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Heat Transfer Analysis of Thermal Oil Plant on Fuel Oil Tanks of 17500 LTDW Product Oil Tanker

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***Abstract*— The thermal oil system is one type of heater that widely used on ships. The system is an important system used to heat fuel that will be used for the operation of the main engine, auxiliary engine, and boiler. This system has been installed on 17500 LTDW Product Oil Tanker, MT. Parigi, but not yet tested so that it does not know whether the system is able or not to transfer heat from heating equipment (boiler and economizer) to each fuel tank in accordance with the desired value. Therefore, this research performs an engineering evaluation in term of heat transfer analysis to ensure that the heat transfer process of thermal oil from heating equipment to the fuel tanks is already meeting the required temperature or not. This analysis is done by using thermodynamic equation, namely heat balance equation and heat loss equation. The result shows that the heat transfer of thermal oil to each fuel tank corresponds to the desired value, namely 180°C for the thermal oil inlet temperature to each fuel tank and 140°C for the thermal oil re-enter temperature to the heating equipment.**

Keywords—Heating System, MT. Parigi, Thermodynamic, Heat Balance, Heat Loss.

I. Introduction

Fuel heating system is one of the most important systems on the ship. This system is intended to maintain the temperature of fuel oil that will be used for the operation of the main engine, auxiliary engine, and boiler. The heating process of fuel is generally done by several types of heating, namely by using steam, electric, and thermal oil. MT. Parigi (17500 LTDW Product Oil Tanker) uses the thermal oil heating system as its fuel heating system.

The thermal oil heating system on MT. Parigi is done by using two kinds of heating equipment, namely boiler and exhaust gas economizer. In the operating scenario, the system will use boiler as its heating equipment when the ship sails in the territorial sea, while the exhaust gas economizer will be used when the ship sails at high sea (minimum 85% MCR of the main engine).

This system is already installed on board, but not yet tested so that it does not know whether the system is able or not to transfer heat from the heating equipment to the each fuel tank in accordance with the desired value. This system is designed to operate at working pressure of 5kgf/cm^2, working temperature of 180°C for the thermal oil inlet temperature to each fuel tank and 140°C for the thermal oil re-enter temperature to the heating equipment. If the system is not evaluated, consequently the fuel can not be pumped to the next tank or process. Therefore, it is needed an analysis to ensure that the heat transfer of thermal oil heating system is appropriate with the designed value, namely heat transfer analysis.

This research will conduct an engineering evaluation in term of heat transfer analysis in solving the problem statement. This analysis will use some thermodynamic equations, namely heat balance equation and heat loss equation. The analysis is done on two scenarios, namely boiler scenario and exhaust gas economizer scenario.

II. METHOD

The analysis is divided into several stages, which will be explained as follows.

A. Data Collection

In doing the analysis, there are several data must be known, as follows.

- *ISO Exhaust Gas Data of Main Engine*
  The following table shows the ISO exhaust gas data of the main engine used on MT. Parigi, namely MAN 6S35MC7.1-TRII with 1 MAN TCR22-21.
- *Shop Trial Record of Main Engine*
  The following table 2 will show the result of shop trial record of the main engine.
- *Exhaust Gas Properties*
  Properties of exhaust gas depending on their temperature, which can be seen in the following table. 3
- *Technical Data of Economizer*
  The following table 4 will show the technical data of exhaust gas economizer that has been installed on board.

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TABLE 1.
ISO EXHAUST GAS DATA OF MAIN ENGINE USED ON MT. PARIGI

Load (%MCR)	Power (kW)	Speed (r/min)	Exh. Gas Amount (kg/h)	Exh. Gas Temp. (ºC)
100	4440	173	37200	265
95	4218	170.1	35900	258
90	3996	167	34600	253
85	3774	163.9	33300	249
80	3552	160.6	31900	246
75	3330	157.2	30400	245
70	3108	153.6	28800	245
65	2886	149.9	27200	247
60	2664	145.9	25500	250

TABLE 2.
SHOP TRIAL RECORD OF MAIN ENGINE

Load (%)	Engine Speed (rpm)	Engine Output (kW)	Exhaust T/C Inlet (ºC)	Exhaust T/C Outlet (ºC)
110	178,6	4884	455	265
100	173	4440	420	240
85	163,9	3774	380	225
75	157,2	3330	365	225
50	137,3	2220	385	240
25	109	1110	290	240

TABLE 3.
EXHAUST GAS DATA PROPERTIES

Temp. (K)	Density (kg/m^3)	Enthalpy (kJ/kg)	Specific Heat (kJ/kgK)	Thermal Cond. (W/mK)
260	1,34	260	1,006	0,0231
280	1,245	280,2	1,006	0,0247
300	1,161	300,3	1,007	0,0263
350	0,995	350,7	1,009	0,0301
400	0,871	401,2	1,014	0,0336
450	0,774	452,1	1,021	0,0371
500	0,696	503,4	1,030	0,0404
600	0,58	607,5	1,051	0,0466
800	0,435	822,5	1,099	0,0577
1000	0,348	1046,8	1,141	0,0681
1200	0,290	1278	1,175	0,0783
1400	0,249	1515	1,207	0,0927

TABLE 4.
TECHNICAL DATA OF ECONOMIZER

Economizer Specificiation	
Type	Aalborg EXV632 46 48.3 900DD
Quantity	23,7 m^3/h
Inlet Temperature	140ºC
Outlet Tempearature	180ºC
Flow Resistance	17,5 m.l.c
Diameter Without Insulation	1664 mm
Weight (Empty)	6200 kg
Liquid Contents	1190 Litres

TABLE 5.
TECHNICAL DATA OF THERMAL OIL FLUID

Thermal Oil Fluid Specification	
Type	Therminol 66
Composition	Hydrogenated Terphenyl
Kinematic Viscosity (40ºC)	29,64 cSt
Density (15ºC)	1011 kg/m^3
Flash Point	170 ºC
Fire Point	216 ºC
Total Acidity	<0,02 mgKOH/g
Pour Point	-32 ºC

- *Thermal Oil Fluid*

  From the shipyard, it is stated that the thermal oil fluid to be used in the system has not been determined. In the catalog of thermal oil heater from Alfa Laval, there are several types of thermal oil fluid recommended by the manufacturer. One of them is Therminol 66 with the following specifications that could be seen on Table 5.

B. *Heat Transfer Analysis*

After collecting the data as mentioned above, the analysis will be carried out in the following several stages.

- *Exhaust Gas Flow Rate*

  This analysis will be done by using shop trial record data of main engine, not ISO data. The flow rate of exhaust gas in shop trial record data is not measured. Therefore, must be defined first the value of exhaust gas flow rate in accordance with the data in table 2, by using this following formula.

$$M_{exh} = M_{L1} x \frac{P_M}{P_{L1}} x \left\{1 + \frac{\Delta m_{M\%}}{100}\right\} x \left\{1 + \frac{\Delta M_{amb\%}}{100}\right\} x \left\{1 + \frac{\Delta m_{s\%}}{100}\right\} x \frac{P_{s\%}}{100} \quad (1)$$

Where, M_{L1} is Exhaust gas amount at nominal in *kg/h*; P_M is power at SMCR point in *kW*; P_{L1} is power at desired value in *kW*; $\Delta m_{M\%}$ is specific gas amount at nominal MCR in *%*; $\Delta M_{amb\%}$ is change in exhaust gas amount in *%*; $P_{s\%}$ is continuous service rating of engine in *kW*; and $\Delta m_{s\%}$ is specific gas amount at MCR poin in *%*.

The value of $\Delta m_{M\%}$ can be found by using the following formula.

$$\Delta m_{M\%} = (14 \, x \, ln(^{P_M}/_{P_{L1}})) - (24 \, x \, ln(^{n_M}/_{n_{L1}})) \quad (2)$$

The value of $\Delta M_{amb\%}$ can be found by using the following formula.

$$\Delta M_{amb\%} = -0{,}41 \, x \, (T_{air} - 25) + (\rho_{bar} - 1000) + 0{,}19 \, x \, (T_{CW} - 25) - 0{,}011 \, x \, (\Delta p_M - 300) \quad (3)$$

The value of $P_{s\%}$ can be found by using the following formula.

$$P_{s\%} = (^{P_S}/_{P_M}) \, x \, 100\% \quad (4)$$

The value of $\Delta m_{s\%}$ can be found by using the following formula.

$$\Delta m_{s\%} = 37 \, x \, (^{P_S}/_{P_M})^3 - 87 \, x \, (^{P_S}/_{P_M})^2 + 31 \, x \, (^{P_S}/_{P_M}) + 19 \quad (5)$$

- *Economizer Analysis*

  This analysis is intended to determine the outlet temperature of exhaust gas from the economizer. The analysis can be done by using heat balance equation as follows.

$$m_1 \, x \, Cp_1 \, x \, \Delta T_1 = m_2 \, x \, Cp_2 \, x \, \Delta T_2 \quad (6)$$

Where, m_1 and m_2 are mass flow rate of each fluid in *kg/s*, respectively; Cp_1 and Cp_2 are specific heat of each fluid in *kJ/kgK*, respectively; and ΔT_1 and ΔT_2 are temperature difference of each fluid in *K*, respectively.

- *Heat Loss Analysis*

  Heat loss analysis is performed to find out how much heat loss occurs along the distribution path of thermal oil, namely from boiler or economizer to each fuel oil tank and from each fuel oil tank going back to the boiler or economizer. All types of pipes used along distribution path are JIS G3454 STPG 370S with Schedule of 80. The analysis can be done by using heat balance equation as follows.

$$Q_{Loss} = \frac{T_{\infty_1} - T_{\infty_2}}{R_{total}} \quad (7)$$

Where, $T_{\infty 1}$ and $T_{\infty 2}$ are fluid temperature in area 1 and 2 in *K*, respectively; and R_{total} is total resistance of the system in *K/W*.

The following figure is an example in calculating the total resistance of thermal resistance network equation.

Based on figure 1., the total resistance formula can be arranged as the following equation.

$$R_{total} = \frac{1}{h_1 A} + \frac{L}{KA} + \frac{1}{h_2 A} \quad (8)$$

Where, h_1 and h_2 are convection heat transfer coefficient in W/m^2K, respectively; *L* is length of the object in *m*; *K* is thermal conductivity in W/m^2K; and *A* is area of the object in m^2.

The heat losses that occur along distribution line are defined in each section of the pipe. The initial scenario of the distribution path for all tanks is the same, that is, starting from distribution line to consumer line. Right after that, the pipe will be branched off according to the position of each tank. Return path scenario of thermal oil after passing the fuel tank is the same as the line of thermal oil distribution.

- *Time Needed to Heat Fuel Oil*

  This analysis is intended to determine how long time needed to heat fuel in each fuel tanks, namely storage tank portside, storage tank starboard, settling tank, service tank portside, and service tank starboard in two scenarios, by using boiler and economizer.

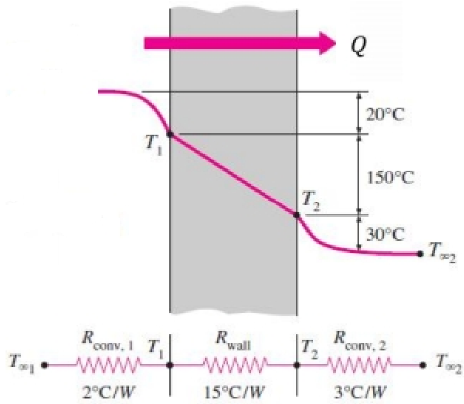

Figure 1. Thermal Resistance Network

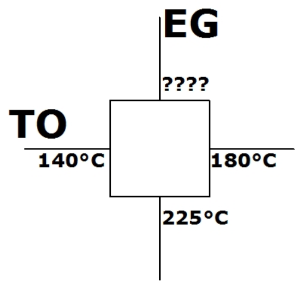

Figure 2. Heat Diagram at 75%MCR to Find Outlet Temperature of Exhaust Gas from the Economizer

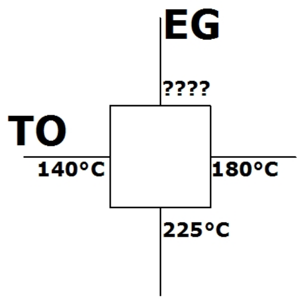

Figure 3. Heat Diagram at 85%MCR to Find Outlet Temperature of Exhaust Gas from Economizer

TABLE 6.
SUMMARY OF EXHAUST GAS FLOW RATE BASED ON SHOP TRIAL RECORD DATA

Load (%)	Engine Speed (rpm)	Engine Output (kW)	Exh. Gas Amount (kg/h)
100	173	4440	35757
85	163,9	3774	26862
75	157,2	3330	21670

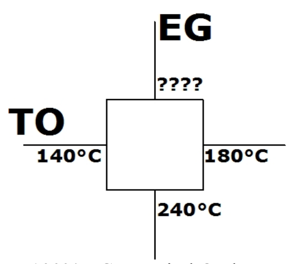

Figure 4. Heat Diagram at 100%MCR to Find Outlet Temperature of Thermal Oil

III. Results and Discussion

The results and discussion are in accordance with the steps outlined above.

A. Exhaust Gas Flow Rate

The value of exhaust gas flow rate of diesel engine used on MT. Parigi based on shop trial record will be determined by using equation (1), (2), (3), (4), and (5). This calculation is done at 75%, 85%, and 100% MCR. The following table 6 shows the summary of the result of this calculation.

Based on the summary above, it is known that the exhaust gas amount will decrease in line with the decrease of the main engine load.

B. Economizer Analysis

This analysis should be done because of the differences between data from manufacturer's document with shop trial record of the main engine which will be shown in the following table.

TABLE 7.
EXHAUST GAS PARAMETER COMPARISON BETWEEN MAKER'S DATA AND SHOP TRIAL DATA

	Maker's Data			Shop Trial Record Data	
Load (%)	Exh. Gas Quantity (kg/h)	Exh. Gas Temp. Before Heater (°C)	Exh. Gas Temp. After Heater (°C)	Exh. Gas Quantity (kg/h)	Exh. Gas Temp. Before Heater (°C)
100	37200	265	209	35757	240
85	33300	249	197	26862	225
75	30400	245	-	21670	225

Therefore it will be analyzed the exhaust gas outlet temperature from the economizer at 75%, 85%, and 100% MCR.

1. Analysis at 75% MCR

Analysis at 75% MCR will be performed by using heat balance formula. The following figure will show the diagram between the exhaust gas and thermal oil fluid.

To determine the outlet temperature of exhaust gas from economizer, the Heat of Thermal Oil (Q_{TO}) will be kept constant. The value of Thermal Oil Heat (Q_{TO}) is as follows.

$$Q_{TO} = \dot{m}_{TO} \times Cp_{TO} \times \Delta T_{TO}$$
$$= 6{,}1067\ {}^{kg}/_{s} \times 1{,}978\ {}^{kJ}/_{kgK} \times (180 - 140)K$$
$$= 483{,}16\ kW$$

After obtaining the value of Thermal Oil Heat (Q_{TO}), find the outlet temperature of exhaust gas by using Heat Balance Formula (Q_{TO}=Q_{EG}) as follows.

$$Q_{TO} = Q_{EG}$$
$$Q_{TO} = \dot{m}_{EG} \times Cp_{EG} \times \Delta T_{EG}$$
$$T_{2(EG)} = T_{1(EG)} - \frac{Q_{TO}}{\dot{m}_{EG} \times Cp_{EG}}$$
$$T_{2(EG)} = 498{,}15\ K - \frac{483{,}16\ kW}{6{,}02\ {}^{kg}/_{s} \times 1{,}030\ {}^{kJ}/_{kgK}}$$
$$T_{2(EG)} = 420{,}2\ K$$
$$= 147{,}05\ {}^{o}C$$

Based on the calculation above, it can be concluded that at 75% MCR of diesel engine, the outlet temperature of exhaust gas after passing through the economizer is 147,05°C

2. Analysis at 85% MCR

This analysis will be performed by using the same way with 75% MCR. The following figure will illustrate the diagram between the exhaust gas and thermal oil fluid.

The value of Thermal Oil Heat (Q_{TO}) is the same with the 75% MCR. So, the outlet temperature of exhaust gas is as follows.

$$Q_{TO} = Q_{EG}$$
$$Q_{TO} = \dot{m}_{EG} \times Cp_{EG} \times \Delta T_{EG}$$
$$T_{2(EG)} = T_{1(EG)} - \frac{Q_{TO}}{\dot{m}_{EG} \times Cp_{EG}}$$
$$T_{2(EG)} = 498{,}15\ K - \frac{483{,}16\ kW}{7{,}462\ {}^{kg}/_{s} \times 1{,}030\ {}^{kJ}/_{kgK}}$$
$$T_{2(EG)} = 435{,}26\ K$$
$$= 162{,}11\ {}^{o}C$$

Based on the calculation above, it is known that at 85% MCR, the outlet temperature of exhaust gas after pass through the economizer is 162,11°C.

3. Analysis at 100% MCR

This analysis will be performed by using the same way with 85% MCR. The following figure 4 will illustrate the diagram between the exhaust gas and thermal oil fluid.

The value of Thermal Oil Heat (Q_{TO}) is the same with the 75% MCR. So, the outlet temperature of exhaust gas is as follows.

$$Q_{TO} = Q_{EG}$$
$$Q_{TO} = \dot{m}_{EG} \times Cp_{EG} \times \Delta T_{EG}$$
$$T_{2(EG)} = T_{1(EG)} - \frac{Q_{TO}}{\dot{m}_{EG} \times Cp_{EG}}$$
$$T_{2(EG)} = 513{,}15\ K - \frac{483{,}16\ kW}{9{,}932\ {}^{kg}/_{s} \times 1{,}033\ {}^{kJ}/_{kgK}}$$
$$T_{2(EG)} = 466{,}05\ K$$
$$= 192{,}9\ {}^{o}C$$

Based on the calculation above, it can be concluded that at 100% MCR, the outlet temperature of exhaust gas after pass through the economizer is 192,9°C.

4. Summary of Economizer Analysis

Based on the economizer analysis that has been done above, it can be concluded that the heat of exhaust gas can heat thermal oil fluid in desired value, but with different of exhaust gas temperature in each condition. The following is a graph of exhaust gas output temperature under some load conditions.

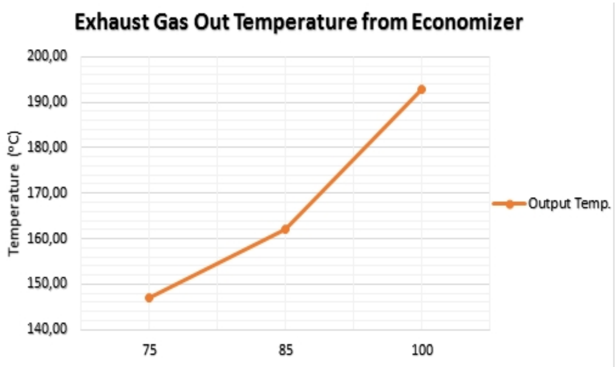

Figure 5. Exhaust Gas Outlet Temperature from Economizer in Several Loads of Main Engine

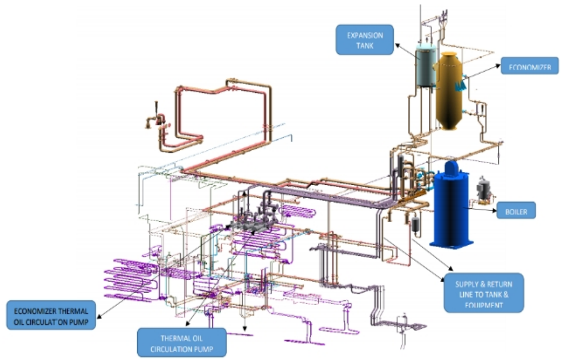

Figure 6. Thermal Oil Distribution System or Path on MT. Parigi

TABLE 8.
SUMMARY OF HEAT LOSSES CALCULATION ON STORAGE TANK PORTSIDE IN BOILER SCENARIO

Section	Total Resistance (Km/W)	Heat Loss (kW)	Initiate Temp. (ºC)	Temp. Drop (ºC)
Distribution Line	0,5655	2,33	180	179,97
Consumer Line	0,995	1,679	179,97	179,95
Main Line	0,995	3,101	179,95	179,92
Branch Line	1,467	0,229	179,92	179,92
Heating Coil	-	-	179,92	140,06
Return Branch Line	1,41	0,2755	140,06	140,06
Return Main Line	0,947	1,977	140,06	140,03
Return Consumer Line	0,947	1,44	140,03	140,02
Deaerated Line	0,462	1,651	140,02	140
Pump Line	0,425	3,342	140	139,96
Boiler Line	0,462	4,845	139,96	139,90

TABLE 9.
SUMMARY OF HEAT LOSSES CALCULATION ON STORAGE TANK STARBOARD IN BOILER SCENARIO

Section	Total Resistance (Km/W)	Heat Loss (kW)	Initiate Temp. (ºC)	Temp. Drop (ºC)
Distribution Line	0,5655	2,33	180	179,97
Consumer Line	0,995	1,679	179,97	179,95
Main Line	0,995	3,101	179,95	179,92
Branch Line	1,467	0,229	179,92	179,92
Heating Coil	-	-	179,92	140,06
Return Branch Line	1,41	0,18	140,06	140,06
Return Main Line	0,947	2,631	140,06	140,03
Return Consumer Line	0,947	1,44	140,03	140,02
Deaerated Line	0,462	1,651	140,02	140
Pump Line	0,425	3,342	140	139,96
Boiler Line	0,462	4,845	139,96	139,90

From the graph above, it can be concluded that the outlet temperature of exhaust gas is directly proportional to the engine load. So, when the engine load decreases, the outlet temperature of exhaust gas from economizer will go down as well. It can happen because the exhaust gas temperature of the engine decreases in accordance with the engine load at 75%, 85%, and 100% MCR.

C. Heat Loss Analysis

Heat loss analysis is done in two scenarios, namely boiler scenario and economizer scenario. This analysis is performed by using equation (6), (7), and (8). The following figure shows the distribution line or path of thermal oil system on MT. Parigi.

- Boiler Scenario

Boiler scenario is equipped with two pumps with the same capacity of 163,5 m^3/h. The following tables summarize the calculation of heat losses in each section for storage tank portside, storage tank starboard, settling tank, service tank portside, and service tank starboard in boiler scenario.

TABLE 10.
SUMMARY OF HEAT LOSSES CALCULATION ON SETTLING TANK IN BOILER SCENARIO

Section	Total Resistance (Km/W)	Heat Loss (kW)	Initiate Temp. (°C)	Temp. Drop (°C)
Distribution Line	0,5655	2,33	180	179,97
Consumer Line	0,995	1,679	179,97	179,95
Main Line	0,995	1,642	179,95	179,93
Branch Line	2,071	0,74	179,93	179,93
Heating Coil	-	-	179,93	140,06
Return Branch Line	2,292	0,491	140,06	140,05
Return Main Line	0,947	2,040	140,05	140,03
Return Consumer Line	0,947	1,44	140,03	140,02
Deaerated Line	0,462	1,651	140,02	140
Pump Line	0,425	3,342	140	139,96
Boiler Line	0,462	4,845	139,96	139,90

TABLE 11.
SUMMARY OF HEAT LOSSES CALCULATION ON SERVICE TANK PORTSIDE IN BOILER SCENARIO

Section	Total Resistance (Km/W)	Heat Loss (kW)	Initiate Temp. (°C)	Temp. Drop (°C)
Distribution Line	0,5655	2,33	180	179,97
Consumer Line	0,995	1,679	179,97	179,95
Main Line	0,995	1,683	179,95	179,93
Branch Line	2,071	0,796	179,93	179,93
Heating Coil	-	-	179,93	140,06
Return Branch Line	2,292	0,535	140,06	140,05
Return Main Line	0,947	2,073	140,05	140,03
Return Consumer Line	0,947	1,44	140,03	140,02
Deaerated Line	0,462	1,651	140,02	140
Pump Line	0,425	3,342	140	139,96
Boiler Line	0,462	4,845	139,96	139,90

TABLE 12.
SUMMARY OF HEAT LOSSES CALCULATION ON SERVICE TANK STARBOARD IN BOILER SCENARIO

Section	Total Resistance (Km/W)	Heat Loss (kW)	Initiate Temp. (°C)	Temp. Drop (°C)
Distribution Line	0,5655	2,33	180	179,97
Consumer Line	0,995	1,679	179,97	179,95
Main Line	0,995	2,676	179,95	179,92
Branch Line	2,071	0,732	179,92	179,91
Heating Coil	-	-	179,91	140,06
Return Branch Line	2,292	0,433	140,06	140,05
Return Main Line	0,947	2,091	140,05	140,03
Return Consumer Line	0,947	1,44	140,03	140,02
Deaerated Line	0,462	1,651	140,02	140
Pump Line	0,425	3,342	140	139,96
Boiler Line	0,462	4,845	139,96	139,90

Based on the tables above, it is known that the inlet temperature of thermal oil into each fuel tank is around 179,92°C and the outlet temperature of thermal oil from each fuel tank are 140,06°C. Then, thermal oil will re-enter the boiler with the temperature of 139,90°C.

- Economizer Scenario

Economizer scenario is equipped with two pumps with the same capacity of 23,7 m^3/h. The heat losses that happened is the same with the boiler scenario. The following tables summarize the calculation of heat losses in each section for storage tank portside, storage tank starboard, settling tank, service tank portside, and service tank starboard in economizer scenario.

TABLE 13.
SUMMARY OF HEAT LOSSES CALCULATION ON STORAGE TANK PORTSIDE IN ECONOMIZER SCENARIO

Section	Total Resistance (Km/W)	Heat Loss (kW)	Initiate Temp. (ºC)	Temp. Drop (ºC)
Distribution Line (65A)	0,995	1,979	180	179,84
Distribution Line (125A)	0,659	0,066	179,84	179,84
Distribution Line (150A)	0,565	1,144	179,84	179,75
Consumer Line	0,995	1,676	179,75	179,61
Main Line	0,995	2,491	179,61	179,41
Branch Line	1,467	0,357	179,41	179,39
Heating Coil	-	-	179,39	140,71
Return Branch Line	1,41	0,277	140,71	140,69
Return Main Line	0,947	1,989	140,69	140,52
Return Consumer Line	0,947	1,448	140,52	140,40
Deaerated Line	0,462	1,658	140,40	140,27
Pump Line	0,822	2,308	140,27	140,07
Economizer Line	0,947	1,398	140,07	139,96

TABLE 14.
SUMMARY OF HEAT LOSSES CALCULATION ON STORAGE TANK STARBOARD IN ECONOMIZER SCENARIO

Section	Total Resistance (Km/W)	Heat Loss (kW)	Initiate Temp. (ºC)	Temp. Drop (ºC)
Distribution Line (65A)	0,995	1,979	180	179,84
Distribution Line (125A)	0,659	0,066	179,84	179,84
Distribution Line (150A)	0,565	1,144	179,84	179,75
Consumer Line	0,995	1,676	179,75	179,61
Main Line	0,995	3,093	179,61	179,37
Branch Line	1,467	0,229	179,37	179,35
Heating Coil	-	-	179,35	140,74
Return Branch Line	1,41	0,181	140,74	140,72
Return Main Line	0,947	2,645	140,72	140,51
Return Consumer Line	0,947	1,448	140,51	140,40
Deaerated Line	0,462	1,658	140,40	140,27
Pump Line	0,822	2,308	140,27	140,07
Economizer Line	0,947	1,398	140,07	139,96

TABLE 15.
SUMMARY OF HEAT LOSSES CALCULATION ON SETTLING TANK IN ECONOMIZER SCENARIO

Section	Total Resistance (Km/W)	Heat Loss (kW)	Initiate Temp. (ºC)	Temp. Drop (ºC)
Distribution Line (65A)	0,995	1,979	180	179,84
Distribution Line (125A)	0,659	0,066	179,84	179,84
Distribution Line (150A)	0,565	1,144	179,84	179,75
Consumer Line	0,995	1,676	179,75	179,61
Main Line	0,995	1,638	179,61	179,48
Branch Line	2,071	0,737	179,48	179,42
Heating Coil	-	-	179,42	140,68
Return Branch Line	2,292	0,494	140,68	140,64
Return Main Line	0,947	2,052	140,64	140,47
Return Consumer Line	0,947	1,448	140,47	140,40
Deaerated Line	0,462	1,658	140,40	140,27
Pump Line	0,822	2,308	140,27	140,07
Economizer Line	0,947	1,398	140,07	139,96

TABLE 16.
SUMMARY OF HEAT LOSSES CALCULATION ON SERVICE TANK PORTSIDE IN ECONOMIZER SCENARIO

Section	Total Resistance (Km/W)	Heat Loss (kW)	Initiate Temp. (ºC)	Temp. Drop (ºC)
Distribution Line (65A)	0,995	1,979	180	179,84
Distribution Line (125A)	0,659	0,066	179,84	179,84
Distribution Line (150A)	0,565	1,144	179,84	179,75
Consumer Line	0,995	1,676	179,75	179,61
Main Line	0,995	1,679	179,61	179,48
Branch Line	2,071	0,793	179,48	179,42
Heating Coil	-	-	179,42	140,68
Return Branch Line	2,292	0,539	140,68	140,64
Return Main Line	0,947	2,086	140,64	140,46
Return Consumer Line	0,947	1,448	140,46	140,40
Deaerated Line	0,462	1,658	140,40	140,27
Pump Line	0,822	2,308	140,27	140,07
Economizer Line	0,947	1,398	140,07	139,96

TABLE 17.
SUMMARY OF HEAT LOSSES CALCULATION ON SERVICE TANK STARBOARD IN ECONOMIZER SCENARIO

Section	Total Resistance (Km/W)	Heat Loss (kW)	Initiate Temp. (ºC)	Temp. Drop (ºC)
Distribution Line (65A)	0,995	1,979	180	179,84
Distribution Line (125A)	0,659	0,066	179,84	179,84
Distribution Line (150A)	0,565	1,144	179,84	179,75
Consumer Line	0,995	1,676	179,75	179,61
Main Line	0,995	2,669	179,61	179,40
Branch Line	2,071	0,729	179,40	179,34
Heating Coil	-	-	179,34	140,76
Return Branch Line	2,292	0,436	140,76	140,72
Return Main Line	0,947	2,105	140,72	140,55
Return Consumer Line	0,947	1,448	140,55	140,40
Deaerated Line	0,462	1,658	140,40	140,27
Pump Line	0,822	2,308	140,27	140,07
Economizer Line	0,947	1,398	140,07	139,96

Based on the tables above, it is known that in economizer scenario, the inlet temperature of thermal oil into each fuel tank is around 179,40ºC and the outlet temperature of thermal oil from each fuel tank are around 140,70ºC. Then, thermal oil will re-enter the economizer with the temperature of 139,96ºC.

D. Time Needed to Heat Fuel

Time needed to heat fuel is divided into two scenarios, by using boiler scenario and economizer scenario. It can be done by using the same formula as economizer analysis, namely compare the heat of fuel oil with the heat produced by thermal oil circulation inside the heating coil. The following table shows the summary of heating duration by using both scenarios.

TABLE 18.
HEATING DURATION SUMMARY OF THERMAL OIL SYSTEM ON MT. PARIGI

Fuel Oil Tanks	Heating Duration (hours)	
	Boiler Scenario	Economizer Scenario
Storage Tank P/S	0,673	4,706
Storage Tank S/B	0,701	4,907
Settling Tank	0,053	0,369
Service Tank P/S	0,105	0,730
Service Tank S/B	0,105	0,732

TABLE 19.
SUMMARY OF TEMPERATURE INLET, OUTLET, AND RE-ENTERED HEATING EQUIPMENTS

Fuel Oil Tanks	Temperatures (ºC)					
	Boiler Scenario			Economizer Scenario		
	Input	Output	Re-entered	Input	Output	Re-entered
Storage Tank P/S	179,92	140,06	139,90	179,39	140,71	139,96
Storage Tank S/B	179,92	140,06	139,90	179,35	140,74	139,96
Settling Tank	179,93	140,06	139,90	179,42	140,68	139,96
Service Tank P/S	179,93	140,06	139,90	179,42	140,68	139,96
Service Tank S/B	179,91	140,06	139,90	179,34	140,76	139,96

From the table above, it is known that the longest and shortest time needed to heat fuel in boiler scenario is storage tank starboard and settling tank, namely 0,701 and 0,053 hours respectively. Then, the longest and shortest time needed to heat fuel in economizer scenario is storage tank starboard and settling tank, namely 4,907 and 0,369 hours respectively.

IV. CONCLUSION

Based on data analyses, results, and discussion which have been done above, there are several conclusion can be made as follows.

1. The exhaust gas flow rates based on shop test result are as follows.
    - 75% MCR of Main Engine, exhaust gas flow rate is 21670 kg/h;
    - 85% MCR of Main Engine, exhaust gas flow rate is 26862 kg/h;
    - 100% MCR of Main Engine, exhaust gas flow rate is 35757 kg/h.

2. The exhaust gas outlet temperatures from the exhaust gas economizer on MT. Parigi based on shop test result are as follow.
    - 75% MCR of Main Engine, exhaust gas outlet temperature from economizer is 147,05^{o}C;
    - 85% MCR of Main Engine, exhaust gas outlet tempearature from economizer is 162,11^{o}C;
    - 100% MCR of Main Engine, exhaust gas outlet temperature from economizer is 192,9^{o}C.
3. Thermal oil heating system on MT. Parigi is able to distribute heat to each fuel oil tank in accordance with the design value in order to increase the fuel oil temperature inside each fuel tanks, both using boiler scenario and economizer scenario, as follows.

From the table above, it is known that the re-entered temperature of the thermal oil to the heating equipment in boiler scenario is lower than economizer scenario. It happens because the pump capacity in boiler scenario is bigger than the pump capacity in economizer. Bigger the capacity of the pump, the value of temperature decrease also become bigger.

4. Based on the summary of heating duration in table 18, it is known that boiler scenario has faster heating duration than economizer scenario in full pump capacity. It can happen because the pump capacity of boiler scenario is bigger than the pump capacity of economizer scenario. The bigger pump capacity, the faster the duration of heating will take place.

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