Universidad
Rey Juan Carlos

Ángela García-Gil
Ph.D. Thesis

SOLAR WATER DISINFECTION IN LARGE-VOLUME CONTAINERS FOR LOW-INCOME COUNTRIES

Abstract

The lack of safe drinking water in low-income regions remains a challenge today. Alternative water treatments are available that are suitable for domestic use. However, these processes still have limitations that ultimately have an impact on the efficiency of the process. Solar water disinfection or SODIS process is one of these household water treatments, whose standardised procedure is ineffective in the production of safe drinking water (by recommending a minimum of 6 hours of solar exposure when in many cases this time is overestimated). The development of comprehensive kinetic models that rigorously consider the influence of all the variables involved in the process is essential to optimise solar exposure times and maximise safe drinking water production.

In this PhD Thesis, a comprehensive kinetic model that estimates the required solar exposure time in large-volume containers subjected to the SODIS process was developed. This model accounts for the spectral radiation transport from the sun to the pathogens (including the attenuation caused by the atmosphere, containers' walls, and naturally occurring substances dissolved in water) and the mechanistic chemical reactions that happen during the solar disinfection of viruses, protozoa, and bacteria. The following conclusions highlight for each piece of the entire model:

- SOLAR RADIATION: An algorithm was developed to predict the real daily dose depending on the latitude and the day of the year. As a particular strength, this procedure accounts for spectral distribution, being possible to calculate the actual daily dose reaching SODIS containers for each wavelength.
- CONTAINER: The Solar UV Calculator tool was developed to determine the spectral irradiance within SODIS containers manufactured with alternative suitable plastic materials. PMMA and PP with 1% UV-stabiliser were identified as excellent materials for manufacturing SODIS devices (excellent optical properties and disinfection rates). Due to their mechanical properties, PPMA is recommended for static SODIS devices and PP for portable containers.
- WATER COMPOSITION: A radiation distribution-based procedure was developed to calculate the effective available incident radiation in large-volume containers as a function of naturally occurring substances present in water such as (bi)carbonates, soluble carbohydrates, solids and humic acids. The two latter and iron act as radiation-attenuating factors, but iron also enhances bacterial

damage, probably because of its permeation into the cell and contribution to the intracellular Fenton process.

- KINETIC MODEL: A set of three mechanistic kinetic models were developed to predict solar water disinfection of viruses, protozoa, and bacteria and successfully reproduced experimental data. The three kinetic models consider the effect of the water temperature, the photoinactivation, and the UV-T synergistic effects, but their own ways to reproduce the behaviour of each pathogen. Due to the relative simplicity of the kinetics for viruses and protozoa, in which the action of light was only noticeable by direct damage, the dependence on the spectral irradiance was included fairly reproducing the spectral absorption of DNA/RNA. In the case of the bacterial model, the enhancement caused by H_2O_2 addition was studied and modelled, helping to elucidate the internal cellular mechanisms and their kinetic parameters.

In conclusion, this PhD Thesis presents the development of a comprehensive kinetic model that estimates the required solar exposure time in large-volume containers subjected to the SODIS process. The complexity of the microbes forces the adoption of assumptions to get plausible mechanistic kinetic models. However, despite their limitations, these models offer an unparalleled framework for future developments and improvements, and new reactions, processes, and microbial targets can be envisaged.