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Ships and marine technology — Ballast water management systems (BWMS) — Computational physical modelling and calculations on scaling of UV reactors

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 8, *Ships and marine technology*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Ballast water management systems (BWMS) are intended to treat ships' ballast water discharges to comply with applicable standards (Reference [14]). Disinfection using ultraviolet (UV) light is common to many BWMS. A key specification for a given model of a BWMS is its treatment rated capacity (TRC), which indicates the unit's rated volumetric flow rate during treatment of ballast water. A base system (with a low range TRC) is empirically validated through land-based testing, while a unit with a larger TRC (ideally at the highest rating) is validated through shipboard testing. The remaining models that are not empirically tested can be validated through scaling, using a verified numerical approach to predict performance at untested TRCs.

Effective 13 October 2019, the type approval of BWMS (both UV and other technologies) requires testing in accordance with the BWMS Code (MEPC 72/17/Add.1 Annex 5)[11], adopted as an amendment to the IMO International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004[14]. The BWMS Code specifies that a manufacturer of BWMS must provide technical specifications for any scaling of TRC. Guidance on scaling is provided by the IMO through its 'Guidance on Scaling of Ballast Water Management Systems' (BWM.2/Circ. 33/Rev. 1)[12]. One of the requirements is for validation of the modelling and calculations through comparison of predicted performance to land-based, shipboard, or laboratory test data as appropriate. In scaled models, parameters affecting performance must demonstrate equivalence to the base model, identify system design limitations (SDL) for each scaled model, and conduct shipboard testing of the most vulnerable model as determined through scaling.

This document is focused on the modelling of UV reactors for scaling purposes, i.e. justifying the applicability of a UV reactor design across a range of TRCs, through the use of validated numerical models and calculations. Numerical models are used to solve equations governing physical characteristics of a computational domain that represents a model of the physical object (i.e. the UV reactor). This requires numerical representation of the geometry of this system, a discretization of the representation into volumetric sub-elements (meshing), and solving for parameters for various scales. Results are submitted to an Administration to justify the type approval of UV reactors having TRC ratings that have not been validated through type approval testing.

Ships and marine technology — Ballast water management systems (BWMS) — Computational physical modelling and calculations on scaling of UV reactors

1 Scope

This document specifies the methodology to conduct computational modelling of ultraviolet (UV) reactor designs for ballast water management systems (BWMS) that incorporate ultraviolet disinfection technology (UVBWMS). The computational modelling is used to calculate the UV reduction equivalent dose (RED) and to compare calculated REDs of the scaled reactor to its base reactor. REDs are determined using organisms with a given dose response.

NOTE The IMO requires validation of the computational model.

The simulation of a physical UV reactor using a computational model requires that the model be validated (i.e. it performs as intended and reflects the correct physical constraints) and verified (i.e. produces outputs consistent with empirical data). A model developed according to this document is intended to validate the performance of simulated but untested, scaled UV reactors, where the simulation has been verified with test data from base model UV reactors within the product line. As a complete UV BWMS typically incorporates other treatment methodologies such as filters, the impact of changes to external subsystem performance on the overall BWMS is not considered in this document.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
American Type Culture Collection
ATCC
repository of cell lines and cultured organisms used for research

3.2
base model
ultraviolet ballast water management system (UVBWMS) (3.30) model that has successfully completed land-based testing as defined in the BWMS Code

Note 1 to entry: Typically, a base model is with low range *TRC* (3.28).

3.3
base reactor
UV reactor (3.41) of the *base model* (3.2)

3.4
biodosimetry
measurement of biological response as a proxy for *UV dose* (3.34)

3.5
computational fluid dynamics
CFD
numerical methods and algorithms to solve and analyse problems that involve fluid flows

3.6
detached eddy simulation
DES
computational simulation used to numerically solve the *Navier-Stokes equations* (3.17), using *RANS modelling* (3.23) to solve small length scales

3.7
discrete ordinates modelling
DO modelling
development and use of mathematical models to numerically solve the *radiative transfer equation* (3.18) by discretizing the volume domain and directional vectors

3.8
direct numerical simulation
DNS
computational simulation used to numerically solve the *Navier-Stokes equations* (3.17) at all length scales

3.9
emission spectrum
relative power emitted by a lamp at different wavelengths

3.10
germicidal range
range of UV wavelengths responsible for microbial inactivation in water (200 nm to 300 nm)

3.11
large eddy simulation
LES
computational simulation used to numerically solve the *Navier-Stokes equations* (3.17), excluding small length scales

3.12
low pressure UV lamp
LP
discharge lamp of the mercury vapour type, without a coating of phosphors, in which the partial pressure of the vapour does not exceed 100 Pa during operation and which mainly produces ultraviolet radiation of 253,7 nm

3.13
medium pressure UV lamp
MP
medium pressure mercury arc lamp having a polychromatic *emission spectrum* (3.9) between 200 nm and 400 nm

3.14
model validation
comparison between the output of the calibrated model and the measured data, independent of the data set used for calibration

Note 1 to entry: Typically, the model outputs are compared to empirical results of real world experiments at different scales to determine whether the accuracy of the prediction matches design requirements.

3.15
model verification
process of confirming that a model is correctly implemented with regard to specifications and assumptions of the design

Note 1 to entry: Typically, verification ensures that analysis logic follows the model design, checks for reasonable outputs over the acceptable range of model parameters, and that the model can be run without errors.

3.16
MS2 phage
ATCC 15597-B1
non-pathogenic bacteriophage commonly used as a challenge organism in *UV reactor* (3.41) *biodosimetry* (3.4)

3.17
Navier-Stokes equations
equations derived from the conservation equations to describe the motion of viscous fluid substances

3.18
radiative transfer equation
mathematical relation describing the variation along a path of the spectral radiance in an absorbing, emitting and scattering medium.

Note 1 to entry: The solution of this equation depends on the radiative properties of the medium: spectral extinction coefficient, spectral albedo and spectral phase function, and on the thermal and optical boundary conditions.

3.19
reduction equivalent dose
RED
UV dose (3.34) derived by entering the log reduction after UV treatment using a collimated beam with the same UV spectrum output as in the reactor testing into the *UV dose-response* (3.36) curve that was derived through collimated beam testing, or the UV dose computed by combining the dose distribution computed in *CFD* (3.5) modelling with the UV sensitivity (dose response) of the organism

Note 1 to entry: RED values are always specific to the challenge microorganism used during experimental testing and the validation test conditions for full-scale reactor testing.

3.20
residence time
time period that a particle resides within the boundaries of the *UV reactor* (3.41) during treatment, which varies with flow rate and path

3.21
residence time distribution
RTD
probability distribution of *residence time* (3.20) that microorganisms stay in a flow-through *UV reactor* (3.41), typically shown as a histogram

3.22
Reynolds-averaged Navier-Stokes equations
RANS equations
time-averaged equations of motion for fluid flow derived from *Navier-Stokes equations* (3.17), primarily used to describe turbulent flows

3.23
Reynolds-averaged Navier-Stokes modelling
RANS modelling
turbulence modelling (3.29) conducted by solving the *Reynolds-averaged Navier-Stokes equations* (3.22) at all length scales

3.24
scaled model
ultraviolet ballast water management system (UVBWMS) (3.30) model that is based on the *base model* (3.2) but has been modified to accommodate to a higher or lower *treatment rated capacity (TRC)* (3.28)

3.25
scaled reactor
UV reactor (3.41) of the *scaled model* (3.24)

3.26
spectral output
distribution of wavelength and relative intensity emitted by a UV lamp

3.27
***Tetraselmis* sp.**
ATCC 50244
marine phytoflagellate commonly used as a test organism and a representative of organisms in the ≥10 µm and <50 µm size class

3.28
treatment rated capacity
TRC
maximum continuous capacity expressed in cubic meters per hour for which the BWMS is type-approved

Note 1 to entry: It states the amount of ballast water that can be treated per unit time by the BWMS to meet the standard in regulation D-2 of the BWMS Convention.

Note 2 to entry: The TRC is measured as the inlet flow rate of the BWMS.

Note 3 to entry: TRC values pertain to stated intake water quality conditions.

3.29
turbulence modelling
development and use of mathematical models to predict the evolution of turbulence in fluid flows

3.30
ultraviolet ballast water management system
UVBWMS
system that uses *UV light* (3.31) to process ballast water, generally in combination with filtration, to remove, render harmless, or avoid the uptake or discharge of harmful aquatic organisms and pathogens within ballast water and sediments

Note 1 to entry: In addition to the *UV reactor* (3.41), the UVBWMS includes ballast water treatment equipment, all associated control equipment, monitoring equipment, piping, and sampling facilities.

Note 2 to entry: Most UVBWMS include a filter to remove larger particles (that can impact UV transmission) and organisms (that can be resistant to UV treatment).

3.31
ultraviolet light
UV light
light emitted with a wavelength ranging from 100 nm to 400 nm

Note 1 to entry: Light in the range of 200 nm to 280 nm is known as UVC and has the capacity to be germicidal. UV light in the range of 260 nm to 270 nm can be particularly effective in deactivating the DNA or RNA of bacteria, viruses and other pathogens at appropriate requisite doses and thus destroys their ability to multiply and cause disease.

Note 2 to entry: Specifically, UVC light causes damage to the nucleic acid of microorganisms by forming covalent bonds between certain adjacent bases in the DNA or RNA. The formation of such bonds prevents the DNA or RNA from being unzipped for replication, and the organism is unable to reproduce.

3.32
user-defined function
UDF
function provided by the user of a program or environment, in a context where the usual assumption is that functions are built into the program or environment

3.33
UV absorbance
radiant power absorbed within a material

3.34
UV dose
product of *UV intensity* (3.38) and *residence time* (3.20), typically reported in units of mJ cm^{-2} or J m^{-2}

3.35
UV dose distribution
probability distribution of delivered *UV doses* (3.34) that microorganisms receive in a flow-through *UV reactor* (3.41), typically shown as a histogram

3.36
UV dose-response
inactivation kinetics of a microbial species resulting from UV exposure

3.37
UV exposure time
time elapsed between UV radiation initial and final exposures

3.38
UV intensity
intensity of UV radiation at a specific geometric location with respect to the UV source, measured in mW cm^{-2}

Note 1 to entry: UV Intensity measures the "amount" of UV energy actually penetrating through the water being treated.

3.39
UV irradiance
power passing through a unit area perpendicular to the direction of propagation

Note 1 to entry: UV irradiance is typically reported in watt per square metre (W/m^2). It is also usually reported in mW/cm^2 or uW/cm^2.

Note 2 to entry: Irradiance varies with UV lamp output power, efficiency and focus of its reflector system, and distance to the surface.

3.40
UV light emitting diode
UV LED
semiconductor source, in this context providing narrow wavelength emission at a given wavelength in the UV spectrum

3.41
UV reactor
vessel or chamber where exposure to *UV light* (3.31) takes place, generally consisting of UV lamps, quartz sleeves, UV sensors, quartz sleeve cleaning systems, and baffles or other hydraulic controls

Note 1 to entry: The UV reactor also includes additional hardware for monitoring UV dose delivery; typically comprising (but not limited to) UV intensity sensors.

Note 2 to entry: The wavelengths emitted by a UV lamp are dependent on the lamp type (e.g. LED, low pressure [LP], medium pressure [MP]).