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THE IMPACT OF ULTRAVIOLET TRANSMITTANCE ON THE POWER OF UV REACTORS IN BALLAST WATER TREATMENT SYSTEMS

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Abstract

The article explores the influence of ultraviolet transmittance (UV-T) on the power of UV reactors in ballast water treatment systems, a crucial aspect for preventing the invasion of non-native organisms into marine ecosystems. The study shows that low UV-T values require greater power to ensure effective disinfection, while high UV-T allows for reduced energy consumption. A corrective coefficient, KUV-T, is proposed to adjust the power of the UV reactor according to water transparency, thereby significantly improving system efficiency. Additionally, trend dependencies are presented that can be used in the design and selection of equipment for new vessels and retrofitting of existing ones.

Keywords: UV-T, purification methods, ballast water, bwts, ultraviolet sterilizer.

Ultraviolet (UV) disinfection is a key method for treating ballast water to prevent invasive organisms from entering aquatic ecosystems. The efficiency of UV reactors largely depends on the water's ultraviolet transmittance, or UV-T, which indicates the water's ability to transmit UV light at a specific wavelength (typically 254 nm) and is expressed as a percentage [1, p. 3]. Low UV-T indicates the presence of organic substances, particles, and other impurities that absorb or scatter UV light, reducing the effectiveness of microorganism irradiation. Thus, at low UV-T levels, the reactor requires higher power to compensate for UV energy absorption, which can increase energy consumption, operating costs, and lower overall disinfection efficiency.

Conversely, high UV-T (e.g., above 90%) indicates cleaner water, allowing the UV reactor to operate at lower power as the radiation more effectively penetrates the water to reach pathogens. Therefore, analyzing the impact of UV-T on the required UV reactor power is critically important for efficient and economical ballast water treatment systems and a key factor in selecting reactor power when designing ships or refurbishing existing vessels to meet the D-2 standard of the International Convention for the Control and Management of Ships' Ballast Water and Sediments.

UV-T is a key parameter when comparing ballast water treatment systems, defining the transparency of water that the system can efficiently treat and reflecting system performance rather than specific design characteristics. Therefore, UV-T can standardize the evaluation of system capability to process water of varying transparency. The UV-T of water supplied to the system can vary significantly depending on the loading port [2, p. 30]: Istanbul (Turkey) – 95%, Rotterdam (Netherlands) – 93%, Houghton (USA) – 91%, Zeebrugge (Belgium) – 76%, Houston (USA) – 74%, Lisbon (Portugal) – 53%, Southampton (England) – 51%, Shanghai (China) – 49%.

This variability arises from factors such as organic and inorganic matter content, turbidity, and seasonal and tidal conditions affecting water clarity in each port, creating additional power requirements for UV systems depending on UV-T values [3, p. 2]. Comparing the power of ballast water UV treatment systems is challenging due to diverse approaches manufacturers use in specifying equipment characteristics. Some list maximum power, others average, some provide power for different UV-T values, while others specify power without conditions or give multiple power values (maximum, average, or minimum) without UV-T values [4, p. 90]. This complicates accurately assessing system performance in real-world conditions and comparing them, as maximum and average power values can differ significantly depending on UV-T values.

In a previous study [4, p. 91], the authors derived functional dependencies of maximum UV reactor power based on ballast intake but did not explore the impact of water UV-T on reactor power. Thus, the relationship between maximum reactor power and ballast water treatment system performance can be described by the trendline equation [4, p. 91]:

$$N = 0,1058 \cdot Q_{bn}, \qquad 1)$$

where, N – UV reactor power in kW;
Q_{bn} – nominal ballast water flow rate in m³/h.

To account for the impact of water UV-T on the necessary UV reactor power, the use of the corrective coefficient K_{UVT} is proposed. Statistical data from source [3, p. 2] was used to determine $K_{UV\text{-}T}$ values. Depending on the base UV reactor power values, three initial conditions were considered for K_{UVT}: $K_{UVTmin}=1$ corresponds to minimum power at a UV-T value of

100%, K_{UVTav}=1 to average power at UV-T=85% and K_{UVTmax}=1 to maximum power at UV-T=62%

Figure 1 shows statistical data for the condition K_{UVTmin} =1 corresponding to the minimum UV reactor power at a UV-T value of 100%.

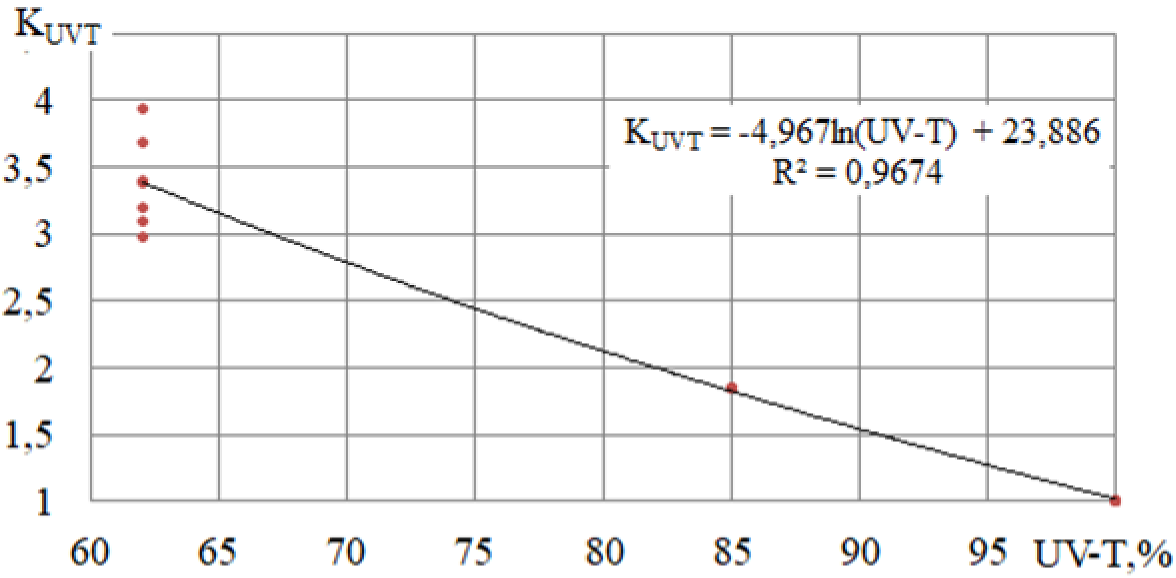

Figure 1. Coefficient K_{UVT} values depending on water UV-T for the condition K_{UVTmin} =1 at UV-T = 100%.

Preliminary consideration of the impact of water UV-T on reactor power can use coefficient K_{UVTmin} following:

$$K_{UVTmin} = -4{,}97\ln(UV\text{-}T) + 23{,}9 \quad (2)$$

When using this equation, note that accuracy decreases for UV-T values below 60%, as the power required for effective water disinfection would approach infinity at very low UV-T levels. This equation is optimal for practical application due to its fundamental point K_{UVTmin}=1 at UV-T = 100%, which can be easily obtained during design testing.

Figure 2 shows statistical data for conditions K_{UVTav}=1, corresponding to average power at UV-T = 85%, and K_{UVTmax}=1 at UV-T = 62%.

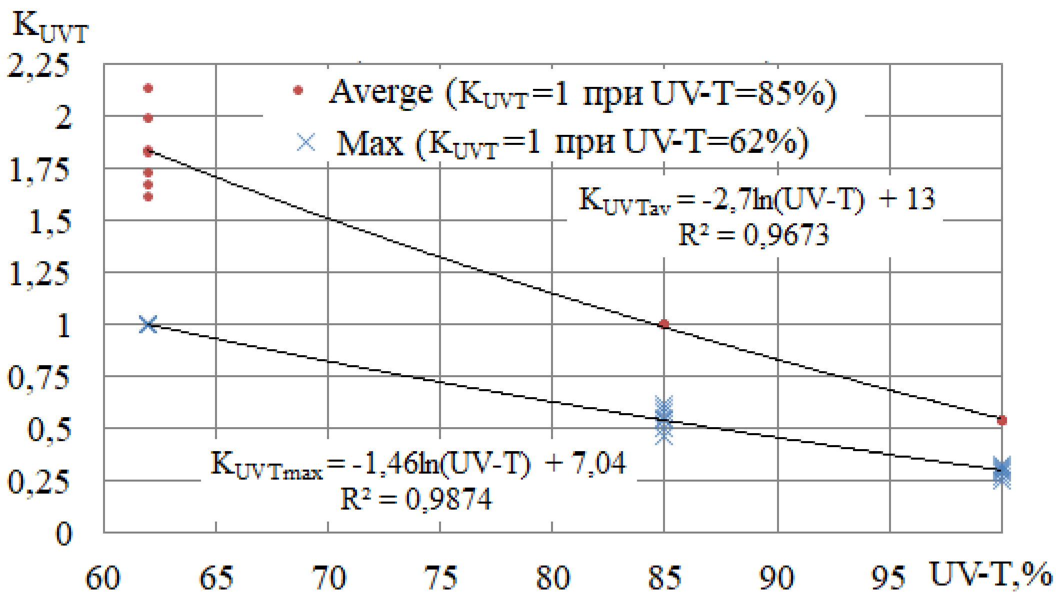

Figure 2. Coefficient K_{UVT} values for UV-T values of 85% and 62%.

The following trend equations (3) and (4) were derived:

$$K_{UVTav} = -2{,}67\ln(UV\text{-}T) + 13 \quad (3)$$

$$K_{UVTmax} = -1{,}46\ln(UV\text{-}T) + 7{,}04 \quad (4)$$

Conclusions. The study results confirm that ultraviolet transmittance (UV-T) is a key factor for selecting and adjusting UV reactor power in ballast water treatment systems. The corrective coefficient K_{UVT} allows UV reactor power adjustment according to real-world water transparency. The proposed trend dependencies for different UV-T values enable more accurate power calculations, essential for optimal design of UV-based ballast water treatment systems. These dependencies also account for varying loading port conditions, aiding in the design of new vessels and equipment selection for existing vessel retrofits.

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References:

1. Alfa Laval, Holding times and UV measurements in ballast water treatment: How to understand the mechanisms and benchmark accurately, 2017. p. 5. URL: https://www.alfalaval.com/globalassets/documents/products/process-solutions/ballast-water-solutions/mdd00657en.pdf.

2. Making sense of ballast water management: a guide to international ballast water regulations and compliance alternatives, 2017. p. 64. URL: https://assets.alfalaval.com/documents/p7181fe30/alfa-laval-making-sense-of-ballast-water-management-product-brochure-en-lowres.pdf.

3. Desmi, Compact Clean Bulker, Non-EX, Loose Components. p. 2. URL: https://desmiocean-guard.com/media/s5ggxl4t/cc_bulker-non-ex_loose-components.pdf.

4. Berestovoi, I., Smyrnova, I., & Maslov, I. Impact assessment of the power and size parameters of ultraviolet reactors on the performance of ballast water treatment systems. Transport Development, 4(19), 2023. P. 87-96. https://doi.org/10.33082/td.2023.4-19.07