he 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 of 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 ultraviolet 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 the discrete ordinates model for radiation. The wall reflectivity is in the range of zero (no reflection) to 100 (ideal reflection) percent. In this range of reflections, for the reactor walls with aluminum cover, the reflectivity of 80.5% and 26.1% for the steel wall and ultraviolet transmittance of 87.7% and 78.5% were calculated. For ultraviolet transmittance of 78.5%, the received dose and log inactivation change with increasing reflectivity were very low but for ultraviolet transmittance of 87.7%, there is a tangible increase in these values and the results variation trend for two different flow rate was similar in ultraviolet transmittance of 78.5%. The performance of the reactor was investigated in two different lamp powers and ultraviolet transmittance of 78.5%, which is related to the higher power, the reflectivity effect has become more apparent.

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 reflection of the inner wall is a way to increase the UV energy received by the microorganism. One of the few works 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 steady-state, 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 Eq. (1):

$$R = 1 - \varepsilon \tag{1}$$

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

Particle tracking is done in the 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 coliphage 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 Fig. 1. The inlet pipe diameter is 0.125 m and its 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

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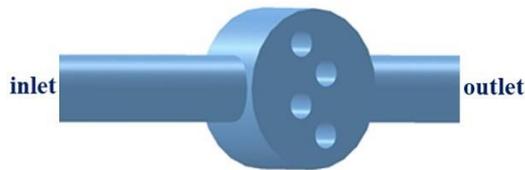
Fig. 1. The geometry of the UV reactor

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

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

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.

The Ansys Fluent 17.2 commercial package was used to simulate the flow field, radiation field and trajectory of the microorganisms. Uniform velocity at the inlet boundary and 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 the reactor, and reflect and escape were considered for the walls boundary condition and exit boundary condition, respectively. The 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. A 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 ineffective parameters on the radiation field.

According to Fig. 2, in the UVT of 78.5, the log-inactivation of both types of microorganisms increases 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 Figs. 2 and 3, it can be seen that the reflection of the inner walls at higher UVT leads to more log-inactivation.

By decreasing the flow rate from 4.9 to 2.5 m³/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%.
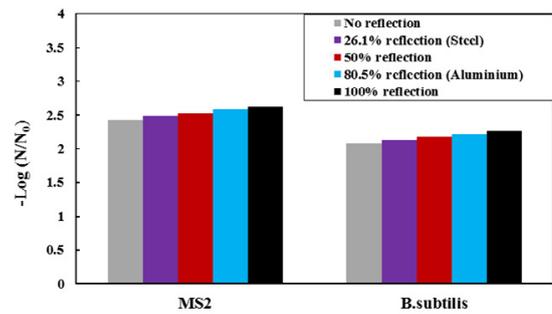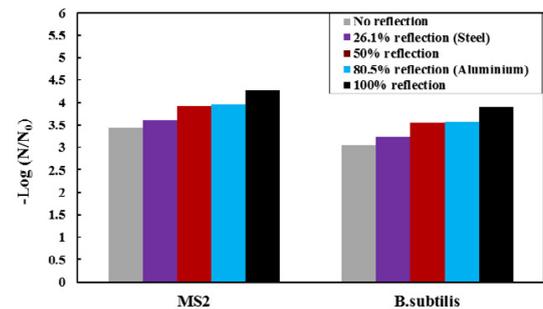
5. CONCLUSION

In this study, the effect of the reflection of the walls which has different values in the range of zero (without reflection) to 100% (ideal reflection) was investigated on the 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 m³/h to 2.5 m³/h, the effect of wall reflection under UVT of 78.5% did not experience any significant change..

6. REFERENCES

[1] M. Polo-López, M. Castro-Alférez, I. Oller, P. Fernández-Ibáñez, Assessment of solar photo-Fenton, photocatalysis, and H2O2 for removal of phytopathogen fungi spores in synthetic and real effluents of urban wastewater, Chemical Engineering Journal, 257 (2014) 122-130.

[2] K. Song, M. Mohseni, F. Taghipour, Application of ultraviolet light-emitting diodes (UV-LEDs) for water disinfection: A review, Water research, 94 (2016) 341-349.

[3] W. Li, M. Li, J.R. Bolton, J. Qu, Z. Qiang, Impact of inner-wall reflection on UV reactor performance as evaluated by using computational fluid dynamics: the role of diffuse reflection, Water research, 109 (2017) 382-388.

[4] S. Elyasi, F. Taghipour, Simulation of UV photoreactor for water disinfection in Eulerian framework, Chemical Engineering

Science, 61(14) (2006) 4741-4749.

[5] D. Liu, C. Wu, K. Linden, J. Ducoste, Numerical simulation of UV disinfection reactors: Evaluation of alternative turbulence models, Applied mathematical modelling, 31(9) (2007) 1753-1769.

[6] H. Li, H. Osman, C. Kang, T. Ba, Numerical and experimental investigation of UV disinfection for water treatment, Applied Thermal Engineering, 111 (2017) 280-291.

[7] B. Wols, D. Harmsen, J. Wanders-Dijk, E. Beerendonk, C. Hofman-Caris, Degradation of pharmaceuticals in UV (LP)/ H2O2 reactors simulated by means of kinetic modeling and computational fluid dynamics (CFD), Water research, 75 (2015) 11-24.

[8] C. Xu, X. Zhao, G. Rangaiah, Performance analysis of ultraviolet water disinfection reactors using computational fluid dynamics simulation, Chemical engineering journal, 221 (2013) 398-406.

[9] B.A. Wols, CFD in drinking water treatment, (2010).

[10] D.A. Sozzi, F. Taghipour, UV reactor performance modeling by Eulerian and Lagrangian methods, Environmental science & technology, 40(5) (2006) 1609-1615.