How Municipal Water Authorities Are Using Simulation Tools to Improve Performance and Reduce Costs

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Introduction

With the unrelenting population growth in large and mid-size North American cities, water resources have become a critical concern. The old paradigm that considered water an unlimited resource has led to inefficient usage. In the past fifteen years, the average unit price of raw water in the United States has increased at more than 1.5 times the rate of inflation. Capacity for wastewater has also become an increasing challenge, leading to more stringent regulations. As one example, in the US, the discharges from Combined Sewer Overflow (CSO) chambers are a major water pollution concern for approximately 900 communities containing around 40 million people. The US Environmental Protection Agency's (EPA) CSO control policy, published in 1994, is a national framework for the control of discharges through the National Pollution Discharge Elimination System (NPDES) permit program. Key milestones of the CSO policy include the implementation of “nine minimum controls” and the development of long term CSO control plans. Elements of these plans include characterization, monitoring, and modeling activities, along with the evaluation of alternatives.

How are municipal water utilities dealing with these challenges? They have been forced to become efficient by using advanced technology. One of these technologies is virtual flow modeling – using computer software to predict three-dimensional flow behavior in water treatment equipment. This white paper introduces flow modeling, and shows how municipal water authorities are benefiting from its use and how they can further streamline their operations.

An Introduction to Flow Modeling

Computational Fluid Dynamics (CFD) moved from the academic and national laboratory realm to commercial availability in the early 1980’s, with a focus primarily on aerodynamics, automotive, and power generation applications. It was introduced in water treatment industry 10 years later when a handful of visionary consulting firms realized they could revolutionize some aspects of their business by substituting field testing and scaled physical modeling with computer analysis. At that time, taking on this technology was a significant investment, with the requirement to train someone with an advanced degree, and to keep that analyst busy with regular modeling projects. But the investment paid off, and large municipalities soon followed suit, bringing CFD expertise into their organizations.

Since that time, flow modeling tools have become easier to use, and, for basic flow distribution and residence time calculations, an advanced degree or a constant string of projects to maintain the required skill set are no longer required. Figure 1 shows the user interface for one such tool. It displays pathlines colored by velocity magnitude for a simple baffle tank.
A CAD drawing of the equipment geometry is required as input. Clear guidance is given at each stage in the analysis, with “next” and “back” buttons available for navigation between steps. Alternatively, movement between set-up stages can be accomplished through the navigator in the upper left of the screen. Green checkmarks indicate which steps have been finished. This user-friendly analysis capability is allowing small municipalities to benefit from in-house flow simulation at a significantly lower investment cost, in terms of software licensing fees, personnel, and training expenses.

Following are various examples of how municipal water utilities are benefiting by using flow modeling technology.

**Virtual Biodosimetry for Analysis of Ultraviolet Disinfection Systems**

The use of ultraviolet radiation to purify drinking water has grown significantly in the last 10 years, primarily for two reasons. Firstly, the cryptosporidium bacteria appearing in drinking water sources has become a significant challenge, and UV radiation is a highly effective method for eliminating this contaminant. Secondly, UV disinfection leaves no residual chemicals, odors, or tastes in the treated water.

For any UV disinfection system installation, however, the EPA requires physical biodosimetry tests to prove that the kill rate is sufficient. Each installation must be tested because upstream piping can sometimes cause short-circuiting through the UV disinfection reactor. This means that recirculation regions cause some fluid to move more quickly through the system than designed, resulting in insufficient irradiation of the bacteria moving with it. Physical biodosimetry costs are typically in the $100,000 range which is cost-prohibitive for smaller municipalities. In the event that the biodosimetry validation fails, the proposed installation piping will need to be changed, followed by further testing. This risk can be avoided, however, by performing virtual biodosimetry analysis through flow modeling prior to physical testing.

The largest unfiltered surface water system in the world supplies New York City with 1.3 billion gallons of drinking water per day. Because of the high quality of the water (coming from three primary reservoirs—Catskill, Delaware, and Croton), the city received a Filtration Avoidance Determination from the US EPA for the Catskill and Delaware reservoirs. Under the terms of the determination, the city was required to meet the goals of the EPA’s Surface Water Treatment Rule, investigating UV disinfection as an alternative to filtration. A joint venture of Camp, Dresser & McKee (CDM) and Hazen & Sawyer has taken on the task of designing a UV system to meet the city’s needs. When the project was initiated, there were logistical difficulties in performing full-scale biodosimetry tests of UV units with capacity greater than 20 million gallons per day, so computational flow modeling was used in conjunction with light intensity distribution software. The accuracy of the computational modeling results was confirmed for the 20 million gallon per day system analysis, which provided confidence that the performance of 40 million gallon per day units could be accurately predicted. Since that time, physical testing capabilities have improved, and the final units will be tested in the field.
In the verification work done by Hazen & Sawyer, the modeling results for reduction equivalent dose (RED) were within about 19% of the testing results to within a 90% confidence interval. Figure 2 shows pathlines, colored by dose through a Wedeco-Ideal Horizons K3000 Reactor. This graphic makes clear the necessity to model three dimensional flow through the reactor, showing that not all pathlines receive the same dosage, even in this favorable scenario where there is no severe recirculation or short-circuiting.

Service Reservoirs

Anglian Water Services Limited was a partner in the design and construction of the Manton Lane Service Reservoir, near Bedford, UK, built to replace an existing storage structure which came to the end of its serviceable life. The 45 TCM reservoir is the sole provider to 130,000 customers including a university, a prison, schools and industry. CFD was used to simulate the flow pattern within the proposed design of the new reservoir to identify possible short-circuiting or dead zones which would compromise water quality. The simulations were carried out to determine the effect of a number of proposed changes to the inlet and outlet pipe arrangements. From the results of this analysis, it was determined that a reduction in the inlet pipe length did not result in the formation of flow dead zones and flow short circuits, so construction costs could be reduced by using less pipe without compromising final water quality.

As a direct result of the flow modeling work, the original construction costs were reduced by £60,000. CFD also provided greater confidence in the ability of the reservoir to maintain water quality standards.

Combined Sewer Overflows

As mentioned in the introduction, discharges from CSO’s are a major concern in the US, requiring the NPDES to impose additional controls. Fluid flow modeling has been used effectively to simulate the hydraulic and particle retention efficiency performance of standard and nonstandard designs of extended stilling pond, high side weir, and hydrodynamic separator CSO chambers. Figure 3 shows velocity magnitude contours along the center plane of one such chamber. It is the local flow velocity which generally dictates whether solids are suspended or sink, so these results are very helpful in improving CSO performance. In addition, however, it is possible to predict the motion of solids explicitly.

For example, in response to the need for an effective solution to the problem of CSO discharges, Johnston Pipes Ltd produced a new chamber design called the StormFox. The StormFox consisted of an enlarged pipe built along the line of the existing sewer that contains two longitudinal spill weirs protected by scumboards. Benching was included to prevent sediment deposition and to form a dry weather flow channel. A cross-section through a model StormFox is shown.
Most biological treatment processes are aerobic, meaning that oxygen is required. These processes often take place in tanks or basins where oxygen is introduced and mixed, either by surface aerators or by injecting pure oxygen through a vent. It is important to ensure both optimal mixing of the oxygen and to minimize regions of low speed flow where flocculation may occur, building up sludge.

Figure 5 shows oxygen bubble pathlines in a combined oxygen injection (VENTOXAL™) and turbulator (TURBOXAL™) system developed by Air Liquide. The bubble paths are colored by oxygen concentration, and are shown for varying oxygen flow rates, revealing the different distribution and flow fields for the different cases. Air Liquide used CFD in this analysis in order to help design an optimal tank deploying these technologies.

Optimizing Aeration Basins

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Contactor Tank Capacity

Physical tracer studies for determining residence time in contactor tanks can be expensive. Nonetheless, residence time is the key to determining proper disinfection through either ozonation or chlorination. Virtual tracer studies can be a precursor to physical tracer studies, and can significantly cut expenses associated with disinfection projects.

An example is the capacity increase at the West Basin water recycling plant in California, made necessary by an increasing population and ensuing demand, reported in a poster at the 2005 WEFTEC Conference. The disinfection process included a chlorine contactor, operating at 5 million gallons per day. It was believed that an additional contactor train would be necessary to accommodate the increased load of 6.9 million gallons per day. In order to save time and
money, the engineering contractor, CDM, recommended that modeling be used to confirm the necessity of an additional contactor train rather than physical testing. CDM created a CFD model of the existing contactor and performed a virtual tracer study, providing an estimate of the residence time using the increased flow volume.

The model results revealed that there was sufficient residence time to handle the increased flow rate in the existing contactor. At the end of the expansion project, West Basin provided the required physical tracer study, which confirmed the modeling results and reaffirmed that the residence time met the Department of Health Services’ requirements. Due to the insight gained from CDM’s virtual tracer study, the West Basin utility saved an estimated $3 to $5 million in design and construction costs.

**Summary**

In both drinking water supply and wastewater management, municipal water authorities are facing ever increasing costs and challenges, due to increasing population and environmental regulations. Flow modeling is one of the tools municipalities are using to address the need to optimize both existing and new technology that streamlines water processing. This white paper has shown how computational modeling can be used to identify technical improvements that result in substantial savings.

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