Computer Simulation Reduces Cost of Trihalomethane Compliance by 60%

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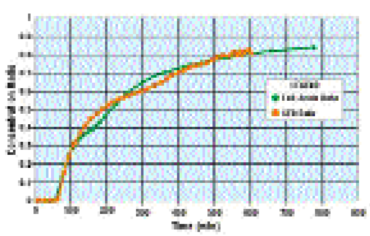

Fig 1. Val Vista WTP reservoir CFD and chemical tracer comparison

A recent application of computer simulation helped reduce by 60% the cost of complying with new drinking water regulation. The Environmental Protection Agency (EPA) recently reduced the allowable content of trihalomethanes from 100 to 80 parts per billion (ppb) because they are a suspected carcinogen. Reducing trihalomethanes concentration while maintaining drinking water safety requires increasing disinfection efficiency so less chlorine can be used

Simulation with computational fluid dynamics (CFD) helped develop an optimized baffle design that increased the efficiency of a reservoir at an Arizona water treatment plant from 10% to 35%. This design complies with the new regulations, at a cost of about $1,000,000, compared to an estimated $2,500,000 that would have been required to achieve compliance using conventional design methods.

Carollo Engineers is one of the United States' leaders in the planning, design and construction management of water and wastewater projects for public agencies,municipalities, private developers and industrial companies. The professional corporation has 29 principals and 44 associates. Carollo designed the Alfred Merrit Smith Water Treatment Facility in Las Vegas, Nevada, which is the largest direct filtration treatment plant in the country with a capacity of 624 million gallons per day (mgd). The firm has done extensive work with the Orange County (California) Sanitation District including facilities upgrades and designing two ocean outfalls. Other major projects include the Union Hills Water Treatmen Plant, Phoenix, Arizona, The 91st Avenue Wastewater Treatment Plant, Phoenix, Arizona, and work for the following clients: East Bay Municipal Utility District in Oakland, California, and the City of Arlington, Texas.

Trihalomethane formation

The use of chlorine and chlorine compounds is by far the most common disinfection method in the United States. Chlorine reacts with organic matter that might be present, breaking it down into simpler substances. Chlorine is an effective bacteriacide, given appropriate contact time for a given concentration. The downside of chlorine treatment is that disinfection by-products, including trihalomethanes, are formed when chlorine reacts with naturally occurring organic matter in the source water. The primary trihalomethanes of concern are chloroform, dibromochloromethane, bromodichloromethane and bromoform.

Results from toxicology studies have shown very high doses of trihalomethanes to be carcinogenic in laboratory animals and some have also been shown to cause adverse reproductive or developmental defects. Human epidemiological studies have suggested a weak association between certain cancers and reproductive and developmental defects and exposure to chlorinated surface water. More than 200 million people in the United States consume water that has been disinfected with chlorine so health risks associated with trihalomethanes need to be taken seriously even though they are very small.

The Safe Water Drinking Act established a 100 ppb annual average maximum residual for total trihalomethanes in 1979. EPA's Stage 1 Disinfectant and Disinfection Byproduct Rule reduced the maximum to 80 ppb. Large surface water systems are required to comply with the Stage 1 rule by December 2001. Ground water systems and small surface water systems must comply by December 2003. The EPA estimates that the total cost of meeting the Stage 1 rules will be about $700 million. The EPA estimates that water bills will increase by $10 to $33 per month for 1% of U.S. households, by $1 to $10 for 4% of households and by less than $1 for the rest. The majority of systems incurring the highest costs are smaller systems that have never been regulated for trihalomethanes in the past.

Reservoir efficiency

One option for utilities that must comply with the new regulations is switching toan alternate disinfection method. Unfortunately, the cost of switching to an alternate method is high and most alternate disinfection methods also have health and environmental concerns. For the majority of water treatment plants, the least expensive method of compliance is increasing the efficiency of their chlorination process in order to reduce the amount of chlorine required to kill bacteria. The problem at some water treatment plants is that water flows through disinfection reservoirs with a relatively short exposure to the chlorine. As a result, chlorine concentration needs to be maintained at high values in order to thoroughly disinfect the fraction of the water with the lowest contact time.

A reservoir's efficiency is calculated by injecting an arbitrary amount of tracer and waiting for 10% of that tracer to exit the reservoir. The time needed for the tracer to exit the reservoir divided by the theoretical residence time yields the efficiency. The theoretical residence time is simply the volume of the reservoir divided by the flow rate. The efficiency of most reservoirs is quite low, in the 10% to 15% range, because of the phenomenon known as short circuiting in which water injected into the reservoir tends to shoot through the reservoir and exit relatively quickly.

Fig 2. Union Hills Reservoir: Baffle configuration C, speed contour plot.

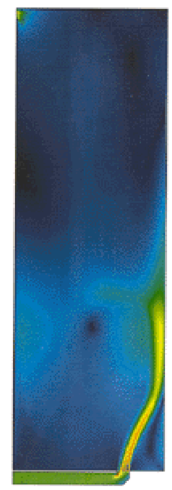

Fig 3. Union Hills Reservoir: Inlet configuration 5, speed contour plot

Scale models

The efficiency of a reservoir can usually be improved by adding baffles that increase the length of the path that water must travel from the inlet to the outlet. The value added by the baffles must be weighed carefully against their cost and installation time. It might cost $200,000 to add a single baffle and require that the plant be shut down for several weeks. Another problem is the difficulty in determining the number of baffles required to raise the efficiency of the reservoir by a certain amount and their ideal configuration and location. In the past, the only method engineers had to determine the effectiveness of a proposed baffle arrangement was to build a scale model of the reservoir and baffles and perform experiments. This approach is expensive and time-consuming and, worst of all, provides inaccurate results in many cases because of scaling factors. In order to overcome this problem, Carollo engineers have in recent years begun using computational fluid dynamics (CFD) software to simulate the flow of water through disinfection reservoirs. A CFD analysis provides fluid velocity, pressure and solute concentration values throughout the solution domain for problems with complex geometries and boundary conditions. As part of the analysis, a researcher may change the geometry of the system or the boundary conditions such as inlet velocity, flow rate, etc. and view the effect on fluid flow patterns or concentration distributions. CFD also can provide detailed parametric studies that can significantly reduce the amount of experimental work necessary to develop prototype equipment and thus reduce design cycle times and costs.

Finite element approach

Carollo selected FIDAP CFD software from Fluent Inc., Lebanon, New Hampshire. Disinfection reservoirs are very challenging from a modeling standpoint because of the difficulty in capturing the complicated shear effects near the walls of the reservoir. The finite element approach used by FIDAP provides high accuracy on problems of this type. Carollo engineers have found that FIDAP provides ±5% accuracy in predicting the efficiency of disinfection reservoirs. In one recent application, the City of Phoenix asked Carollo to design modifications to an existing 40 million gallon reservoir at the Val Vista Water Treatment Plant that would increase its efficiency from the current 10% to the 35% level required to meet the new EPA regulations while minimizing construction costs and downtime. The Val Vista plant processes 220 mgd for the communities of Phoenix and Mesa. Without the benefit of simulation, Carollo engineers would have had to play it safe by designing a five baffle modification that would have certainly improved efficiency to the required level but would have cost approximately $2.5 million. Instead, engineers constructed a two-baffle configuration that increased reservoir efficiency to 35%. Engineers wrote FIDAP subroutines to create special boundary conditions at the inlet and around the walls of the reservoir. An RNG turbulence module was used to model the separation, recirculation and swirl regions in the flow. Engineers then used the software to simulate the addition of a tracer chemical to the reservoir and measured the elapsed time before tracer appeared at the outlet. The results matched experiments on the existing reservoir within ±5%. The next step was modifying the model to evaluate a range of different baffle configurations. In only one month, the engineers examined six different design iterations the best of which achieved the required efficiency level at a cost of only $1,000,000.

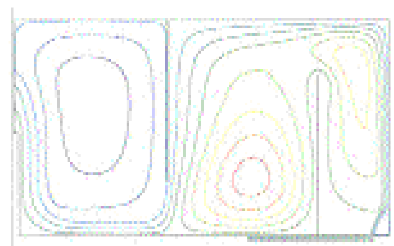

Fig 4. Union Hills Reservoir: Baffle configuration C, streamline contour plot