The Effect of Inner Walls Reflection on Microorganisms Inactivation in Water Ultraviolet Reactor using computational fluid dynamics

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ABSTRACT

The inner walls reflection of ultraviolet radiation is one of the effective components on the ultraviolet reactor efficiency. In this study, the effect of inner walls reflection of the reactor on the performance of the multi-lamp ultraviolet reactor has been evaluated using of UV dose distribution and log inactivation values of MS2 and Bacillus subtilis microorganisms. The simulation of the flow field is performed using the SST k-ω model and discrete ordinates model for radiation is considered. The wall reflectivity are in the range of zero (no reflection) to 100 (ideal reflection) percent. In this range of reflections, for the reactor walls with aluminum cover, reflectivity of 80.5% and 26.1% for the steel wall and UV transmittance of 87.7% and 78.5% was calculated. For UV transmittance of 78.5%, the received dose and log inactivation change with increasing reflectivity was very low but for UVT of 87.7%, there is a tangible increase in these values and the results variation trend for two different flow rate was similar in UVT of 78.5%. The performance of the reactor was investigated in two different lamp powers and UVT of 78.5%, which in higher power, the reflectivity effect has become more apparent.

KEYWORDS

Ultraviolet reactor, Computational Fluid Dynamics, Discrete Ordinates Model, reflection, Bacillus subtilis and MS2 microorganism

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1. Introduction

Ultraviolet (UV) technology is an effective method in the water disinfection process due to its desirable effectiveness in deactivating resistant pathogens and non-production of harmful byproducts [1, 2]. Inactivation of microorganisms in UV disinfection reactors depends on the amount of UV energy received by the microorganism during it passes through the UV reactor. Increasing the inner walls reflection is a way to increase the UV energy received by the microorganism. One of the few work in the field of inner walls reflection was the study of Li et al. [3], who investigated the effect of inner walls reflection in two high and ordinary reflective modes on the performance of single-lamp UV reactors and higher radiation rates were observed at high reflectivity.

In the present paper, the effect of the reactor inner walls reflection on the performance of the multi-lamp UV reactor is studied. In this study, the effect of reflection on the UV dose distribution and the log-inactivation values of two microorganisms were evaluated in two UV transmittance (UVT). One of the highlights of this paper is how different wall reflections under different lamps power and flow rates are effective, so as to gain a better understanding of the effect of reflection on disinfection reactor performance.

2. Governing equations

The mass and momentum conservation equations are fluid governing equations that are solved under steady state, incompressible, isothermal and constant fluid physical properties assumption [4]. The SST k-ω model is used to simulate turbulent flow [5]. The discrete ordinates model (DOM) has been used for radiation field calculations [6]. The reflection coefficient of the reactor inner walls is calculated from relation (1):

$$R = 1 - \varepsilon \quad (1)$$

Where ε is internal emissivity of wall and R is the reflection coefficient at the wall surface.

Particle tracking is done in Lagrangian approach [7]. By applying drag, virtual mass and pressure gradient forces in the equilibrium equation of forces applied to each particle, the trajectory of each particle is obtained. [6]. Using the user defined function (UDF) and applying it in fluent software, the dose of each particle was calculated using the time integral of the radiation intensity [8]. The MS2 coli phage (MS2) log-inactivation is calculated using the Chick-Watson model and the Bacillus subtilis (B.subtilis) log-inactivation using the model of Wols's study [5, 9].

3. Simulation procedure

The geometrical model in this study is the cross-flow UV reactor shown in Figure 1. The inlet pipe diameter is 0.125 m and it's length is 50 times the diameter. The outlet pipe diameter is 0.125 m and has a length of 1 m. The main part of the reactor, a cylinder with a diameter of 0.3 meters and a length of 0.15 meters, has four cylindrical pipes of quartz, perpendicular to the flow of the reactor that the diameter of each quartz pipe is 0.0478 m.

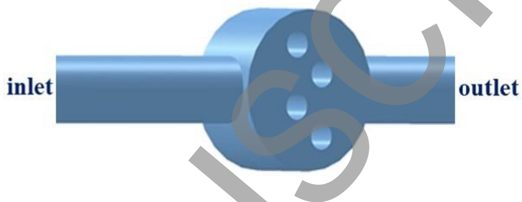

Figure 1. The geometry of the UV reactor

The Ansys fluent 17.2 commercial pakage was used to simulate the flow field, radiation field and trajectory of the microorganisms. A uniform velocity is used at the inlet boundary and a constant pressure is used at the outlet boundary. The non-slip condition was applied to all walls. To solve the radiation transfer equation (RTE) of each of the polar and azimuthal angles considered for the eighth of the angular space, it was discrete in seven directions. Five pixels were also placed at each control angle. Approximately 5,000 particles were injected into the flow from the inlet of reactor, and reflect and escape were considered for the walls boundary condition and exit boundary condition, respectively. discrete random walk model was used to apply the effect of turbulence on the particles [10].

4. Results

The grid of 316,000 cells is the grid independence for this simulation. Comparison of the axial and vertical velocity results obtained from the present numerical model and the Wols's experimental data [9] illustrates the desirable prediction of the flow field, especially for the axial velocity. Also, a comparison of the particles dose distribution of the current numerical model and the experimental data confirms the accuracy of the simulation in the UVT of 78.5%; however, the present numerical model results under the UVT of 87.7% in the minimum dose have a significant discrepancy with the experimental data, which the cause should be searched in effective parameters on the radiation field.

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According to Fig. 2, in the UVT of 78.5, the log-inactivation of both types of microorganisms increase with increasing reflectivity, but the growth is relatively small. The log-inactivation difference for MS2 phage in non-reflection and 100% reflection is about 7% and for B.subtilis is about 8%. In Fig. 3, the log-inactivation of two microorganisms B.subtilis and MS2 can be seen in the UVT of 87.7%. Log-inactivation for both types of microorganisms increased with increasing reflectivity. For MS2 microorganisms, the difference in the absence of internal wall reflection and 100% reflection is about 20%, and for B.subtilis, this difference is 21%. By comparing Figures 2 and 3, it can be seen that the reflection of the inner walls at higher UVT leads to more log-inactivation.

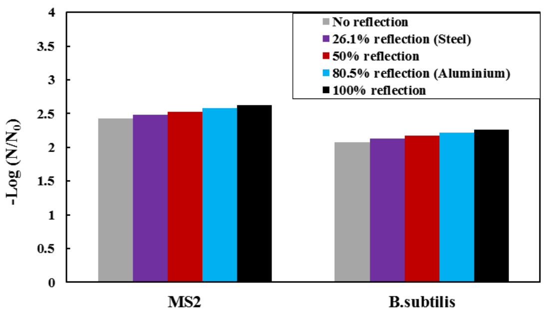

Figure 2. Log-inactivation values under 78.5% UVT with zero to 100% wall reflection

By decreasing the flow rate from 4.9 to 2.5 m^3/h under UVT of 78.5%, the log-inactivation values of microorganisms show very little reflection effect, so that the difference between the non-reflection and 100% reflection for MS2 is about 7% and for B.subtilis 7.7%. By increasing the power from 32 to 46.9 watts at a UVT of 78.5%, the effect of reflection on the log-inactivation values under non-reflection and 100% reflection for MS2 phage was about 7.9% and for B.subtilis 8.6%.

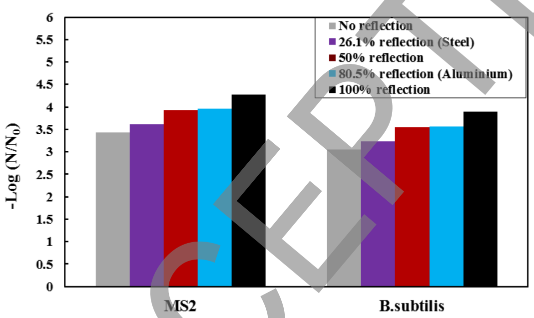

Figure 3. Log-inactivation values under 87.7% UVT with zero to 100% wall reflection

5. Conclusion

In this study, the effect of walls reflection different values in the range of zero (without reflection) to 100% (ideal reflection) was investigated on UV reactor performance. The performance of the UV reactor was evaluated under two UVT, two flow rate and two different lamp power for two types of microorganisms. The results showed that the effect of wall reflection on the UV reactor performance under higher UVT (87.7%) was more pronounced. With increasing power, a slight increase in performance indices was observed despite wall reflection. By decreasing the flow rate from 4.9 m^3/h to 2.5 m^3/h, the effect of wall reflection under UVT of 78.5% did not experience any significant change.

6. References

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