CHEMICAL ENGINEERING TRANSACTIONS

VOL. 110, 2024

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Marco Bravi, Antonio Marzocchella, Giuseppe Caputo

ISBN 979-12-81206-10-6; **ISSN** 2283-9216

DOI: 10.3303/CET24110062

Retrofitting Ballast Water Treatment System: a Container Ship Case Study

Shahrul Miza Mahmud [a,b], Lai F. Chuah[c], Wan Mohd Norsani Wan Nik*[d], Anuar Abu Bakar[a], Mohd Azlan Musa[a]

[a] Faculty of Ocean Engineering Technology, Universiti Malaysia Terengganu, Malaysia.
[b] Nautica Ship Management Sdn Bhd, Malaysia.
[c] School of Technology Management and Logistics, Universiti Utara Malaysia, Malaysia.
[d] Faculty of Maritime Studies, Universiti Malaysia Terengganu, Terengganu, Malaysia.
niksani@umt.edu.my

The utilization of ballast water in ships is known to have detrimental effects on the marine environment, leading to economic losses, ecological harm and potential risks to human health. This impact stems from the transfer of non-native species and harmful pathogens through ballast water discharge. In response to these issues, the international convention on ballast water management entry into force on 8 September 2017. This paper showcases a thorough 3D scanning assessment for retrofitting the Ballast Water Treatment System (BWTS) in a container ship. The study conducted an extensive analysis of the technological intricacies associated with Ultraviolet (UV) and Filtration type Ballast Water Treatment Systems (BWTS), focusing on both installation and operational aspects. The results reveal that the weight of BWTS represented only 0.04% of the initial lightship weight, resulting in a minimal impact of less than 2% on vessel stability. Significant cost reduction was observed, with a twofold decrease in instances where UV treatment was utilized at 100% UV Transmission compared to levels below 65%. This underscores the economic advantages associated with UV treatment technology, suggesting substantial cost savings potential in ballast water management practices and the significance of integrating 3D scanning analysis in future research endeavours to accommodate specific ship-related variables and to embrace a more nuanced approach in assessing BWTS effectiveness.

1. Introduction

The utilization of ballast water plays a crucial role in maintaining the trim and stability of ships. The inadvertent release of this ballast water during offloading poses a significant ecological threat. Unwanted microorganisms, including phytoplankton and zooplankton are released into new regions, often resulting in severe ecological damage (Olsen et al., 2016). The impact of non-indigenous species has been well-documented, leading to ecological disturbances (Drake et al., 2007) and resulting in significant economic losses and adverse effects on human health (Wang et al., 2020).In response to these environmental challenges, global efforts have been underway particularly within the International Maritime Organization (IMO) leading to the establishing of the International Convention for the Control and Management of Ships' Ballast Water and Sediments in 2004. Scheduled to take effect on September 8, 2017, this convention mandates stringent measures to address the ecological and economic consequences of ballast water discharge (IMO, 2019).

Numerous strategies for Ballast Water Management (BWM) have been suggested, encompassing both port-based and shipboard treatments, the latter including ballast water exchange and onboard treatment through physical separation or secondary treatment involving mechanical and chemical means (Gonçalves and Gagnon., 2012). With the imminent enforcement of the BWM Convention, the installation of Ballast Water Treatment Systems (BWTS) becomes mandatory for both new and existing ships as mandated by the convention. This indicates an expected increase in demand for BWTS (Sayinli et al., 2022). Despite the imminent enforcement of the BWM Convention, a comprehensive examination of the feasibility of retrofitting BWTS via 3D scanning on existing ships remains scarce (Edl et al., 2018). The adequacy of retrofitting BWTS in fulfilling

Paper Received: 09 February 2024; Revised: 27 March 2024; Accepted: 04 June 2024
Please cite this article as: Mahmud S.M., Chuah L.F., Norsani Wan Nik W.M., Abu Bakar A., Musa M.A., 2024, Retrofitting Ballast Water Treatment System: A Container Ship Case Study, Chemical Engineering Transactions, 110, 367-372 DOI:10.3303/CET24110062

vessel stability safety requirements, particularly concerning the evaluation of additional lightship weight changes, poses a significant concern in maritime operations (Priftis et al., 2018). There is a distinct gap in the current understanding regarding the comparative cost implications of retrofitting BWTS on targeted ships (Wang and Corbett., 2021). This study aims to assess the feasibility of retrofitting BWTS to meet the vessel's stability safety requirements. It evaluates potential changes in the vessel's lightship weight and conducts a comparative cost analysis for retrofitting BWTS on container ships to address this gap.

2. BWTS profiles

Ballast water is recognized as a major pathway for the spread of harmful aquatic organisms and pathogens, presenting a considerable threat to the environment and human health due to marine pollution. This convention introduced two regulations standards, the Ballast Water Exchange Standard (Regulation D-1) and the Ballast Water Performance Standard (Regulation D-2). The latter mandated the installation of BWTS equipment on ships for compliance (Campara et al., 2019).

2.1 BWTS UV-type

BWTS UV configurations can be determined by conducting on-site inspection onboard ship and 3D scanning for retrofitting (Edl et al., 2018). The BWTS adopted a comprehensive approach integrating both filtration and UV radiation technologies. The filtration component featured a mechanical filter with an automatic backflush mechanism and a basket-type 20 µm filter mesh. Medium-pressure UV lamps integrated within the UV units were employed to optimize UV radiation effectiveness. This dual-functionality system was specifically engineered to address ballast water treatment requirements during both uptake and discharge processes.

In terms of deployment configurations, the loose component option provided the highest level of flexibility, rendering it the preferred choice for retrofit projects. With this arrangement, all components except for electrical wiring and pipe spools were arranged freely enabling placement wherever space permits. The skid-mounted configuration, featuring a fully assembled system on a skid, highlights a compact footprint and ensures a seamless, plug-and-play installation experience. The deckhouse configuration caters to a vessel lacking space below the deck, such as chemical tankers with submerged ballast pumps. This plug-and-play option can be easily installed on deck, with or without a booster pump, providing a versatile solution for diverse vessel types. The amalgamation of these technological features and deployment options underscores the system's adaptability and efficiency in addressing various ballast water treatment scenarios.

3. Considerations on installation and operation

This paper presents a case study illustrating the successful implementation of 3D scanning during the initial phases of retrofitting UV-type BWTS on a vessel. The focus is on elucidating the encountered challenges, providing detailed insights into the retrofitting procedures and demonstrating the resulting benefits which include improved environmental compliance and operational efficiency. The study scrutinized the application of 3D scanning in informing critical decisions including the identification of optimal retrofitting locations, selection of appropriate BWTS versions and formulation of cost analysis strategies (Edl et al., 2018).

3.1 Determination of potential locations

The process of identifying potential locations involved a systematic multi-step approach aimed at strategically placing BWTS hardware to optimize operational efficiency and ensure environmental compliance as shown in Figure 1. Prior to commencing 3D scanning, the ship's general arrangement drawing was thoroughly reviewed to identify critical factors influencing hardware placement. Case study selection focused on representative vessels that had undergone successful BWTS retrofitting, specifically targeting UV-type systems, and ensuring diversity in vessel types. Spatial analysis was conducted using 3D models and CAD software to assess spatial arrangements considering factors such as accessibility, proximity, and regulatory requirements. Performance metrics, including accessibility, integration, and compliance were determined, and proposed arrangements were validated through expert consultation. Optimization strategies were developed based on spatial analysis, and performance metrics with validation carried out through simulations, and onboard inspections for 3D scanning.

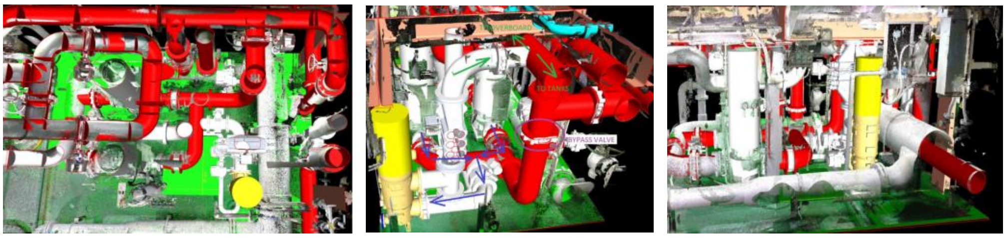

Figure 1: Employed 3D scanning target ship, from left to right, top, aft and side views

3.2 Piping and Instrumentation Diagram (PID) simulation for selection BWTS version

A PID simulation was generated from a targeted container vessel to systematically assess the feasibility and compatibility of integrating BWTS retrofitting into the existing ship infrastructure as shown in Figure 2. The data gathering process involved obtaining information from the vessel's design specifications, including details of ship's ballasting system, pump specifications, engine room structure and layout, and ship's stability booklet, all provided by the ship's owner. To facilitate integration with the ship's ballasting system, technical specifications, and dimensions of BWTS hardware were directly sourced from the selected BWTS manufacturer. Utilizing the industry standard PID simulation software AutoCAD P&ID, the simulation enabled precise digital modelling of the vessel's existing piping and instrumentation system. The simulation encompassed several critical stages including input data preparation, component placement, piping integration, instrumentation integration, and a thorough evaluation criteria. A sensitivity analysis was performed by systematically varying critical parameters to evaluate the robustness of the retrofitting BWTS across various operating conditions. In the results and discussion section, challenges encountered during integration were addressed, along with proposed optimizations and modifications for successful implementation. The section further elaborated on how the PID simulation played a crucial role in informing the selection process and conducting a feasibility assessment of the BWTS for the container vessel.

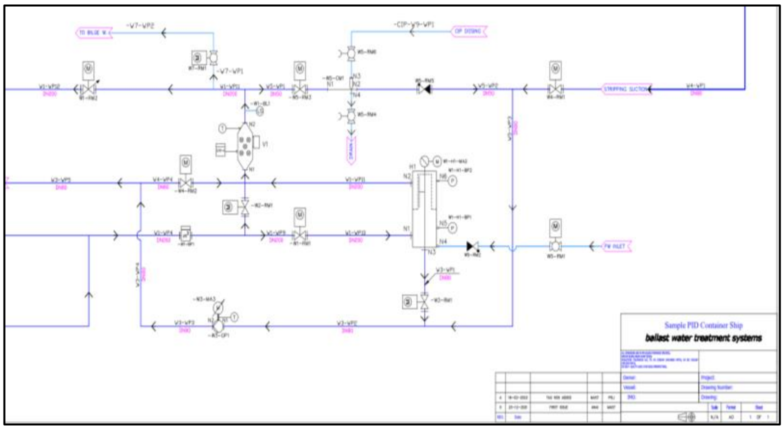

Figure 2: BWTS PID simulation into existing ship's ballast system

3.3 Retrofitting BWTS integration

The primary objective of this research was to systematically evaluate the retrofitting process which involved integrating BWTS from various manufacturers into the existing ballast system of a selected container vessel as shown in Figure 3. The focus was on evaluating the compatibility of various BWTS models with the ship's structure as shown in Figures 4 and 5. The data collection phase involved a comprehensive review and extraction of technical specifications, design features, and operational parameters of BWTS from various profiles along with crucial ship parameters such as ballasting data and engine room layout. Utilizing sophisticated 3D scanning and simulation software ensured an accurate digital representation of the ship's ballast system, enabling the virtual placement of BWTS hardware. The simulation involved input data preparation, strategic placement of BWTS components, seamless piping integration, and instrumentation integration. A comprehensive evaluation including assessment of spatial compatibility and adherence to safety standards was conducted. A sensitivity analysis explored the robustness of different BWTS models under varied operating conditions.

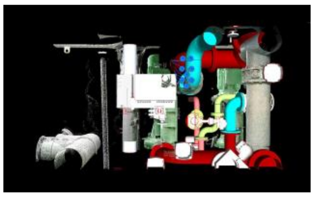

Figure 3: The 3D scanning of ship’s structure

Figure 4: The ship’s ballast system

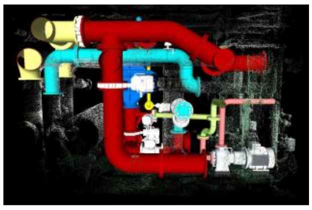

Figure 5: The 3D scanning BWTS compatibility with the ship’s ballast system Cost analysis

3.4 Target vessel specifications

This paper presents a comprehensive evaluation of retrofitting a BWTS on a 24-year-old container vessel. The study examined crucial vessel specifications, operational schedules, ballast system configurations, and associated costs to assess the impact on cargo capacity, ship stability, and economic factors involved in retrofitting BWTS. Considerations for predicting future oil prices and labor rates were incorporated to provide a holistic understanding of the retrofitting viability.

The container vessel with an overall length of 175 m and a deadweight tonnage (DWT) of 23,577 t is designed with 19 ballast tanks, totalling a capacity of 7865.5 m^3. Two strategically positioned ballast pumps with a rate of 300 m^3/h facilitate ballast water supply and overboard discharge. The vessel was trading with an average of 24 times international return voyages annually, necessitating one ballasting and de-ballasting operation per voyage. Table 1 demonstrates the delivery of modifications include a nominal change in the lightship weight, amounting to 3.3 t, representing a marginal variation of 0.04%. This magnitude of change was considerably less than 2% of the prevailing lightship weight, signifying a relatively minimal impact on the overall stability of the vessel. The adjustment in the Longitudinal Center of Gravity (LCG) was determined to be 0.012 m, corresponding to a mere 0.01% deviation concerning the ship's length. This alteration, being less than 1% of the vessel's longitudinal, indicates a minimal impact on the longitudinal stability characteristics. The new Vertical Center of Gravity (VCG) was determined to be -0.004 m, reflecting a nominal shift constituting 0.03% of the moulded depth. This change was found to be less than 1% of the vessel's moulded depth, indicating a marginal influence on the vertical stability attributes for a range of BWTS specifications, as shown in Table 1.

The study outlined the overall costs, including capital expenditure (CAPEX) and operating expenditures (OPEX). CAPEX encompassed product and installation costs with general BWTS UV-type (Table 2) installation costs considered (Table 3). The retrofitting project period aligned with the ship's life expectancy (30 y), resulting in a remaining 6-year BWTS operation period on targeted ship. To enhance economic viability analysis, the study utilized current oil prices, with IFO180 (0.5%) and IFO380 (3.5%) priced at approximately Euro 490 and Euro 410 per t as of December 2023. A flat labor rate of Euro 82 per h is applied uniformly for all activities with a BWTS installation duration of 17 days for UV-type. This comprehensive assessment offers valuable insights into the technical, operational, and economic facets of retrofitting a BWTS on container vessels. It provides essential considerations for shipowners, operators, and regulatory bodies in their endeavours to pursue sustainable bwm practices.

Table 1: Assessment of retrofitting BWTS

Retrofitting assessment	Weight (t)	VCG (m)	LCG (m)
Lightship weight before retrofitting	8,529.476	11.720	-14.175
BWTS equipment’s	1.100	3.780	-49.300
BWTS foundations	0.200	3.500	-49.400
BWTS accessories	1.800	2.850	-47.510
Total additional weight for BWTS	3.300	-	-
New lightship with BWTS	8,532.776	11.716	-14.187

Table 2: Specification of BWTS

Description	BWTS specification
Type	Filtration + UV
Flow range	Ballast: 45 – 340 m^3/h, De-ballast: 9 – 340 m^3/h
Filter capacity	340 m^3/h
UV capacity	340 m^3/h
Ambient temperature range	0 °C to 50 °C
Relative humidity electronics	100%
System pressure loss	Filter: 0.3 bar, UV system: 0.2 bar, Total: 0.5 bar
Power supply range	440 V, 50/60Hz, 3 phase
Power requirement	3 phase x 67 kW

4. Results and discussion

Table 3 demonstrates a concise summary of the CAPEX derived from the results of 3D scanning.

Table 3: Capital expenditure cost retrofitting BWTS for a container vessel

Descriptions	Cost (Euro)
Engineering package (inspection and 3D scanning)	37,000
BWTS hardware	98,000
Shipyard	110,000
Testing, commissioning and training	4,000
Supervision	6,000
Total	255,000

The operating costs included hours of operation, filter usage, fuel, and power consumption. Table 4 demonstrates the estimated five years operational costs for BWTS UV-type. Tables 5 and 6 provide a comprehensive assessment of project costs over the operational period, encompassing spare parts replacement interval costs and OPEX.The UV-type BWTS emerged as the most cost-effective option for installation and operation costs. These findings contributed valuable insights into the economic considerations surrounding BWTS implementation.

Table 4: Five years operational cost of BWTS

Data	UVT < 65%	UVT 85%	UVT 100%
Total operating hours (h)	1,440	1,440	1,440
Hours of filter in operations (h)	720	720	720
Power consumption (kW)	67	36	24
Total power (kWh)	96,480	52,531	34,560
Fuel oil consumption (kg)	21,612	11,767	7.741
Fuel cost in five years, MGO (0.1%) per t	Euro 13,000	Euro 7,000	Euro 5,000
Fuel cost in five years, IFO180 (0.5%) per t	Euro 12,000	Euro 6,000	Euro 4,000
Fuel cost in five years, IFO380 (3.5%) per t	Euro 9,000	Euro 5,000	Euro 3,000

Table 5: Spare parts replacement interval cost

Item	UVT < 65%	UVT 100%
8 x UV lamp	6,000 h operation	Euro 600 per pieces x 0 = 0
Filter insert	10,000 h operation	Euro 12,000 per pieces x 0 = 0
UV intensity sensor	Three years operation	Euro 800 per pieces x 1 piece = Euro 800
Pressure transmitter	Five years operation	Euro 300 per pieces x 2 pieces = Euro 600
Temperature transmitter	Five years operation	Euro 250 per pieces x 1 piece = Euro 250
Flow meter	Five years operation	Euro 3,000 per pieces x 1 piece = Euro 3,000
Total spare parts cost	Five years operation	Euro 4,000

Table 6: Operating expenditure cost

Description	UVT < 65%	UVT 85%	UVT 100%
Total OPEX in five years (MGO + spare parts)	Euro 17,000	Euro 11,000	Euro 9,000
Total OPEX in five years (IFO180 + spare parts)	Euro 15,000	Euro 10,000	Euro 8,000
Total OPEX in five years (IFO380 + spare parts)	Euro 13,000	Euro 9,000	Euro 7,000

5. Conclusion

This study offered a comprehensive examination of various BWTS, explicitly focusing on the UV-type and encompassed a detailed cost analysis focusing on retrofitting UV-type BWTS on a container vessel. The analysis covered the cost of pre-installation, installation, and operational retrofitting of BWTS, along with elucidating the primary functionalities of UV-type BWTS and suggesting potential retrofitting configurations in the engine room. Acknowledging the distinctive attributes of container vessels, this study emphasizes the possibility of divergent outcomes among various vessel types. Factors viz. type, size, weight, voyage schedule, power load, ballast capacity, arrangement, ballast tanks, and cargo space contribute to the diversity in outcomes. The findings offered valuable insights, emphasizing the need for tailored analyses due to the heterogeneous nature of vessels. In further analyses concerning retrofitting BWTS, the study emphasizes the importance of considering ship specific factors, advocating for a nuanced and vessel specific approach. The research findings highlighted the weight of the BWTS with a minimal 0.04% of the initial lightship weight, resulting in less than a 2% impact on vessel stability within safe margin. The study also revealed a substantial cost reduction about two-fold when utilizing UV treatment at 100% compared to levels below 65%. This cost efficiency added an essential dimension to the understanding of retrofitting BWTS, making UV treatment a financially advantageous choice. This study significantly contributed to the shipping industry field by providing detailed exploration 3D scanning in pre installation of BWTS and a thorough cost analysis. This study serves as a valuable resource for future analyses, advocating for the integration of 3D scanning analysis in research to accommodate specific ship factors and promote a nuanced approach to retrofitting BWTS.

Acknowledgments

The authors wish to acknowledge Universiti Malaysia Terengganu and Universiti Utara Malaysia in the field study and data collection.

References

Campara L., Francic V., Maglic L., Hasanspahic N., 2019, Overview and comparison of the IMO and the US Maritime Administration ballast water management regulations, Journal of Marine Science and Engineering, 7(9), 283.

Drake L. A., Doblin M. A., Dobbs F. C., 2007, Potential microbial bio invasions via ships' ballast water, sediment, and biofilm, Marine Pollution Bulletin, 55(7–9), 333–341.

Edl M., Mizerák M., Trojan J., 2018, 3D laser scanners: History and applications, Acta Simulatio, 4(4), 1–5.

Gonçalves A. A., Gagnon G. A., 2012, Recent technologies for ballast water treatment, Ozone: Science and Engineering, 34(3), 174–195.

IMO, 2019. Ballast water management - the control of harmful invasive species. Available online at <www.imo.org/en/MediaCentre/HotTopics/Pages/BWM-default.aspx> accessed on 20.03.2024.

Olsen R. O., Hoffmann F., Hess-Erga O. K., Larsen A., Thuestad G., Hoell I. A., 2016, Ultraviolet radiation as a ballast water treatment strategy: Inactivation of phytoplankton measured with flow cytometry, Marine Pollution Bulletin, 103(1–2), 270–275.

Priftis A., Boulougouris E., Turan O., Papanikolaou A., 2018, Parametric design and multi-objective optimisation of containerships, Ocean Engineering, 156, 347–357.

Sayinli B., Dong Y., Park Y., Bhatnagar A., Sillanpää M., 2022, Recent progress and challenges facing ballast water treatment – A review, Chemosphere, 291(2), 132776.

Wang Z., Corbett J. J., 2021, Scenario-based cost-effectiveness analysis of ballast water treatment strategies, Management of Biological Invasions, 12(1), 108–124.

Wang Z., Nong D., Countryman A. M., Corbett J. J., Warziniack T., 2020, Potential impacts of ballast water regulations on international trade, shipping patterns, and the global economy: An integrated transportation and economic modeling assessment, Journal of Environmental Management, 275, 110892.