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# DEVELOPMENT OF UV-BASED STERILIZATION SYSTEMS FOR AIR AND WATER TREATMENT IN SHIPS

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**Abstract**
Ballast Water (BW) management is an efficient strategy to prevent the migration of species and bacteria via BW to other regions. The International Maritime Organization (IMO) enacted the International Conventions on the Conservation and Management of Bilge Water and Ship Sediments, which govern bilge water management practices. Many methods have been investigated and produced; specifically, the utilization of Ultraviolet (UV) rays is assessed with many benefits and aligns with the stipulations of the Conventions. The UV reactors in the BW sterilization systems possess substantial capacity, necessitating the usage of multiple high-power UV lamps within a single reactor. These high-intensity UV lamps require significant electrical power and are pretty costly. It is essential to research the regulation of UV radiation during water disinfection to enhance the longevity of UV lamps, reduce electricity consumption, and ensure excellent antibacterial performance. The article details the creation of a control device for UV reactors and BW flow within the BW sterilization system implemented on vessels. Experimental findings on vessels demonstrate the efficacy attained by the designed UV controller.
**Keywords – Ultraviolet, Sterilization, Water Treatment, Ships**

## 1. INTRODUCTION

Ships convey substantial commodities between nations and regions [1]. The advantages provided by this media are significant. Issues linked to that advantage include reduced travel speed, environmental pollution from fuel utilized in engines for vessels or cargo, and Ballast Water (BW) [11]. Comprehensive research on this vehicle is essential to enhance the efficiency of ships as a transport mode. Compared to terrestrial and aerial modes of transport, vessels operate at a significantly reduced speed [2]. Numerous studies have demonstrated that research and computational modeling can yield efficient solutions for enhancing speed and associated aspects. Practical strategies to strengthen ship speed might be identified in pertinent studies, including research on optimal propulsion systems, investigations into the impact of currents on vessels, and analyses of the effects of hull design on hydrodynamic efficiency [3]. Vessels consume substantial fuel for their engines during voyages, and research to identify appropriate fuels for maritime engines is actively encouraged [12].

Research on successful engine fuel catalysts and examining fuel injection issues pertinent to boat engines contributes to the optimal fuel utilization in ship motors. Research has indicated potential alternatives to fossil fuels utilized by ships, including biodiesel and other fuel alternatives [13].

A study is now being conducted on renewable energy to optimize and utilize energy sources effectively. Effective energy management constitutes a sustainable approach. Simultaneously, before the onset of the COVID-19 pandemic, the shift towards renewable energy within the global energy framework and the substantial demand for clean fuel were unavoidable [10]

[14]. The considerable fuel consumption of engines on ships results in emissions detrimental to the environment [4]. Research has been conducted on reducing emissions, including implementing electric motors. Research has been conducted on technologies and processes to mitigate emissions. Research conducted during the COVID-19 pandemic indicated reduced Carbon dioxide ($CO_2$) and nitrogen oxides ($NO_x$) emissions [9]. Maritime pollution has become a significant challenge.

Environmental pollutants infiltrate the surroundings, including oil leaks from ship motors, oil spills from maritime accidents, and heavy metals in fuel or cargo [5]. Numerous studies have been conducted to address this issue, including investigations into heavy metal remediation, oil spill response equipment, and the development of spill absorbents.

Absorbent substances or apparatus for the remediation of oil-contaminated water are the answer to this issue. BW is regarded as the primary cause of the unforeseen introduction of non-native species into new ecosystems [17]. To mitigate and avert the adverse impacts of BW on the identified issues, the world community ratified the "International Agreement for the Control and Maintenance of Ships' BW and Deposits". Specifications regarding the quantity and makeup of BW will be rigorously regulated. Various physical and chemical processing techniques are examined to fulfill the objectives above optimally [18].

Approximately 10k metric tons of BW are exchanged annually during sea transport operations. During BW processes, thousands of non-native organisms inevitably infiltrate new marine ecosystems daily, damaging both economies and the ecology [20]. A research group asserted that more than 150 species had been identified in the lake region. BW, not alone from the Great Lakes, is a primary catalyst for introducing foreign species into new ecosystems in various seas. The assessment indicates that Zebra mussels caused $5k in damage by fouling fishing netting, boat hulls, and buoys, as well as obstructing water intake systems of coastal buildings.

BW purification systems utilizing Ultra Violet (UV) reactors frequently necessitate the incorporation of several high-intensity UV lamps within a single reactor [6] [19]. To attain the bactericidal force, the UV Reactors (UVR) must be regulated throughout operation to ensure that the UV Dose (UVD) stays consistent and complies with the recommended dose. The dosage of UV rays is contingent upon two factors: the water flow rate through the unit and the strength of UV radiation within the vessel. The control is contingent upon various circumstances, and the control methodology presents an issue that necessitates examination and implementation. The regulation of the UVR in global brands' BW sterilization systems is limited to an ON/OFF control mechanism. Some corporations consistently allow the reactor to function at its full potential despite variations in water flow [21]. These approaches result in an unpredictable UVD, leading to increased electrical energy consumption and a diminished lifespan of the UV bulb [16]. This essay will concentrate on synthesizing and constructing an operator for the UVR to mitigate the shortcomings above [22].

## 2. BACKGROUND

Two primary approaches exist for sterilizing BW and particles: physical separation and disinfection. Actual or solid-liquid distinction is a process that isolates suspended solid materials, specifically larger microbes, from water used as ballast. This occurs either through settling, where substances settle due to gravity, or through surface filtering, where living things are eliminated because the pores of the filtering medium are smaller than the particles themselves [23]. The devices developed in the initial stage, consisting of mechanical particle elimination filters, are engineered as pre-treatment solutions to eliminate microorganisms and organic particles over 50 micrometers. A notable advantage of filtration is the diminishment of silt that disrupts sterilization processes, such as impairing optical transmission during subsequent UV light therapy. Filters employed in the second step of mechanical processing of BW typically possess an approximate pore size ranging from over 10 µm to 50 µm. Hydrocyclone (HC) filters are constructed hydrodynamically to produce centrifugal momentum through cyclonic flow, enabling the separation of particles denser in water without employing an external barrier to impede particle movement [7]. HCs are utilized in the processing of BW structures, albeit infrequently. HC filters are constructed hydrodynamically to generate centrifugal energy through cyclonic flow, enabling the separation of particles heavier than water without employing a barrier to impede particle passage. HCs have been utilized in BW sterilization structures, albeit infrequently [15].

Given that the HC and adjustments are more efficient for bigger particles, pre-treatment with a coagulating agent can be employed before these procedures, thereby reducing water-soluble substances and colloidal fragments, and facilitating particle collection. Iron or aluminum salts (chlorides, sulfates) serve as coagulants. Aluminium sulphate $Al_2(SO_4)_3 \times 18\ H_2O$ is the most commonly utilized coagulant. A hydrolysis procedure involving aluminium ions transpires upon introducing this chemical into water, creating aluminium hydroxides and their monomers. These compounds have low solubility, and the hydrolysis process results in a flocculent precipitation known as flocculates.

Disinfection eliminates and/or turns off microbes by two mechanisms. Oxidising biocides are broad-spectrum disinfectants that function by degrading organic compounds, including cell walls or DNA, whereas non-oxidising chemicals disrupt the reproductive, brain, or metabolic processes of animals. Menadione and vitamin K, together with their analogs, are the sole non-oxidizing chemicals employed to eradicate organisms due to their generation of harmful by-products. While frequently utilized in catfish aquaculture and synthetically manufactured for commercial purposes, they are comparatively secure for storage [8]. BW sterilization mainly employs oxidizing biocides, including chlorination, electrolysis, oxygenation, and other techniques.

Electrolysis relies on the partial hydrolysis of NaCl found in saltwater. Seawater traversing an unsegregated electrolytic cell and exiting generates seawater, sodium hydroxide, hydrogen gas, and hypochlorous acid. The electrolysis of a potassium chloride solution (seawater) involves the transmission of direct current across an electrode and a cathode to dissociate salt and water into their fundamental components. Chlorine produced at the

anode promptly synthesizes hypochlorite from sodium and chlorine dioxide, which serve as water disinfecting agents.
Ozone is regarded as a better cleaner than chlorine. Oxidation for disinfecting water is generated by introducing clean, cool air into the electrical discharge zone. The ozone-infused air is introduced into the water for sterilization. Both oxygenation and electrolysis generate potent oxidizers, including bromine (hypobromic acids and hypobromite) and chlorinated (hypochlorous acids and chlorine), effectively eliminating organisms. The primary disadvantage of oxygenation is that this process is considerably more costly than water chlorination.
Hydrodynamic bubbling, as a means of physical and chemical effects, relies on the synthesis of high-temperature and high-pressure shock waves, coupled with the production of highly reactive radicals made of hydroxyl. Shock waves cleave atomic bonds as well. Antioxidants degrade into organic pollution, while extreme conditions or hot spots induce molecules' polymerization if they are near the collapsing cavities.

## 3. PROPOSED STRUCTURAL CONTROLLER OF THE UV REACTOR

The system's microcontroller is engineered to regulate the necessary UVD to fulfill anti-bactericidal functions and to target big plankton, including bivalve larvae, zebrafish larvae, tiny crustaceans, and nematodes. The UVD is calculated using UV intensity (I) and reactor flow rate (F). The ultraviolet dosage necessary for the disinfection of various bacterial species differs. The World Health Assembly states that 35 mW-seconds/cm$^2$ UV radiation effectively eradicates most aquatic microorganisms. The stipulations for BW are distinct. A 65 mW-seconds/cm$^2$ UV radiation is required to eradicate specific viruses efficiently. Certain aquatic algae can only be eliminated at a UVD of 250 mW-seconds/cm$^2$. To guarantee the system's best functioning, controlling the UVR to maintain a steady UVD of 250 mW-seconds/cm$^2$ for the fluid passing through them is essential. In the UVR constructed by the author (Fig. 1), the UVD is defined as the total of the UV lamp's intensity throughout the procedure.

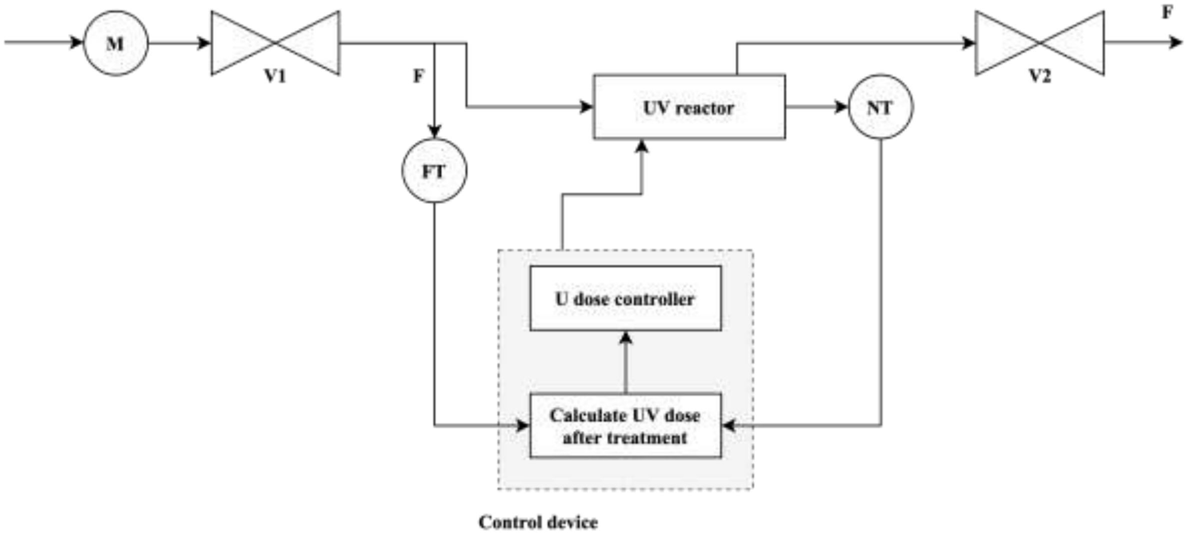


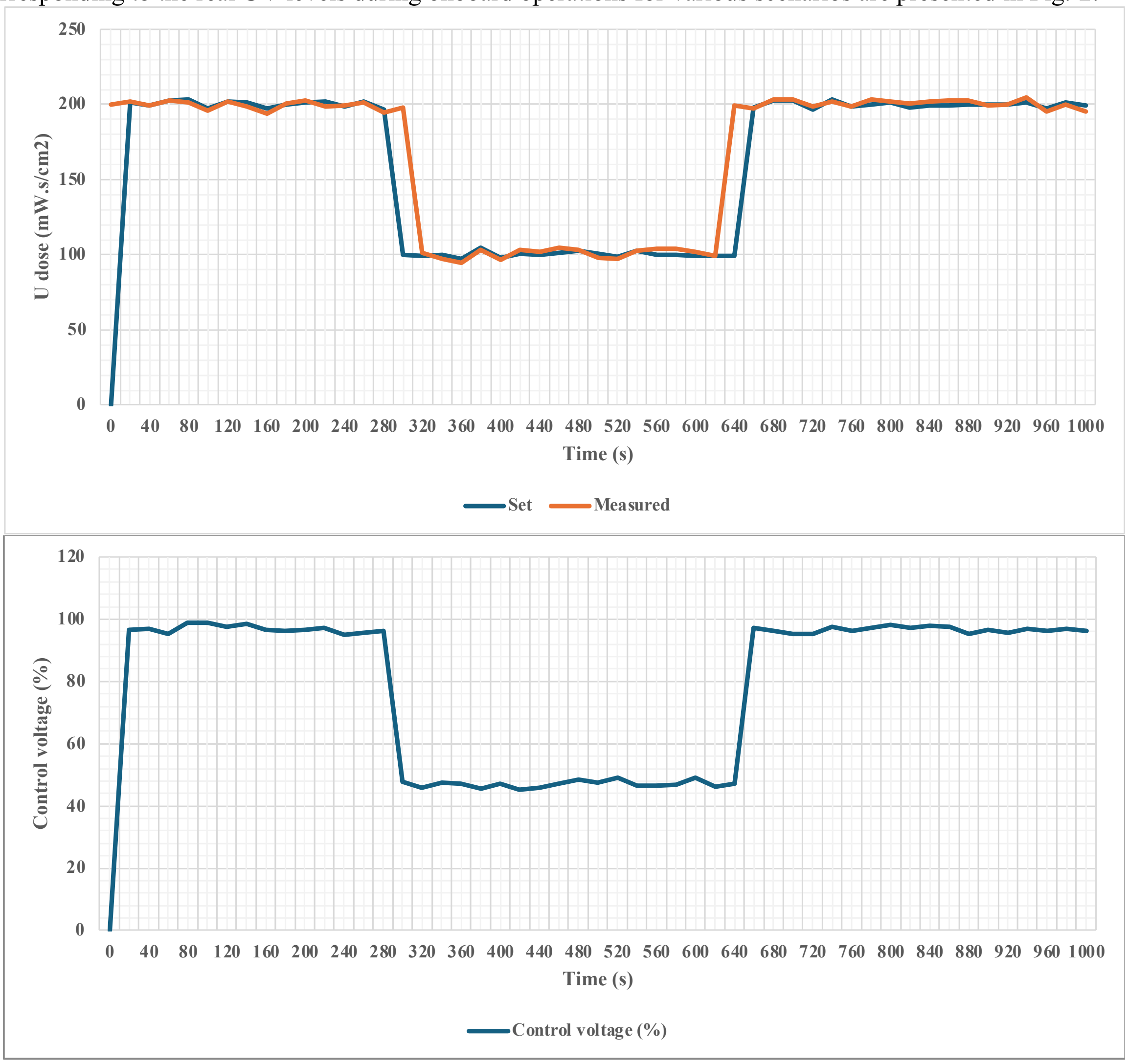

Fig. 1. System architecture

Engineered a flow controller for the ultraviolet reactor control system within the BW sterilization systems. The fuzzy management system for the UVR constructed in the preceding section has been modeled and empirically tested on-site with favorable outcomes. In practice, BW sterilization systems are predominantly installed and fitted aboard vessels currently in operation. Certain vessels occasionally exhibit a flow rate that exceeds the specified processing capability of the UVR. This has impaired the efficacy of the UV light. There exists a discrepancy between the pump flow and the UVR capability, and water turbidity considerably impacts the disinfection efficacy of the UVR. At maximal UV lamp power, a rise in water turbulence results in a drop in UV brightness. The research requires an extended duration for water sterilization (regulated to decrease flow rate) to attain the equivalent dosage of UV disinfection. In response to these needs, the researcher has modified the configuration of the UVR unit to enhance the regulation of BW supply by aligning the BW processing equipment with various pumping systems onboard, ensuring effective sterilization during elevated water clarity.
The research shall incorporate a straight valve V3 into the whole thing. The control unit will include a feature to calculate the maximum allowable amount of BW into the UVR, determined by UV intensity. At the same time, the blocks regulate the permitted flow by managing valve V3.

## 4. RESULTS

Based on the simulations and the developed algorithm, the researchers programmed a PLC to test it with the BW sterilization device for ships. The study team designed and tested it and placed it on the vessel. As elucidated in the preceding theoretical part, the UVR controls the system's function to autonomously adjust and sustain the UVD to match the predetermined UVD by fluctuating water flow rates. The control system's quality is assessed by measuring the real UV dose during the system's onboard operation. The laboratory measuring apparatus comprises a laptop and an information collection card.

The data transmitted from the device to the computer through the connection card encompasses UV magnitude, flow rate (F), UVR control power, and the determined UVD. The machine's signal output indicates the system's UVD setting. It governs the functioning of the complete UVR. It obtains the UVD setpoint signals from the machine via an analog feed. It autonomously calculates and produces a control message, represented as a 0-10 V analog output, to the high voltage converter for the UV lights, based on the UV brightness and flow rate data obtained from detectors, thereby adjusting the UVD to the predetermined value. The findings from measurements corresponding to the real UV levels during onboard operations for various scenarios are presented in Fig. 2.



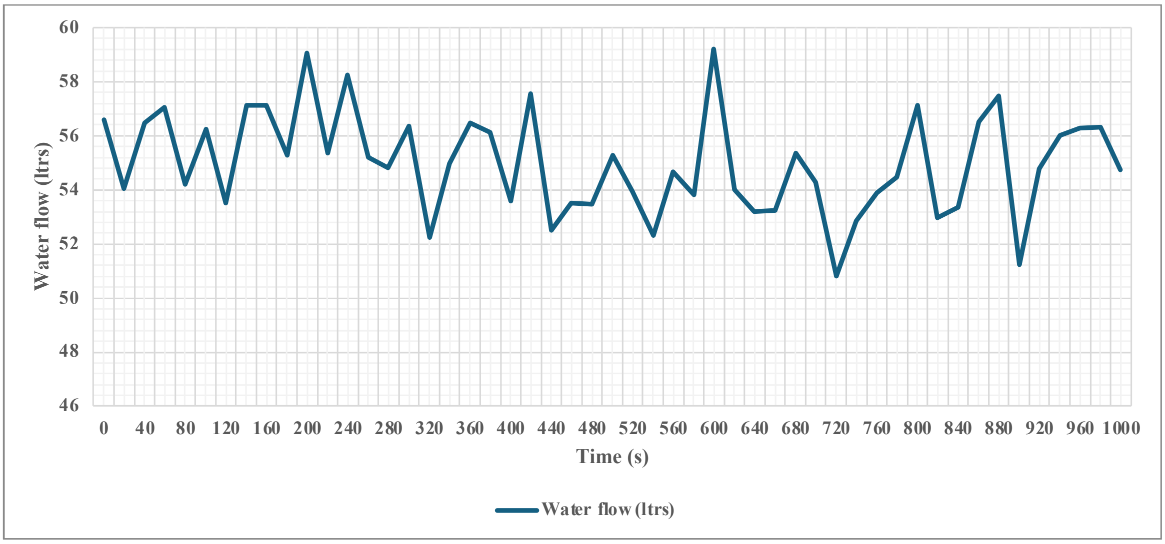



Fig. 2. Response analysis

Two instances were subjected to experimentation. Initially, the research maintained the flow rate at around 250 $m^3$/h, adjusting the UVD setpoint. From 0 to 350 seconds, the UVD is established at 210 mW.s/cm². From the 350s to the 680s, the UVD diminished to 110 mW.s/$cm^2$, rising to 210 mW.s/cm2. The estimated UVD closely aligns with the predetermined value, as the gathered data shows.

In the second scenario, the research maintains the UVD at a fixed value of 210 mW.s/cm², modifying the water inflow by regulating the ocean vent valve before the ballast pump. The results indicate that the UVD consistently adheres to the specified value of 210 mW.s/$cm^2$, regardless of variations in water flow. The outcomes of the two scenarios suggest that the control unit functions effectively, and the system variables align with the design specifications.

## 5. CONCLUSION

BW control is a crucial strategy to prevent the migration of microbes and bacteria via BW, as established in the International Agreement on the Regulation and Control of BW and Ship Sediments, which governs BW management practices. The UVR in the BW sterilization system possesses substantial capacity, necessitating the usage of multiple high-power UV lamps within a single reactor. These high-intensity UV lamps require substantial electricity and are quite costly. It is essential to perform studies on the regulation of UV rays during water disinfection to enhance the longevity of UV lamps, reduce electricity consumption, and ensure practical antibacterial efficacy. The article details the creation of a control unit for a UVR within the BW sterilization system implemented on vessels. Findings from experiments on multiple vessels demonstrate the efficacy attained by the designed UV controller. By establishing more effective sterilization methods, the researchers can enhance BW management and alleviate the adverse effects of introduced species on the marine ecosystem, economies, and human health.

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