A Ballast Water Treatment System Using Engine Waste Heat: Is it Viable?

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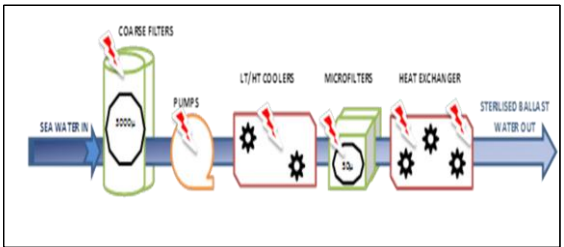
R. Balaji [a*], O. Yaakob [b], K. K. King [b], F. A. Adnan [b], N.Ismail [b], B. Ahmad [b], M. A. Ismail [b], H. L. Siang [c], W. B. Wan Nik [d]

[a] Advanced Marine Engineering Department, Malaysian Maritime Academy, Masjid Tanah, 78300, Melaka, Malaysia.
[b] Marine Technology Centre, Universiti Teknologi Malaysia, Skudai, Johor Bahru, Malaysia.
[c] School of Marine and Environmental Sciences, Universiti Malaysia Terengganu, Kuala Terengganu, Terengganu, Malaysia.
[d] School of Ocean Engineering, Universiti Malaysia Terengganu, Kuala Terengganu, Terengganu, Malaysia.

*Corresponding author
rajoobalaji@alam.edu.my

Graphical Abstract



Abstract

Treatment of ballast water using engine waste heat has been deliberated upon but studies are not substantial. This study presents extension of a treatment system from an existing system with additional components. Tests at laboratory level had been carried out to test the treatment effectiveness in the stages identified for species' elimination. Average heat recoveries from exhaust gases worked to between 15 to 33% of input energies. Tests on species demonstrated >95% mortalities in the temperature range of 55 to 75°C. This paper discusses the viability of the developed system based on the test results and the IMO's requirements. The positive outcomes of the tests are encouraging and further studies are proposed.

Keywords

Heat treatment; Impeller effects; Species' mortalities

Introduction

Shipping is the major transport mode for world trade. A current issue faced by the industry is the shifting of invasive species by the vector of ship's ballast water. The Ballast Water Management Convention is a mitigation measure initiated by the International Maritime Organisation (IMO). As of 2 December 2015, 44 countries representing 32.89% of world tonnage have signed agreement for ratifying the Convention. Treatment of ballast water will become mandatory when the Ballast Water Management Convention is fully ratified. Ships will then have to comply with requirements of Regulation D2 of Ballast Water Performance Standards [1]. While the ratification still requires a miniscule percentage of tonnage, treatment systems are on offer. The methods employed for treatment are either of mechanical, chemical or physical types. Almost all the Ballast Water Management Systems (BWMS) on offer employ a combination of treatment methods.

Heat treatment has been considered as a main treatment technology but heat quanta requirements such as large volumes, discharge of heated waters and low efficacies on certain types of bacteria are difficult issues which make it unfavourable. Yet, the waste heat potential on certain type of vessels makes it an attractive option. Gregg *et al.*, [2] suggested that heat treatment could be effective with other treatment methods such as UV and deoxygenation. In the current listing of approved systems, one of the manufacturers uses engine waste heat for pasteurisation in combination with deoxygenation as part of the treatment [3].

Balaji and Yaakob [4] proposed a heat treatment system where the heat discarded from all the ship's systems is harnessed, including the engine exhaust gases. Such system could complement any proven technology. In relation to heat analysis of an operational petroleum tanker [5], tests had been carried out at laboratory levels and also on a mini-scale system. This paper reviews the envisaged system based on the results from tests.

DESCRIPTION OF THE SYSTEM

The heat based Ballast Water Treatment (BWT) System is envisaged as an extension of the existing system on board an operational vessel without disturbing the existing system [4]. The new lines are designed to branch off from the overboard discharges to harvest the heat emitted from the Low Temperature/High Temperature (LT/HT) systems, condensers and exhaust gases. The pump discharges are connected to the ballast main leading to the tanks. Ballast suctions from tanks are also extended to other pumps than ballast pumps.

Some additions are the filtration units and associated cleaning/disposal arrangements, heat exchanger and an auxiliary BWT unit (if fitted). The other BWT unit is assumed to be fitted out with a proven, compatible technology. The proposed modifications are shown in the layout in Figure 1. The operational vessel on which this system is based has two ballast pumps, but for simplicity, only one pump is shown. The sea water pumps suck sea water through coarse filters having about 2 to 3mm pores and pumps the water through LT/HT coolers and condensers. The heat absorbing water from these heat exchangers passes through the 50µ filter bank. One flow stream is directed to the ballast water heater and directed to ballast tanks and another to the BWT treatment unit (if fitted).

During sailing, the suction is changed from sea chests to the ballast tanks. With additional LT/HT and exhaust gas heat, the water temperature is increased. Suctions are switched to other tanks as a temperature range of 50 to 55°C is achieved while maintaining the entry temperature of sea water in the range of 30 to 35°C. This circulation and recirculation through the filters and heat exchanger will result in mechanical filtration and heat treatment.

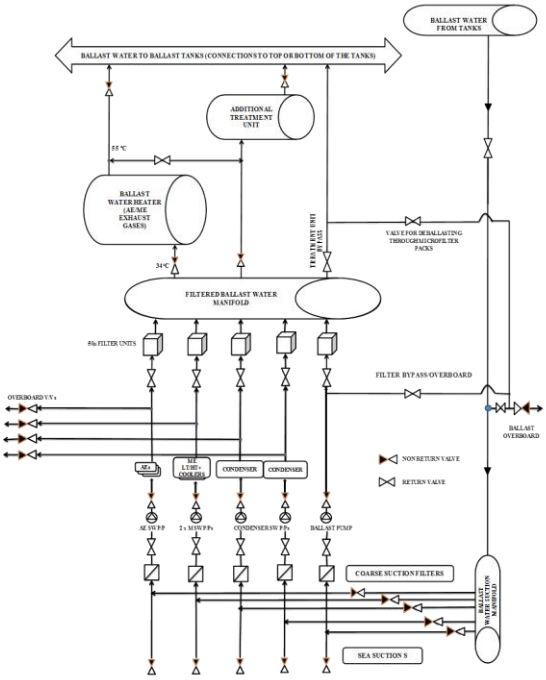


Figure 1: Layout of the modified ballast system

During deballasting, the ballast water can be dropped by gravity and also by using the pumps. In the modified version, the deballasting can also be operated through the microfiltration packs. This option provides additional security as any leftover species will be filtered prior to the discharge in the port waters.

The system design allows two possible ways of ballasting, either by using the Main Sea Water (MSW)/Condenser circulating pumps or by using the main ballast pumps. Else, part ballasting can be done using the MSW pumps and the rest by using the ballast pump. The latter is a more realistic situation in many cases, as stay-ports for oil tankers are limited. Treatment can also be extended during port stays. Treatment protocols are also envisaged for the developed system. Table 1 shows the treatment protocol for different vessel conditions depending on the shipboard heat sources.

Table 1: Treatment protocol

Vessel Position	Pumps			Filters		Treatment Unit		Remarks
	AE CW	MSW	Ballast	Coarse	Fine 50μ	Heat Exchanger	Additional	
Discharge port	On	On or Off	On	On	On	On or Off	On	LT & steam condenser heat available
Sailing	On	On	Off	On	On	On	On or Off	LT, HT & steam condenser heat available
Load port	On	On or Off	On	On	On	On or Off	On or Off	LT & steam condenser heat available

In other BWT systems which employ microfiltration, as the filtration units get clogged, back flushing is employed, but this causes loss of power. In this design, filter packs are blown using compressed air (5 to 7 bar), and the blown matter is routed overboard with any steam condenser sea water inlet. Figure 2 shows the schematic arrangement of the filtration modules. The incoming sea water (with blown matter) will absorb heat from the condensing steam, and the instantaneous high temperature will ensure mortality of any surviving or regrown organisms.

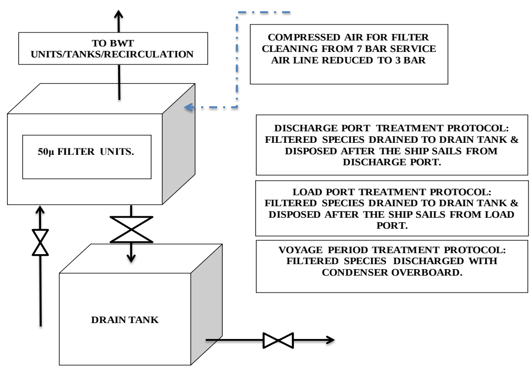


Figure 2: Schematic layout of filtration Unit

Bacteria presence had been observed in pulverized (dead) zooplankton [6]. Post treatment measure of disposing the organic debris through condenser overboard discharges can mitigate such bacteria occurrence. At ports, the blown matter can be retained in storage tanks and disposed later after the vessel sails to a safe distance from the port. The suction arrangement can include an eductor with its suction connected to the drain tank. Direct suction lines are prone to blockages, thus the eductor arrangement would facilitate easier removal of species-debris without any blockage.

In the developed BWT system, treatment is operated through five stages. Figure 3 shows the schematic stages where species elimination is identified. Physical separation in coarse filters, mechanical shear in the impellers of the centrifugal pumps, heat effect in LT/HT coolers, separation in fine filters and heat effect in heat exchanger constitute the treatment stages. Further, efficiency can be contributed by additional treatment unit (UV or other suitable technology, if fitted) and dark ambience in tanks.

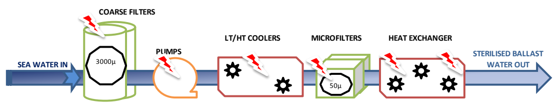


Figure 3: Ballast Water Treatment system: Species' elimination stages

The microfiltration packs, purpose-built heat exchanger and additional treatment system are addenda, whereas the other components are typically present in any regular ballast systems. Through this system, by utilizing waste heat as the major shipboard resource, energy costs will be virtually negligible.

Heat availability is identified in all protocols but higher temperature ranges are only available with the exhaust gases. A low quantum of exhaust gas heat may be obtained from the AEs during port stays, but scope needs to exist to harness more heat from exhaust during sailing when the main diesel engine is in operation. Nevertheless, the efficacy of harvesting this heat requires a well-designed heat exchanger.

Results from Tests on Mini-scale Systems

The first set of tests was carried out to ascertain the heat availability and recovery potential on an engine-auxiliaries arrangement. In previous tests, Balaji and Yaakob [5] had analysed the heat availability of an operational tanker and had verified the recovery potential on this mini-scale arrangement. The arrangement included a heat exchanger placed on the path of the exhaust gases, similar to the heat exchanger arrangement in the envisaged treatment system, as Ballast Water Heater, as shown in Figure 1.

The results of tests in this arrangement showed a recovery of 4.35% from fresh water, while the operational data from ship showed recoveries at 5.14% of the input energy [5]. In the tests, a minimum recovery of 14.87% and a maximum of 33.36% were recorded for exhaust gases after the turbochargers. The ship board operational data showed a recovery of 15.25% of the input energy in the turbochargers and exhaust gas boilers. A heat recovery of 6.62% of the input energies was assumed for the designated heat exchanger, for treatment (Figure 1, Ballast Water Heater) and optimised [7].

The total recovery from the exhaust gases was found achieving 21.87% of the input energy.

In the second set of tests, species' mortalities were assessed using an engine-heat exchanger arrangement apart from laboratory level tests. The tests were conducted on typical plankton and bacteria. The temperature ranges, exposure time needed for mortalities and effects of pump impeller on the species were ascertained. The species' mortalities were considerable in the realisable temperature range and the results from impeller effects were encouraging.

Discussion

The developed system can be assessed for its feasibility based on International Maritime Organisation's (IMO) requirements and the results obtained from the tests.

IMO requires the BWMS to be safe for the crew and ship, environmentally acceptable, technically effective, cost effective and practical.

Firstly, since the system and the methods employed involve no active substances *a priori*, it should be safe to handle and involve no health concerns. Secondly, for the same reasons, the discharges should be free from any chemical byproducts and neutralisation substances.

This would render the waters as environmentally safe and acceptable. This is true for the heat treatment mode which will be complementary. Nevertheless, the treatment system to be employed will be a determinant.

The next requirement is the technical effectiveness of the proposed method. The laboratory level tests and results of the engine-heat exchanger rig confirm mortalities of the tested plankton in mid-range temperature of 30 to 40^{o}C. This is attainable in the LT/HT coolers as confirmed from the analyses on the operational vessel [5].

The earlier studies concerned about the difficulty in assessing a wide variety of ocean species. For example, Rigby *et al*. [8] chose species with greater resistance (dinoflagellates) and demonstrated mortalities. Bolch and Hallegraeff, [9] demonstrated 100% mortalities for *Gymnodinium catenatum* dinoflagellate cysts at 38^{o}C (maintained for 3.5h). At same range of temperature and time, Hallegraeff *et al*. [10] demonstrated 100% mortalities of *Alexandrium catenatum*. The current studies supplement this related research.

During the onboard trial conditions, Quilez-Badia *et al*. [11] cooled the heated waters quickly by exchanging the heat using the incoming waters. In the current system with no such immediate cooling, the temperature drop will be gradual, hence mortalities will be considerably high.

This will be the situation till the waters enter the ballast tanks. Even if sudden drop in temperatures is expected, mortalities are assured. This is significant, considering engine heat as a complementary treatment method.

Further from the analyses by Balaji and Yaakob [5], it seems that with optimal flow rates, if the lower optimum temperature of 55^{o}C is maintained as the target temperature, about 30% of full ballast quantity of the vessel considered for the study can be treated by circulation of regular pumps alone. This is realisable during a voyage period of eight days. The system arrangement assures that the remaining 70% will certainly attain a low temperature range from 35 to 40^{o}C. Additionally, all the waters will pass through the micro filters at least twice.

Cao *et al*. [12], while proving cytometry and fluorescence microscopy to be effective for verification of mortalities, employed *Escherichia coli* as indicator microorganisms (10µ size) for laboratory level tests. The results indicated that a temperature of 80°C was probably required for organisms of 10µ size range to effectively kill the organisms within 60 seconds. Also, inactivation of *Vibrio* sp. had been demonstrated at an exposure for 30 seconds at 73°C or around 65°C for 120 seconds [13].

The current tests indicate that bacteria elimination could be expected if the temperature levels were maintained higher. However, temperature range beyond 65°C would require the flow rates to be reduced. The mortality effect on other types of bacteria might not be significant and will need to be studied.

Veldhuis *et al*. [14] observed that pump effects caused 90% of mortalities on an average but the remaining organisms were above the IMO D2 standards. Treatment would be required for the remaining 10%. Quilez-Badia *et al*. [15] observed that the effect of centrifugal pump impellers will be present in any kind of treatment system.
Though there are some designs of centrifugal pump, the resident time of species in pump casing of any type will be negligible, given high impeller speeds. At stand still condition, some species can be assumed to reside but the quanta will be negligible compared to the densities in the ballast water tanks.

The tests on the experimental set-up confirm that impeller effects are not negligible. It may be surmised that with more number of pumps employed for the circulation (as in the developed system), the impeller effects can be enhanced. This feature of the system itself would ensure increased mortalities of plankton.

For an earlier system harvesting, Radan and Lovric [16] proposed modification on the heat from the engine jacket water alone [8]. However, with these, recoveries were expected from engine systems (scavenge air/lubricating oil/jacket water coolers) only, and the treatment protocol was limited to sailing periods. The modifications suggested by Radan and Lovric [16] included additional insulated ballast tank, additional heat exchanger with two stages and pump apart from extra pipelines. Also, more modifications were proposed for both the sea water and fresh water systems. Acomi *et al*. [17] proposed using a sea water circulating pump to pump the sea water from the overboard line to the ballast tanks.

As novel method, the developed system requires no such modifications to the fresh water system and no additional pumps. Further, considering the function of the system, no additional operations are needed other than the routine line-up and setting of valves. For the operational vessel on which the proposed system is based on, lighter materials with corrosion resistant properties can be used for the additional pipelines. These advantages make the system more practical because the system is primarily seen as an extension of any existing system. The trade-off on this could be the extra space requirements for the heat exchanger and pipelines.

The last requirement to be considered is the cost. The capital cost of a heat based system is in the range of US$350000 to 400000 (Gregg *et al*., 2009). Mesbahi *et al*., [18] projected fuel costs due to additional heat requirements at US$100 to 600 depending on the flow rates between 1000 to 3500 m^3/h. However, these costs are projected for a treatment system entirely dependent on heat and also using additional heat energy producing source such as boiler.

Since the developed system is aligned to complement a regular system, the capital costs are not expected to be high. Since no additional heat energy source such as boiler is required, fuel costs are also not incurred.

If capital costs are excluded, the operating cost for a heat system should mark at US$0.05 to 0.17/tonne [2]. However, this cost is merely based on energy and fuel costs to pump the waters. This additional cost will not be incurred in the proposed system as existing pumps running for various duties are to be used for the circulations.

Consequently, the heat exchanger and pipelines will add to the total cost of any regular BWMS. For example, the installed cost of the optimised heat exchanger may reach US$69829. The additional cost of pipelines would be nominal. Neverthelesss, this increase in the cost is a trade-off as the waste heat recovery will offset the initial increase in costs.

Conclusion

The viability of a ballast water treatment system based on engine waste heat has been demonstrated. The function of the system itself has been envisaged based on the arrangement on an operational vessel. Still, good range of mortalities and the attraction of waste heat utilisation require further investigation. A pilot-scale study with additional treatment system (UV, Deoxygenation) for higher flow rates would be prognostic for shipboard application.

Acknowledgements

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