Utilisation of diesel engine waste heat for ship's ballast water heat treatment

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Abstract

Heat has been proved to be a very attractive method of minimizing the risk of introducing new organisms into the ports where ballast is discharged. It does not necessitate the use of chemicals or biocides that could be harmful to the environment. Waste heat from a ship's main engine can potentially provide a cost-effective source of heat. An analysis of available heat and methods to obtain required ballast water temperature with maximum efficiency is the main concern of this paper. To obtain required ballast water temperature without affecting engine performance and fuel consumption appropriate modifications of ballast piping and diesel engine conventional and central cooling systems have been proposed.

1 Introduction

Heat is one of the options for ship's ballast water treatment that is receiving considerable research attention. Heating of ballast water needs to take place during transit while ship's main engine is running. All explored options are based on biological heat treatment strategies which are shown in table 1. It is very hard to determine the duration of exposure at temperature sufficient for complete organism inactivation because of the huge amount of marine species contained in ballast water. Therefore, only the most resistant organisms have been tested [1], [2].

Table 1: Near complete kill of the most resistant organism

Exposure	duration	temperature
Short	≤ 10 minutes	$\geq 46^o$C
Medium	10 min. to 16 hours	36 to 45 ^{o}C
Long	≥ 16 hours	≤ 36 ^{o}C

Strategies shown in tables are derived from results of laboratory studies but some of them have been confirmed by shipboard trial [2], [3]. Assuming high reliability of these experiments, several methods of diesel engine waste heat utilisation have been proposed. These methods are based on the medium heat treatment strategies and can be obtained depending on time voyage limitations, open ocean depth, and seawater temperature. The journey time and seawater environment temperature are the most important constraints for ballast water heat treatment. If the seawater is lower than 15 to 20 ^{0}C heat method will be less effective and the time required for treatment may be longer than the journey.

2 Possibilities of diesel engine waste heat utilisation

Actual available diesel engine waste heat is determined from engine data supplied by manufacturer, which are essential during propulsion plant design stages. Differences of engine data for various engine types and manufacturers could make approximate evaluation of ballast heating possibilities more difficult. For various diesel engine types available diesel engine waste heat has been determined approximately using simple statistic analysis. Necessary capacities of auxiliary machinery for main engine are stated in tables below. As could be seen from tables, there is no significant diference in these values for various engine manufacturers and specifications.

Table 2: Man B&W MC engines, conventional seawater cooling

	Scavenge air	Lubricating oil	Jacket water	Sum
heat dissipation / engine power, Q / P_{nom}	0.338-0.35	0.071-0.082	0.140-0.150	0.55-0.582
Seawater cooling pump capacity / engine power, M_{SW} / P_{nom} (m^3/kWh)	0.0175-0.019	0.0102-0.0112	0.0102-0.0112	0.028-0.03
Water flow / seawater pump capacity, M / M_{SW}	0.625-0.635 Aver. 63% P_{sw}	0.365-0.375 Aver. 37% P_{sw}	0.365-0.375 Aver. 37% P_{sw}	100%

Table 3: New sulzer diesel engines, conventional seawater cooling without efficiency booster system (EBS)

	Scavenge air	Lubricating oil	Jacket water	Sum
Q / P_{nom}	0.337-0.340	0.092-0.105	0.162-0.184	0.587-0.626
M_{SW} / P_{nom} (m^3/kWh)	0.0128 **	0.0111-0.0126	0.0111-0.0126	0.024-0.025 **
Water flow / seawater pump capacity, M / M_{SW}	0.51-0.54** Aver. 53% P_{sw}	0.46-0.49** Aver. 47% P_{sw}	0.46-0.49** Aver. 47% P_{sw}	100%

** These values can vary because scavenge air seawater flow depends on turbocharger selection

Diagram on fig. 1 reflects heat dissipation percentages for scavenge air. Heat dissipation is dependent on percentages of nominal values for engine load (P%) and revolutions (n%), where *qair80(P%)* is heat dissipation for scavenge air cooling water at 70-100% engine nominal power and 80% engine nominal revolutions. These diagrams are derived using equations determined by regression analysis [4]:

$$q_{air} = e^{-0.8548\ln(n\%)+1.8321\ln(P\%)+0.1045} \tag{1}$$

$$q_{jw} = e^{-0.0811\ln(n\%)+0.8072\ln(P\%)+1.2614} \tag{2}$$

$$q_{air} = 67.3009 \cdot \ln(n\%) + 7.6304 \cdot \ln(P\%) - 245.0714 . \qquad (3)$$

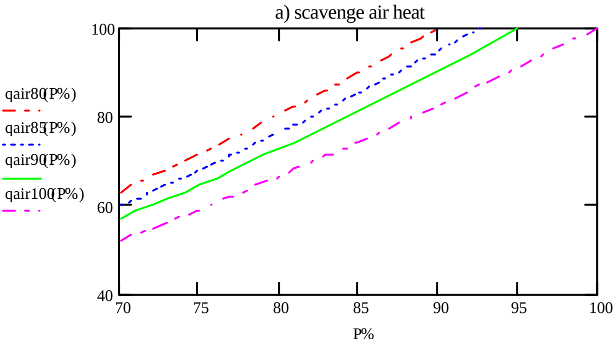

Figure 1: Diagram for for scavenge air heat dissipation in % of engine power(P%) for MAN B&W MC diesel engine - n%=const.=80%

Diagram on Fig. 02. can be used for determining available cooling water waste heat Q_{dm} for various conditions of engine's part load and speed. Available cooling water waste heat Q_{dm} is shown in relation with nominal engine power – P_{L1}:

$$Q_{dm} = q_{air} + q_{jw} + q_{lub} \qquad (4)$$

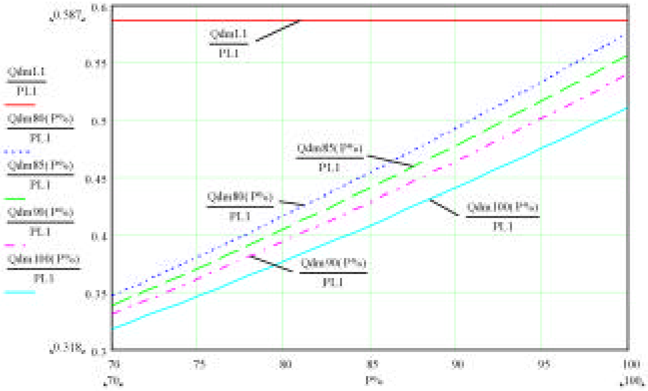

Figure 2: Diesel engine waste heat calculated for various part load conditions (for MAN B&W MC)

3 Circulation of ballast water

3.1 Open circuit ballast water heat treatment

In the open circuit the seawater outlet from the cooling system can be connected to ballast piping and the ballast water in the tank can be flushed by heated seawater sucked from the ship’s chest [3]. Ballast dilution is replacement of ballast water by constant flushing with oceanic seawater, which contains low proportion of marine organisms. It has proved to be the most convenient method for removal of organism contained in ballast water because the tanks are kept full filed with water and the flushed water continuously released through tank’s vent.

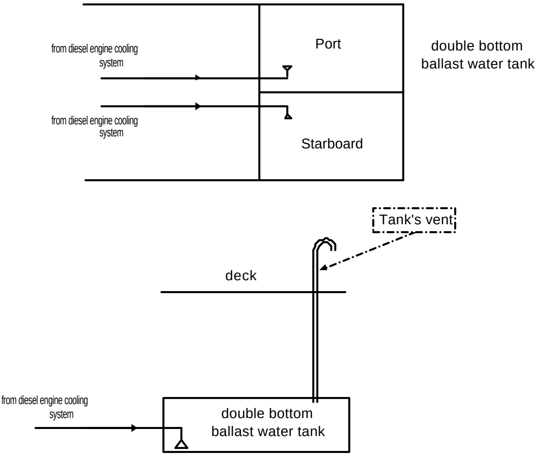

Figure 3: Ballast water heating in open circulation circuit

To obtain 90% replacement of ballast water by oceanic seawater 3 tank exchanges are necessary. The result of flushing is 10% of original water, which remains in tank, mixed with oceanic seawater. An assumption that removing a proportion of the ballast water will remove a similar proportion of organisms present has been proved to be incorrect. If the ballast water is heated, there is no need for 3 tank exchanges. Ballast water have to be flushed by heated oceanic seawater until temperature in the tank is satisfactory raised. Heated ballast water is continuously flushed through the tank's vent. That will significantly increase unrecoverable heat loss, resulting in larger required time for ballast water treatment. Since open ocean area is not defined satisfactorily, there is concern that disposed ballast water may be drawn by sea currents into the coastal area where marine organisms can survive.

3.2 Closed circuit ballast water heat treatment

To increase efficiency of organism inactivation conventional seawater cooling system and central cooling system should be modified appropriately. An additional heat exchanger and circulation pump should be installed, according to fig. 4. One or two ballast water tanks could be insulated and used for ballast water heat treatment. Non-treated water in ballast tanks can be replaced by treated ballast water very fast. High risk of thermal stress within ballast tank can be avoided if one special tank is constructed to compensate thermal expansions. That tank would be used to cool treated ballast water on natural way by heat transfer to suroundíng sea water. Cooling process will be no longer than heat treatment of ballast water in insulated tank.

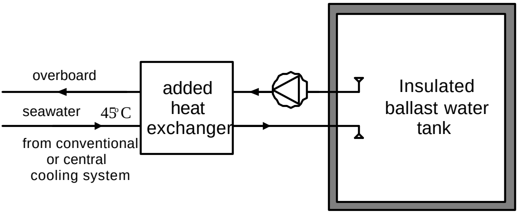

Figure 4: Diagram for closed circle ballast water circulation heating

When the ballast water temperature is lower then 32^0 C there is possibility of direct circulation of ballast water through the engine cooling system. In that case added heat exchanger can be bypassed. When the temperature in ballast water tank is raised to 32^0 C problems with scavenge air cooling will occur. In that case, valves could be manipulated automatically by means of thermostatic control system and ballast water can be heated by passing through the heat exchanger, as proposed on figure 5.

4 Modification of diesel engine cooling water system to achieve maximum ballast water temperature

4.1 Modification of conventional seawater cooling system

Using conventional seawater cooling system it is evident that maximum seawater cooling system temperature can not be higher than 45 ^{0}C. Proposed improvements for conventional seawater cooling system will comply with medium and short duration exposure strategy. Modification of conventional seawater cooling system shown on fig. 5 serves to achieve maximum seawater cooling outlet temperature. By connecting scavenge air cooler outlet to jacket water cooler inlet, the seawater cooling system outlet temperature can be raised to 50 ^{0}C or more. Additional heat exchanger, proposed on fig. 6, should be two stages. 63.4% cooling seawater pump flow capacity with approx. maximum temperature of 40 ^{0}C will pass through the first stage of heat exchanger while the other 36.6% with approx. temperature of 50 ^{0}C will will pass through the second stage.

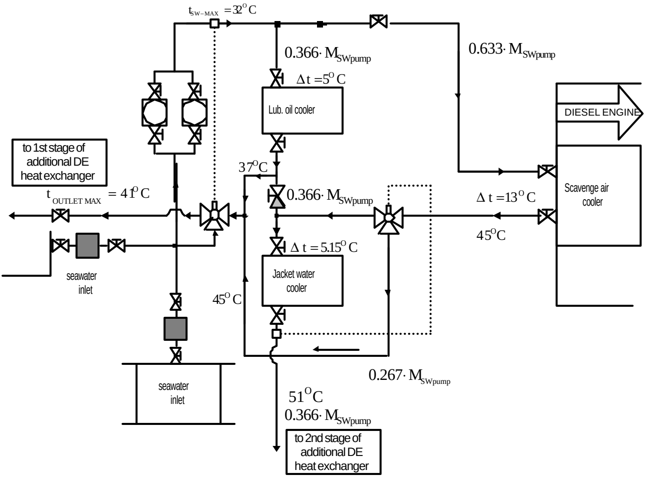

Figure 5: Seawater cooling system for MAN B&W MC adapted for ballast water heating - 80% Engine nominal power, 80% nominal speed

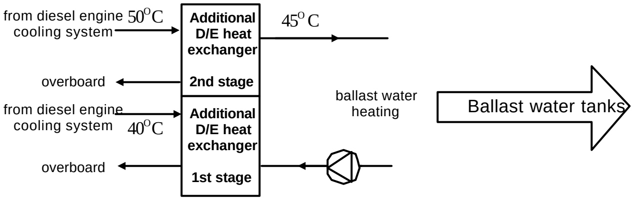

Figure 6: Diagram for closed circle ballast water circulation heating with two-stage ballast water heat exchanger for conventional seawater cooling system

Added 3-way valve serves to protect the engine from overheating by keeping the jacket water cooler minimum temperature difference between cooling seawater outlet and cooling fresh water (HT) inlet to jacket water cooler. The jacket water cooler has to be large enough to compensate the cooling seawater inlet temperature rise (from 37 to 45 ^{0}C) , according to fig. 5. Since, 50% of jacket water heat is used for water production in fresh water generator during ship's voyage this proposition would not be hard to accomplish. In case of fresh water generator failure there is always possibility to convert cooling system by automatic control of 3-way valve.

4.2 Modification of central cooling water system

Central cooling system could also be adapted for ballast water heating. Regarding fig. 7 fresh water passes through jacket water cooler after being heated in scavenge air cooler. On this way more than half of the engine cooling water waste heat is utilised in central cooler no. 2 which can be noted from seawater temperature difference of central cooler. If the seawater mass flow remains unchanged, connecting scavenge air cooler outlet to jacket water cooler inlet will result with the same seawater outlet temperature (45 ^{0}C) as it was the case for classic central cooling water system. Therefore, mass flow through the central cooler second stage should be lowered as proposed on figure 8.

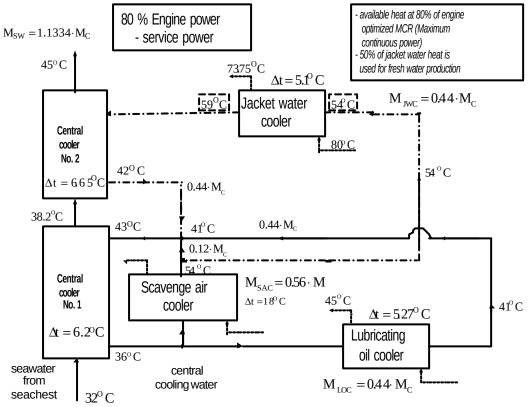

Figure 7: Diagram for adapted central cooling water system for ballast heating

To obtain higher temperature difference, seawater flow through the central cooler no. 2 can be lowered. Seawater outlet from the central cooler should not be higher than 55 ^{0}C for proper heat transfer through the cooler. To achieve temperature difference of 14.3 ^{0}C in central cooler second stage, seawater flow should be approx. M_{SW}=0.78 M_C instead M_{SW}=1.334 M_C. Additional two-stage heat exchanger can be used on similar way as for conventional seawater cooling system. Here, seawater is used for heat transfer from central cooler to ballast water heat exchanger. Using ballast water for engine cooling would not be practical since maximum inlet temperature to central cooler no. 1 should not be higher than 32 ^{0}C. Fresh water temperatures has to be low enough to ensure proper cooling of scavenge air and lubricating oil. System design proposed on fig. 8 seems to be effective for proper ballast heating and comply with engine cooling limitations. It is very important to notice that inlet to and outlet from the central cooler no. 2 can be connected directly to ballast tank line. Heating of ballast would be more effective but ballast water flow must be increased to insure proper jacket water cooling.

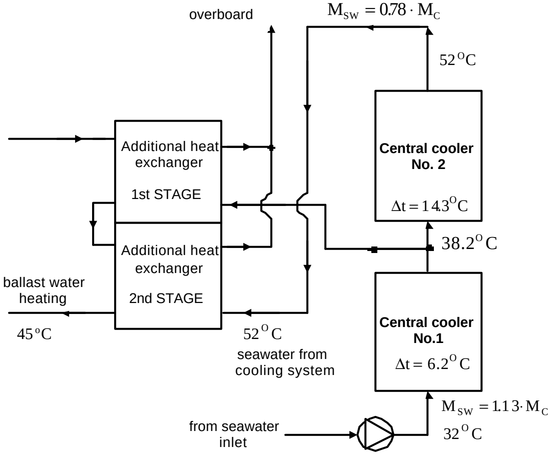

Figure 8: Diagram for closed circle ballast water circulation heating with two-stage ballast water heat exchanger for central cooling system

References

[1] Hallegraeff, G.M., Valentine, J.P., Marshall, J.A., & Bolch, C.J. *Temperature tolerances of toxic dinoflagellate cysts: Application to the treatment of ship's ballast water,* Aquatic Ecology, 32, 1997.

[2] Mountfort, D.O., Dodgshun, T., Gibbs, W. & McCallin B. *Towards a feasible heat treatment system for ship's ballast water,* Proceedings of a workshop, Hillman, S. P.: EcoPorts Monograph Series No.19, Brisbane, Australia, May, 1999.

[3] Rigby, G., Hallegraeff, & G.M., Sutton, C.: *Ballast Water Heating and Sampling Trials on the BHP Ship MV Iron Whyalla in Port Kembla and en-route to Port Hedland*, Report prepared for the Australian Quarantine and Inspection Service, October 1997.

[4] MAN B&W Diesel A/S. *MC Programme Engine Selection Guide,* Copenhagen, Denmark, Feb., 1992.

[5] New Sulzer Diesel Ltd. *Engine Selection and Project Manual: Sulzer RTA52U, RTA62U, RTA72U, Diesel Engines,* Winterthur, Switzerland, Nov., 1994.

SAMPLE SYMBOLS

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