Formerly World Water & Environmental Engineering

world water

Volume 37 / Issue 1
January / February 2014

Water Stewardship
Protecting resources for a secure future

wef publishing uk ltd.
A Supporting Publication of weftec the water quality event
WATER'S WORTH IT
A trademark of the Water Environment Federation

The latest computational fluid dynamics (CFD) modeling techniques have become essential tools in the design and optimization of ultraviolet disinfection systems. **Jon McClean** of ETS LLC and Richard Joshi of atg UV Technology explain.

CFD modeling advances UV system designs

Advances in CFD modeling have become indispensable in the design and optimization of ultraviolet (UV) disinfection systems, forensic diagnosis, and prediction of overall performance. The three principal CFD models – geometric, hydraulic, and UV radiation – are used to safely quantify any corrections required in low-wavelength systems, and were instrumental in the design of new UV chamber features.

UV disinfection is not new. The first municipal-scale UV systems were used in France in the early 1900s and the technology has grown in scale and scope – now a typical step of any multi-barrier municipal treatment train for drinking water, wastewater, and increasingly, reclaimed water. New York City operates the largest UV facility in the world, disinfecting 8.3 billion liters of drinking water per day.

In the early days of UV technology, the lack of scientific rigor or discipline often hampered application. UV monitor cameras were merely light-sensing cells incapable of specifically measuring the UV output of the lamps. Often an operator could simply turn up a gain potentiometer to make a nuisance alarm disappear and make the camera think they were seeing more light. Sizing of UV systems was subjective. Before the advent of rigorous bioassays, not many methods were available to verify the capacity of a reactor or its performance envelope for a range of flow rates and water transmittance.

Most original UV manufacturers understood how UV light radiated from lamps. Some used a series of concentric circles to model UV light reduction, and even used random number generators to illustrate the path that particles would take through the reactors.

The amount of light that a particle was exposed to was crudely calculated using a multi-point source summation (MPSS) method, which correctly showed that the output of the lamps to be highest at mid arc, and lowest at the ends. The dose models were then crudely assembled by using a MPSS light intensity method and, in some cases, assuming a random trajectory through the chamber. This led to some UV systems being conservatively designed. And with the advent of system validation using bioassay, it also led to a number of high-profile failures.

The early spatial intensity mapping was effective, and most manufacturers understood how UV light behaves as it radiates away from the source. The recurring glaring error, caused by a lack of hydraulic understanding, resulted in the use of UV reactor designs, which exacerbated short circuits and poor fluid tracking.

CFD model use increased rapidly as access to the technology improved and prices dropped. Consequently, more UV manufacturers saw how UV systems would work – specifically how fluids flow through reactors – and CFD models quickly became an indispensable diagnostic tool. CFD modeling also revealed the positive effects of inlet and exit bends in UV reactor design, which led to the early inline designs from European manufacturers.

How does UV disinfection work?

UV light can cause permanent damage to the DNA or RNA of all living organisms. UV light waves, from 200 to 300 nanometers (nm), results in permanent damage when absorbed by DNA in the cell nucleus. This damage renders the organism non-viable, which means it cannot replicate, assimilate food, or respirate – all typical, normal cell functions. These processes are now well understood, and unlike chemical-based disinfection techniques, no tolerance in the organism is observed.

Model results should always be compared to the actual data produced from the validation study, and leading UV manufacturers have repetitively refined their CFD models each time a validation exercise is undertaken.

Consider the increased tolerance to chemicals observed in nature: mosquitoes become increasingly tolerant to insecticides, weeds more tolerant to herbicides, and microbes able to survive higher doses of antibiotics. The 1993 *Cryptosporidium* outbreak in Milwaukee, United States, killed 104 people and caused more than 403,000 others to be sick. *Cryptosporidium* is one of a growing list of chlorine-tolerant organisms. The list includes *Giardia*, and *Listeria* – both are harmful to humans.

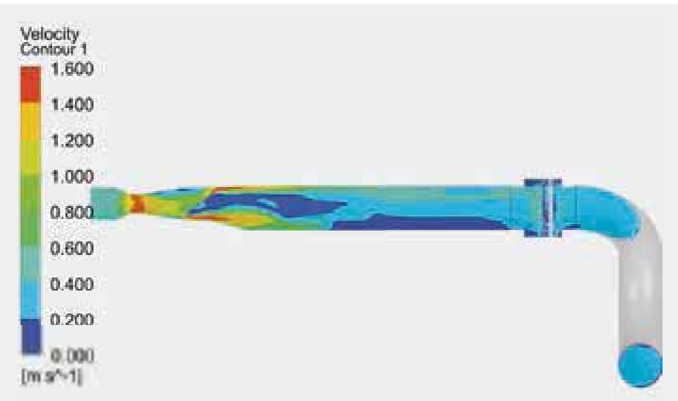

Figure 1 shows effect of butterfly valve on velocity.

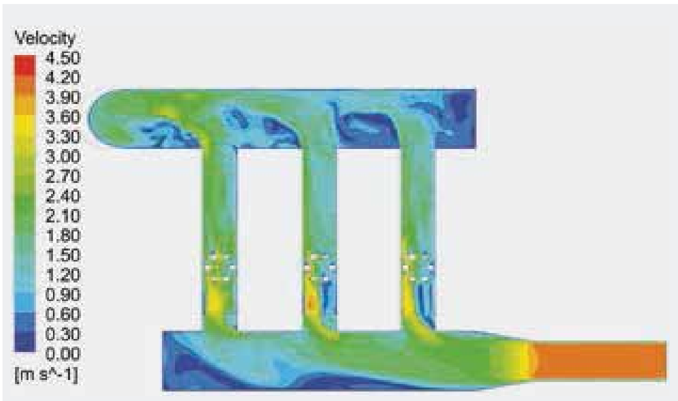

Figure 2 shows how several UV systems must be installed in parallel to achieve better results. Color gradient shows different velocities streaming through the pipe.

Open channel UV disinfection system.

CFD modeling demonstrates that the location of valves and manifolds can affect the UV system.

Three principal input tools are used in the CFD modeling process: geometric model, hydraulic model, and the UV radiation model. Initially, the model determines velocity, pressure, and turbulence, while radiation intensity is solved separately using the converged flow results because the radiation of light has no influence on the flow field.

Model results should always be compared to the actual data produced from the validation study, and leading UV manufacturers have repetitively refined their CFD models each time a validation exercise is undertaken.

Geometric model. Generally derived from a three-dimensional (3-D) computer-assisted design model (CAD), the 3-D geometric model is used to define the boundaries of fluid flow – usually by creating a mesh or grid that the virtual fluid will flow through. The size of the mesh is an important factor in determining how accurate the model will be and the duration the model will run.

The individual cell size is important for these models, and the ability to vary the cell size matters. Close to a point of interest, such as a quartz sleeve or a baffle, typically smaller mesh cells are produced. The cells or elements are hexahedral in shape and several million cells can be used within a single UV chamber.

The mesh cells' relative size can be a critical factor in the accuracy of the modeling, so CFD engineers often study meshes of different sizes to ensure that the range and mix of cells is independent of the results.

Analysis of the different mesh size data sets indicates the standard ETS mesh produces the most conservative result. The analysis also predicts a 1.88 log removal of a target organism, which is a close prediction to the actual model validation results. The ETS standard mesh uses 1.6 million elements, and in this case the 299 iterations took 1 hour and 45 minutes to run.

Hydraulic model. Most CFD models use standard consumer software packages or modified software. It is important to use iteration to refine the model each time a validation is undertaken, which serves as a good calibration tool. The turbulence model most often used is the SST k-w (omega) model, which is widely accepted as being the most suited to capturing flow separation and recirculation as frequently present in UV chambers or open channels.

Radiation model. This model has evolved significantly since the early multi-point source summation models. Discrete ordinate radiation models are most typically used because of their accuracy in tracking UV dosage received by fluid particles.

For example, a Lagrangian particle tracking calculation determines the transportation path of a series of flow-following particles through the mesh elements. Typically, 4,000 to 8,000 particles pass through. The local flow field controls the path of each particle and a stochastic model is used to represent the effect of turbulence. Each of the fluid particles is subject to local incident radiation, which is expressed in watt per square meter per nanometer. Finally, the dose received by each particle is incremented by the local incident radiation product and the particle tracking time step.

Optimized UV designs

Refined CFD modeling generated UV chamber design features that optimize system performance. For example, bends are not used in chamber design anymore. Bends cause differences in fluid velocity as the fluid flows around the bend, and a right angle bend at the exit from a UV reactor actually causes large differences in fluid velocity inside the UV system. Higher fluid velocity causes a reduced UV dose to be received in these regions. In modern reactors, the inlet is designed after a straight pipe, and the outlet is often chamfered to slow down the exit velocity.

For many years lamp arrangement inside the chambers was symmetrical, but research at the UV technology developers ETS and atg demonstrated that lamps running in the less effective location inside the UV reactor did not significantly decrease reactor performance. Instead of assembling lamps symmetrically in the chamber, current design places the lamps where the fluid will flow.

CFD modeling demonstrates that the location of valves and manifolds can detrimentally affect the UV system. Therefore UV systems

Continued on page 48

platform, the Aquavar provides variable frequency pumping control of speed, pressure, flow, and level for submersible and above-ground applications.

According to Xylem, Aquavar ensures quick commissioning and ease of use through its application specific Start-Up Genie tool. The removable, graphic control panel displays large text on a large backlit screen. Start-up is also made easy using the My Personal Menu, which lists the 20 most commonly used parameters, and is customizable by the end user based on their specific pumping system.

"The benefit of this intelligent VFD is that it helps groundwater professionals adapt quickly and efficiently to any application, whether that's standard day-to-day operation or not," said Joshua Allen, Americas product manager, drives and controls for Xylem's Applied Water Systems business unit.

The pump controller comes with built-in features to optimize performance and efficiency. The automatic motor adaption and automated energy optimization help to maximize the compatibility between drive and motor and improve system efficiency as loads change. Aquavar also helps protect against the following: cavitation, dead head, blocked suction, circuit shortage, phase loss, overload, undervoltage and overvoltage over an application range of 1.5 to 125 horsepower.

Continued from page 27

are constructed to ensure as-built UV systems cannot be affected by the location of butterfly valves or manifold arrangements. This is particularly true for drinking water installations with footprint considerations, where the UV systems must be retrofitted into an existing building.

Figure 1 shows the effect of the butterfly valve on velocity. Water must be allowed sufficient time and distance to become uniform, homogeneous velocity, so the valve is located some distance from the UV system inlet.

Flow must be balanced through several UV systems – installed in parallel to achieve better results. Figure 2 shows how this can be done effectively by using orifice plates; this system is required to achieve better than a 2-log credit. The color gradient shows different velocities streaming through the pipe. The inlet to each UV reactor follows several pipe diameters of straight pipe, which allows the flow to enter the UV chamber with a homogenous flow pattern.

Understanding low wavelength correction

Industry experts are working on the absorption spectrum correction factor (ASCF) to account for the effect that very low wavelengths have on disinfection performance.

CFD models are used to understand and safely quantify any corrections required due to the emission of the low wavelengths – which affect the surrogate, but not the target pathogens in the same way. This correction typically reduces the reactor performance by two to seven percent, depending on the type of water, lamp geometry, and validation conditions. For example, CFD models indicate performance is reduced by 30 percent when using dopants in the quartz sleeve.

Conclusion

When installed in a small footprint or convoluted manifold in a water facility, CFD models play an important role in UV systems design, optimization, and predicting overall performance. They have demonstrated high accuracy, and are repeatable. As UV technology has become more widely adopted, they are more accessible and easy to use.

Authors' Note

Jon McClean is the president of ETS LLC, based in Beaver Dam, Wisconsin, USA. ETS LLC is a manufacturer of UV systems, specializing in closed vessel UV technology. Richard Joshi is the technical director of atg UV Technology, based in Wigan, Lancashire, England. The company designs and manufactures UV disinfection systems and integrated UV treatment packages for municipal, industrial, petrochemical, and aquatic UV applications.

This chamber illustrates a non-symmetrical arrangement of 16 lamps with 15 in the upper portion of the vessel.

For further information please see the Advertiser Contact List on page 50