\[ Q = \frac{2\pi kL}{\ln\left(\frac{r_o}{r_i}\right)} (T_{d1} - T_{d2}) \]

where;

\( Q \) = Heat transferred (W)

\( k \) = Heat conductivity (W/m.\(^\circ\)C)

\( L \) = Length of delivery field (m)

\( r_o \) = Outer diameter of pipe conduction area (m)

\( r_i \) = Inner diameter of pipe conduction (m)

\( T_{d1} \) = Temperature in of the conduction field (\(^\circ\)C)

\( T_{d2} \) = Temperature out of the conduction field (\(^\circ\)C)
b. Convection Heat Transfer

The flow of fluid that passes on a surface, it will also be carried away by a number of enthalpies. This enthalpy flow is called convection flow. Convection is a macroscopic phenomenon and only occurs when there is a force acting on the particles or there is a fluid current that can make a movement against the frictional force. Heat transfer is simply the flow of heated water in a cauldron. Heat transfer by convection is expressed by Newton's equations of cooling.

\[ \dot{Q} = h_c \cdot A \cdot \Delta T \]

where:

- \( \dot{Q} \) = Heat transferred (W)
- \( h_c \) = Heat transfer coefficient by convection (W/m\(^2\).°C)
- \( A \) = Heat transfer surface area
- \( \Delta T \) = Changes in inlet and outlet temperature (°C)

c. Heat Exchanger Flow System

The process of heat transfer in two fluids with different temperatures, not only for the purpose of heating but also for cooling the fluid. There are various types of heat exchangers according to size, effectiveness, heat transfer, flow, type of construction (Bidarmaghz & Narsillio, 2018). However, based on the work system used, heat exchangers can be classified into two main systems, namely: 1) Direct heat transfer. An object when heated or cooled, comes into direct contact with hot or cold objects or media; and 2) Indirect heat transfer (Fernandez & Miller, 2015). Indirect heat transfer occurs when one fluid is transferred to another fluid through a separating wall.

d. Heat exchanger

How many types of conventional heat exchangers to date, there are several types that for decades dominate the function as heat exchangers in industry. Conventional heat exchangers that are often used are: 1) Double pipe heat exchanger; 2) Plate and frame heat exchanger; and 3) Shell and tube heat exchanger. The heat exchanger that will be reviewed and discussed in this paper is a modified shell and tube.

e. Shell and tube heat exchanger

The shell and reed heat exchanger consists of a unit neatly arranged in pipes connected in parallel and housed in a mantle (shell) pipe. One fluid flows inside the pipe bundle, while the other fluid flows outside the pipe in the same, opposite, or intersecting directions. To increase the efficiency of heat transfer, usually in the shell and reed heat exchanger a bulkhead is installed (buffle). This aims to create turbulence in the fluid flow and increase the residence time.

f. Calculation of heat transfer and engine performance

The parameters to be calculated in this heat transfer system are:

1. Fluid temperature (\( T_i \)) around the heat transfer area

\[ T_b = \frac{T_{ci} + T_{co}}{2} \] (°C)

where:

- \( T_{ci} \) = The temperature of the fluid entering the flow plane (°C)
- \( T_{co} \) = The temperature of the fluid leaving the flow plane (°C)
- \( T_b \) = Average wall temperature and free flow temperature(°C)

2. Overall heat transfer coefficient (\( U \))

\[ U = \frac{1}{\frac{1}{h_i} + \frac{1}{h_o}} \text{ W/m}^2 \cdot \text{°C} \]
where:

\( h_i \) = Coefficient of convection in the pipe (W/m\(^2\).°C)

\( h_o \) = Convection coefficient outside the pipe (W/m\(^2\).°C)

To calculate \( U \), you must first calculate and search for other parameters related to the heat transfer coefficient \( U \), including:

a. The average velocity of the cold fluid in the pipes of the heat exchanger

\[
V_m = \frac{\dot{m}}{\rho A_c} = \frac{\dot{m}}{\rho \left( \frac{1}{4} \pi D_i^2 \right)} \quad (m/s)
\]

where:

\( A_c \) = \( \frac{1}{4} \pi D_i^2 \) \quad (m\(^2\))

\( V_m \) = Average velocity of flow in the pipe (m/s)

\( \dot{m} \) = Mass flow rate flow (kg/s)

\( \rho \) = Density of cold fluid (kg/m\(^3\))

\( A_c \) = The cross-sectional area of the cold fluid heat transfer (m\(^2\))

\( D_i \) = Cold fluid flow pipe inside diameter (m)

\( \pi \) (pi) = Constants for calculating pipe surface area

b. Maximum velocity of hot fluid flow in shell heat exchanger

\[
V_{max} = V_m \frac{S_r}{S_r - r_o} \quad (m/s)
\]

where:

\( S_r \) = The vertical distance between pipes in a series of pipes (m)

\( D_o \) = Outside diameter of tube/pipe (m)

c. Mass flow rate of cold or hot fluid (\( \dot{m} \))

\( \dot{m} = \rho \times Q \) \quad (kg/s)

Where:

\( Q \) = Cold fluid flow rate (m\(^3\))

d. Average velocity of hot fluid flow in heat exchanger

\[
V_m = \frac{\dot{m}}{\rho A_h} = \frac{\dot{m}}{\rho \left( n_t \pi D_o L \right)} \quad (m/s)
\]

where:

\( A_h \) = \( n_t \pi D_o L \) \quad (m\(^2\))

\( A_h \) = Heat transfer surface area of hot fluid (m\(^2\))

\( L \) = Heat exchanger length (m)

\( D_o \) = Outside diameter of cold fluid flow pipe (m)

\( n_t \) = Number of tubes in 1 series of pipes

\( \rho \) = Density of hot fluid (kg/m\(^3\))

Reynolds number (\( R \))

\[
Re = \frac{\rho V_{max} D_o}{\mu}
\]

Where:

\( \mu \) = The dynamic viscosity of the fluid, kg/m.s,

e. Nusselt number (\( Nu \))

\[
Nu = \frac{h_i D}{k} = 0.023 \sqrt{Re^{0.8} \cdot Pr^{0.4}}
\]

(General definition of Nusselt number)

where:

\( Pr \) = Prandtl numbers,

\( Nu \) = Nusselt number (\( Nu \))
Nu = C₁ . Re<sup>m</sup> (Nusselt definition of shell and tube)
where:
C₁ and m are the Grison correlation constants for the arrangement of pipes in a summary in the form of inline or alternating arrangements.

f. Heat transfer coefficient (h₁) in cold fluid flow (Tube)
h₁ = \frac{k}{D_o} \cdot Nu \quad W/m²°C
where:
k = Thermal conductivity of cold fluid (W/m°C)

g. Heat transfer coefficient (hₒ) on hot fluid (Shell)
hₒ = \frac{k}{D_i} \cdot Nu \quad W/m²°C
where:
k = Thermal conductivity of hot fluid (W/m°C)

h. Temperature Difference (∆T<sub>lm</sub>)

\[
\Delta T₁ = T_{hi} - T_{co} \quad (°C)
\]
\[
\Delta T₂ = T_{ho} - T_{ci} \quad (°C)
\]
\[
\Delta T_{lm} = \frac{\Delta T₁ - \Delta T₂}{\ln(\Delta T₁/\Delta T₂)} \quad (°C)
\]
where:
T<sub>ci</sub> : The temperature of the cold fluid entering the heat exchanger (°C)
T<sub>co</sub> : The temperature of the cold fluid leaving the heat exchanger (°C)
T<sub>hi</sub> : The temperature of the hot fluid entering the heat exchanger (°C)
T<sub>ho</sub> : The temperature of the hot fluid leaving the heat exchanger (°C)

3. Overall heat transfer in Heat exchanger (∆Q)

\[
Q = U \cdot A_s \cdot \Delta T_{lm} \quad (Watt)
\]
Where:
Heat transfer surface area (A = A<sub>s</sub>)
A<sub>s</sub> = \( n_t (\pi \cdot D_i \cdot L) \) m<sup>3</sup> [4]

4. Pump power (W<sub>p</sub>)

\[
W_p = \frac{m \cdot \Delta P}{\rho} \quad (kW)
\]

**g. Engine Performance**

1. Engine Power (BHP = Ne)

\[
BHP = \frac{2 \pi \cdot n \cdot T}{60} \cdot 10^{-3} \quad kW
\]
Where:
T = Torque (Nm)
N = Number of shaft revolutions per minute (rpm)
10<sup>-3</sup> = Conversion factor from Watts to kilowatts
60 = Conversion factor from minutes to seconds

2. Average Effective Pressure (BMEP = Pe)

\[
BMEP = \frac{60 \cdot nR \cdot BHP}{n \cdot V_L} \quad kPa
\]
Where:
nR = 2 cycles/rev for 4 stroke motor
V<sub>L</sub> = Piston stroke volume
\[
V_L = \frac{\pi \cdot D \times S \times Z}{4 \cdot 10^9} \quad m^3
\]
D = Piston cylinder diameter (mm)
S = Piston stroke length (mm)
Z = Number of cylinders

10^9 = Conversion factor from mm^2 to m^2

3. Total Heat Energy Combustion (\(\dot{Q}_{\text{total}}\))

\[
\dot{Q}_{\text{total}} = \frac{FC \times \text{LHV}_{bb}}{3600} \text{ kW}
\]

Where:

FC = Amount of fuel consumption per hour (kg/h)
LHV_{bb} = The calorific value of fuel (low heating value) (kJ/kg)
3600 = Conversion factor from hours to seconds (second)

4. Thermal Efficiency (\(\eta_{\text{th}}\))

\[
\eta_{\text{th}} = \frac{\text{BHP}}{\dot{Q}_{\text{total}}} \times 100 \text{ (\%)}
\]

h. Heat Balance

1. Burning heat energy (\(\dot{Q}_{\text{tot}}\))

\[
\dot{Q}_{\text{tot}} = \frac{FC \times \text{LHV}_{bb}}{3600} \text{ (kW)}
\]

2. Thermal energy that produces braking power (\(\dot{Q}_{\text{BHP}}\))

\[
\dot{Q}_{\text{BHP}} = \frac{2 \times \pi \times n \times T}{60} \times 10^{-3} \text{ (kW)}
\]

Percentage \(\dot{Q}_{\text{BHP}}\)

\[
\%\dot{Q}_{\text{BHP}} = \frac{\dot{Q}_{\text{BHP}}}{\dot{Q}_{\text{total}}} \times 100 \text{ (\%)}
\]

3. The heat energy that comes out with the exhaust gas (\(\dot{Q}_{gb}\))

\[
\dot{Q}_{\text{gb}} = (M_{\text{act}} + FC) \text{Cp}_{gb}(T_{gb} - T_{i}) \text{ (kW)}
\]

Where:

\(M_{\text{act}}\) = Actual air consumption (kg/s)
\[
M_{\text{act}} = \rho_{a} \cdot V_{s} \cdot n \cdot Z \frac{2 \times 60}{R \cdot T} \text{ (kg/s)}
\]

\(\rho_{a}\) = \(\frac{P}{R \cdot T}\) (kg/m^3)

Where:

\(P\) = Ambient air pressure = 1 atm = 101, 325 kPa
\(R\) = Ideal gas constant (kJ/kg.°K)
\(T\) = Ambient air temperature (°K)
\(\text{Cp}_{gb}\) = Exhaust gas heat kJ/kg.°K
\(T_{gb}\) = Exhaust gas temperature (°K)
\(T_{i}\) = Air temperature (°K)

Percentage \(\dot{Q}_{gb}\) to total heat

\[
\%\dot{Q}_{\text{gb}} = \frac{\dot{Q}_{\text{gb}}}{\dot{Q}_{\text{total}}} \times 100 \text{ (\%)}
\]

4. Heat Loss Due to Cooling (\(\dot{Q}_{pm}\))

\[
\dot{Q}_{pm} = q_{pm} - C_{p_{h}}(T_{hi} - T_{ho}) \text{ kW}
\]

Where:
\[ q_{pm} = m_h \]
\[ q_{pm} = A_{pm} \cdot \rho_c \cdot \frac{60 \cdot 1000}{\text{Dan}} \]
\[ A_{pm} = \text{Cooling water flow rate} = 3 \text{ L / minutes} \]
\[ A_{pm} = \frac{Q_{(data)} + 1,8}{0,36} \text{ l/minutes} \]
Heat Percentage (\(\%Q_{pm}\))
\[ \%Q_{pm} = \frac{\dot{Q}_{pm}}{Q_{total}} \times 100 \]

5. Heat energy lost due to other losses (\(\dot{Q}_{oth}\))
\[ \dot{Q}_{oth} = Q_{total} - (\dot{Q}_{BHP} + \dot{Q}_{gb} + \dot{Q}_{pm}) \]
Percentage \(\dot{Q}_{oth}\) to total heat \(\%\dot{Q}_{oth} = \frac{\dot{Q}_{oth}}{Q_{total}} \times 100 \) (%)

C. METHOD

This research uses experimental or research methods that directly design tools, conduct experiments and observations in the field to collect the necessary data. The location for obtaining data related to the problems in this paper is located at the location of the coastal fishermen of Lampu Satu, Samkakai District, Merauke Regency and the Mechanical Engineering Laboratory of Musamus University.

The research implementation is as follows: 1) Tool making. A tool made based on its function and size. Made in the form of a spiral with four stacked rows; and 2) Pump installation. The fresh water pump will be installed at the inlet of the motor cooling system (Wang et al. 2020).

This study was designed with 2 (two) temperature measurement treatments, namely the temperature of the cooling water before it is cooled in the underwater cooling system and the exit temperature when it enters the motor again. The temperature will also be measured at points determined later. The analytical method used is the flow rate of heat transfer analyzed using conduction analysis and convection analysis.

Figure 1. Location of the Cooler on the Hull
D. RESULT AND DISCUSSION

In operation and the results of the analysis and calculation results, the modified cooling system turned out to function better than the original cooling system, because the modified cooling system can release more heat than the original cooling system (Kim et al. 2009). The difference between the original cooling system and the modification of the stationary ship can be seen from the results of the calculations in table 1 and table 2. It can be seen that there is a difference in the amount of heat transfer that occurs between the original heat exchanger and the modified heat exchanger when the ship is stationary. The amount of heat transfer that occurs in the original heat exchanger is smaller than the heat transfer that occurs in the modified heat exchanger. This happens because the heat transfer surface area in the original heat exchanger is smaller, while the modified heat exchanger is larger than the original heat exchanger.

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<tr>
<th>Table 1. Comparison of Original and Modified Silent Ship Heat Exchanger</th>
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<th>Table 2. Comparison of Original and Modified Road Ship Heat Exchangers</th>
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E. CONCLUSION

After observing, analyzing and calculating as a comparison between the original cooling system and the modified cooling system, it can be concluded that: 1) The amount of heat transfer that occurs in the modified cooling system is larger, which is in the range of $Q = 26099, 6 \text{ W}$ for stationary ships and $Q = 197620,3 \text{ W}$ for road ships, when compared to the original heat exchanger which is only $Q = 3196,91 \text{ W}$ for stationary ship and $Q = 16126,2 \text{ W}$ for moving ship. The occurrence of heat transfer in large quantities in the modified heat exchanger because it is also influenced by the speed of the ship, so that heat can move quickly in large quantities to the open sea; 2) In terms of savings, the original cooling system had to use another pump to help channel seawater to cool fresh water, while the modified cooling system did not require an auxiliary pump but only used the fresh water pump on the engine; and 3) The modifications made have no effect on engine performance, because from the results of calculating engine performance as a comparison to determine engine performance, it can be seen that the calculated quantities are the same value, there is only a difference in the amount of heat lost due to other losses, namely $Q_{oth} = 4,1 \text{ kW}$ for the original heat exchanger, while the modified heat exchanger is $Q_{oth} = 4,3 \text{ kW}$.

REFERENCES


