Distribution

Passive Mixing Systems Improve Storage Tank Water Quality

Modeling and field monitoring are helping utilities understand the complexities of water storage tank mixing and how to identify and correct mixing problems. **BY MICHAEL DUER**

Experiments show that distributing the inlet through multiple inlet ports results in significantly faster mixing—up to 50 percent faster compared with a single inlet pipe.

PHOTOGRAPH: TIDEFLEX TECHNOLOGIES

DECREASED WATER quality in storage tanks results from short-circuiting, incomplete mixing, low volume turnover, and high water age. As a result, utilities have problems with temperature stratification, loss of disinfectant residual, disinfection by-product (DBP) spikes, bacteria regrowth, biofilm growth, taste and odor, and nitrification (chloramines). Such problems can be eliminated and water quality can be improved by optimizing turnover and achieving complete mixing with passive mixing systems.

TURNOVER AND WATER AGE

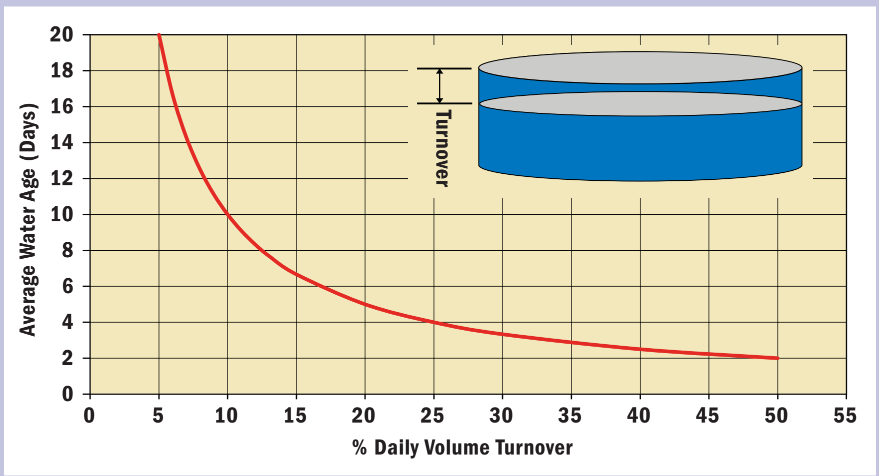
Storage tanks stabilize pressure in distribution systems, provide equalizing storage for peak daily demands, and provide reserves for firefighting and emergencies. With typical daily demand patterns, water is exchanged in and out of a tank, usually filling at night and draining during the day. Storage tanks must also turnover their water to minimize water age.

A tank's volume turnover determines the average age of water in the tank. Figure 1 illustrates average water age vs. daily tank turnover. Acceptable volume turnover depends on factors such as source water, treatment process, distribution system volume, and infrastructure condition. A common goal is a 20–30 percent daily volume turnover, resulting in water age of 3–5 days.

Water age, however, assumes complete mixing of a tank's contents. If a tank isn't mixed, and if the oldest water isn't drawn from the tank first, the tank will short-circuit and cause a localized increase in water age. For example, a tank may have a volume turnover of 20 percent/day, but if the water isn't mixed and short-circuits, the tank may contain water much older than 5 days—perhaps weeks or months old. This localized increase in water age causes water quality problems such as loss of residual, DBP spikes, bacteria regrowth, and other problems associated with high water age and elevated temperature. Experienced water operators have used various methods to increase tank turnover, such as changing pump on–off setpoints or ramping down pumps

Figure 1. Average Water Age vs. Daily Tank Turnover

Increasing tank turnover reduces water age.



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equipped with variable frequency drives. Distribution system operation and optimization are keys to improving water quality in storage tanks.

MIXING

A built-in energy source inherent to distribution systems—differential pressure—can effectively mix tanks with a properly designed passive mixing system, often with 10 percent volume turnover or less. Mixing in tanks occurs during fill cycles, resulting from momentum of flow being injected into tank water that's at zero velocity. The velocity difference between the inlet jet and tank water creates turbulence, which develops circulation patterns throughout the tank. Figure 2 is a computational fluid dynamics (CFD) model of a circular reservoir with a bottom inlet located near the wall of the tank. The colored contours and white vectors illustrate velocity magnitude and direction of circulation patterns that develop throughout the entire water volume. Circulation patterns develop in all tank styles—circular reservoirs, rectangular reservoirs, elevated tanks, and standpipes—but are specific to each tank's geometry and inlet port configuration.

During the fill cycle, new water is dispersed through the tank volume via these circulation patterns, which often persist for hours after the fill cycle has ended. Complete mixing is achieved when a fill cycle lasts longer than the time required for complete mixing, which is calculated with the equation below.

$$\tau_m = K' \frac{V^{2/3}}{M^{1/2}}$$

Where
τ_m = mixing time
K' = an experimental constant (≈ 10.2) for a single inlet with no temperature difference between inlet and tank water
V = tank volume
M = inflow momentum (flow rate x velocity)

However, the equation doesn't account for temperature differences between distribution system and tank water. Temperature differences change circulation patterns and can result in incomplete mixing, even though the equation predicts a mixing time. Also, CFD and scale modeling have shown that a single, fixed-diameter inlet pipe isn't nearly as efficient as multiport mixing systems, because a single inlet concentrates all momentum in one location of the tank.

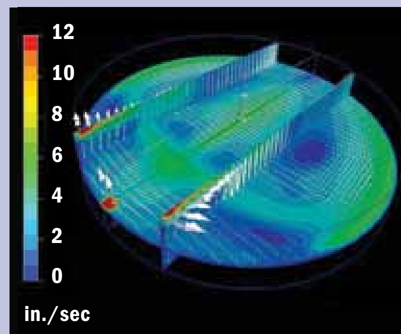
INLET–OUTLET PIPE SEPARATION

Separating inlet and outlet pipes has become more common and is mandated by some states. Conceptually, it's a good design goal. However, locating the outlet pipe as far apart as possible from the inlet pipe is often the incorrect location. The outlet pipe(s) should be located based on the tank's circulation patterns, which are determined by tank style and inlet.

Figure 3 is a CFD model of a circular reservoir with an inlet pipe through the sidewall. Conventional wisdom says to locate the outlet on the opposite side of the tank, 180° from the inlet pipe. However, that isn't the area that mixes

Figure 2. CFD Model of Circular Reservoir, Bottom Inlet

Circulation patterns are 3-D and develop through the entire tank volume.



last. To prevent short-circuiting, this tank needs two outlet pipes—one in each semicircular low-velocity area. With a properly designed passive mixing system, however, the location of the outlet pipe isn't critical because the entire water volume will be mixed and homogenous.

TEMPERATURE EFFECTS

The mixing inefficiency of a single, fixed-diameter inlet pipe can be a problem when tank and distribution system water temperatures differ. Summertime usually presents the greatest challenge, because inlet water is typically colder than tank water. Colder water is denser and negatively buoyant; therefore, it sinks. Figure 4 is a scale model of a 30-ft deep circular reservoir with colder water entering the tank through a bottom inlet pipe near the tank wall. Initially, the jet rises and hits the water surface, but water from the jet is denser, so it falls back to the tank floor and spreads horizontally. Because momentum is concentrated in one area, there's no vertical momentum to mix through the depth away from the inlet. In this case, the bottom half of the tank is mixed and water quality is adequate, but the top half isn't mixed; the water moves up and down like a piston and continually increases

Figure 3. CFD Model of Circular Reservoir, Sidewall Inlet

Dark blue zones on each side of the tank's centerline show the two areas that mix last.

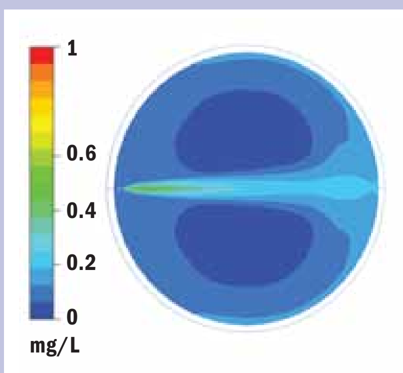
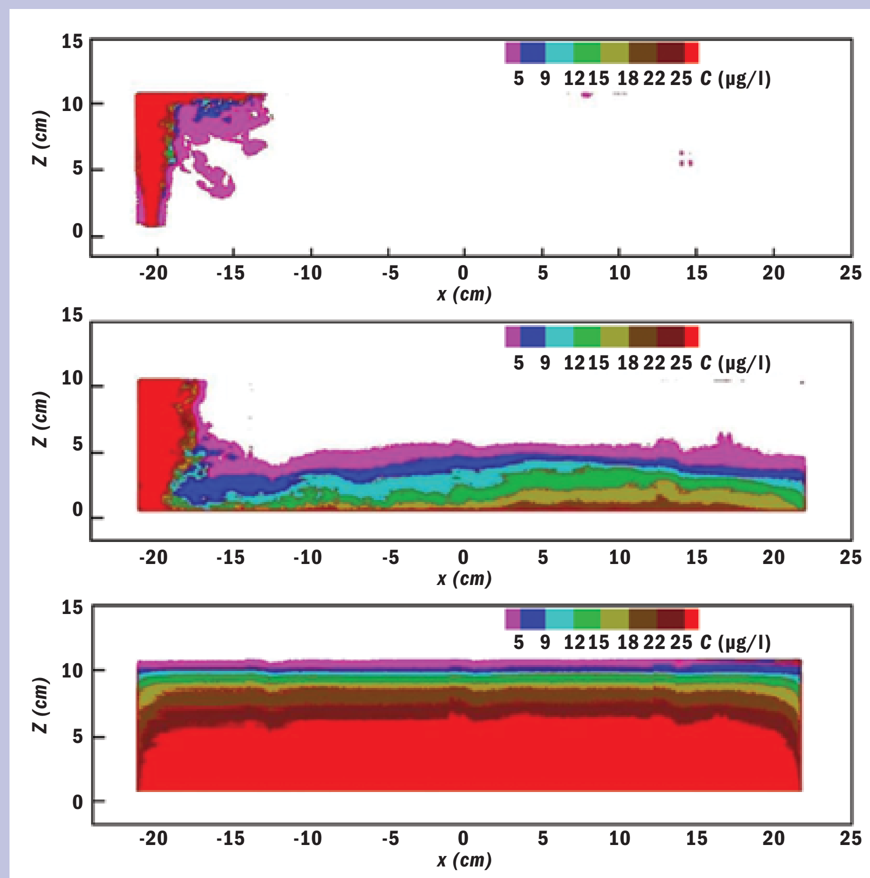


Figure 4. Scale Model of Circular Reservoir, One Inlet With Colder Water

A single, fixed-diameter inlet pipe can lead to incomplete mixing when tank and distribution system water temperatures differ.



in temperature and water age with each fill-and-draw cycle. Deep cycling this tank 50 percent won't correct the problem. The tank will short-circuit because freshwater is pulled from the bottom of the tank, leaving poor-quality water in the top of the tank. This problem can occur in all styles of storage tanks, but particularly in standpipes, because of their depth.

PASSIVE MIXING SYSTEMS

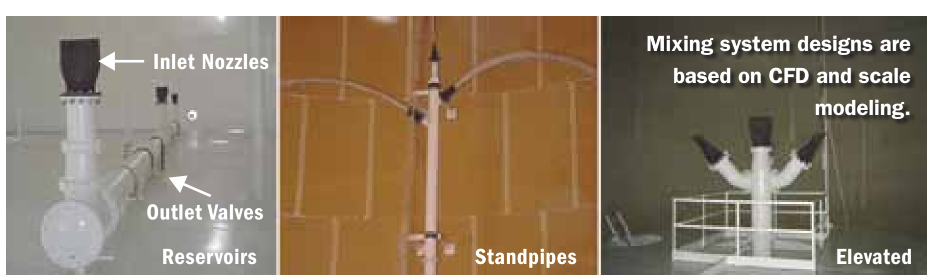
A research report from the Water Research Foundation, *Physical Modeling of Mixing in Water Storage Tanks*, and CFD scale modeling identify two important characteristics of passive mixing systems.

Multiport passive mixing systems (MPMSs) mix tanks up to 50 percent faster than a single inlet pipe, because MPMSs distribute inlet flow momentum through the tank instead of flow being concentrated in one area.

An MPMS can mix tank water during warmer summer months with colder, denser inlet water when a single inlet pipe would result in incomplete mixing and stratification. Figure 5 is a scale model of a six-port MPMS that achieved complete mixing. The same tank with a single inlet (Figure 4) resulted in incomplete mixing and stratification.

Properly designed passive mixing systems require knowledge of jet-induced mixing characteristics—as a function of tank style, flow, turnover, momentum, and density differences—to determine the proper location, elevation, spacing, discharge angles, and jet velocity of inlet and outlet ports to achieve complete mixing.

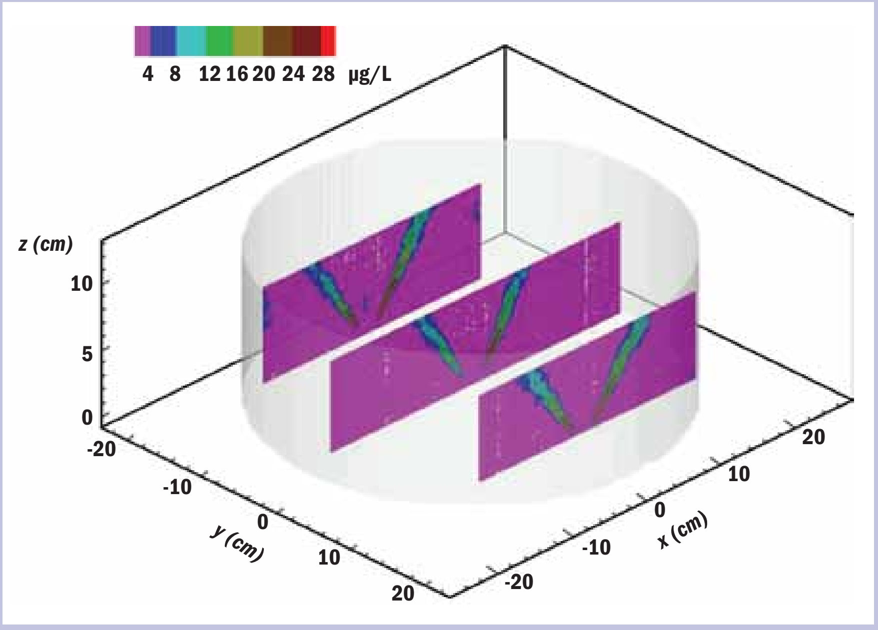
The photos below show MPMSs in various tank styles. The MPMS separates the inlet and outlet inside the tank



Water quality depends on both mixing and volume turnover.

Figure 5. Scale Model of Six Inlet Ports

Unlike the tank shown in Figure 4, multiple ports can completely mix tanks when inlet water is colder than tank water.



with one manifold and two sets of nonmechanical check valves. CFD and scale modeling results for each tank style are used to properly design the system for complete mixing. Hydraulically, the tank operates the same with an MPMS and a common inlet–outlet pipe, but inlet water enters and mixes the tank through strategically located duckbill inlet nozzles and exits the tank through the outlet check valves. The duckbill nozzles are a variable orifice (progressively opening and closing with increased and decreased flow rates), so they maximize jet velocity at all flow rates, resulting in faster mixing. The MPMS is "green" because it uses the energy in the distribution system and doesn't require maintenance.

ACTIVE MIXING

For tanks that have extremely low or no turnover, one way to mix a tank is to use an active mixing system that can operate 24 hours/day if necessary. A recirculation pump in a valve vault and a passive mixing system in the tank are effective. The pump can be low flow and low head, because it can run 24 hours/day and uses pressure from the tank. From an inspection and maintenance standpoint, it's handy for the mechanical components to be in the valve vault where they're easily accessible. However, water quality depends on both mixing and volume turnover. Without volume turnover, continuous mixing only results in mixing continually aging water.

Another application using a pump is to force water back into the distribution system, instead of continuously recirculating it back into the tank. The forced drawdown will achieve volume turnover and mix the tank when the pump is kicked off and the tank refills.

With extensive CFD, scale modeling, and field monitoring, properly designed MPMSs have proven to be a "green," no-maintenance, and effective method to improve storage tank water quality.

CASE STUDY

STANDPIPE COMPARISON REVEALS MIXING BENEFITS

Clark Public Utilities, Vancouver, Wash., compared mixing charateristics of two adjacent standpipes, both 125 ft deep. A 26-ft-diameter (0.5-mil gal) tank had a common inlet–outlet pipe at the bottom of the tank, and a multiport duckbill mixing system was installed in a 45-ft-diameter (1.5-mil gal) tank.

Temperature data loggers collected data through the depth of each tank every 30 minutes for more than 1 year. August data, shown in the accompanying chart, illustrate significant stratification, 12° top to bottom, in the tank without a mixing system. The mixing system eliminated stratification in the larger tank. The utility also reported that lower bulk water temperature decreased chlorine demand and bacteria regrowth potential.