LAYERING AND MIXING

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Water layering and full-depth mixing

How water layering affects tank water quality—and why full-depth mixing is one solution.

Potable water storage tanks are a necessary part of the water distribution system, providing pressure and enough supply for daily and emergency use. Yet, the AWWA estimates that 65 percent of them, over 200,000 tanks, have water quality problems.

These problems—common in both chlorine and chloramine systems, warm or cold climates—can range from temperature stratification, stagnation, dead zones and short-circuiting to biofilm build-up, loss of residual, nitrification events and, in northern climates, ice damage. Chlorine systems commonly experience loss of residual, plus rapid bacteria growth, especially in warm weather, as well as disinfection byproducts (trihalomethanes, or THMs, and halo-acetic acids, or HAAs) if the source water is surface water. Chloramine systems are prone to auto-decomposition and loss of residual, which can occur very rapidly over one to two days, and nitrite and nitrate formation are additional problems.

These myriad problems snowball from the simple fact that water in reservoirs forms thin horizontal layers. Understanding why water layering occurs in storage tanks will help utility managers determine how best to ensure the water their customers receive is of the highest quality.

Differences in temperature, pressure and salinity create density layers

A body of water may look "solid," but it is in fact composed of thin horizontal layers. These layers are caused by a combination of hydrogen bonding of water and gravity; given a set of water of different densities, it requires less energy in nature for the water to form into thin horizontal layers of the same density than to mix together to form a homogeneous body of water. The effect is similar to a ream of copy paper lying on a desktop: it may look like a solid block of paper, but each single sheet forms a separate and distinct horizontal layer. In water, these horizontal density layers are caused by differences in temperature (as little as 0.001° C), pressure (deeper

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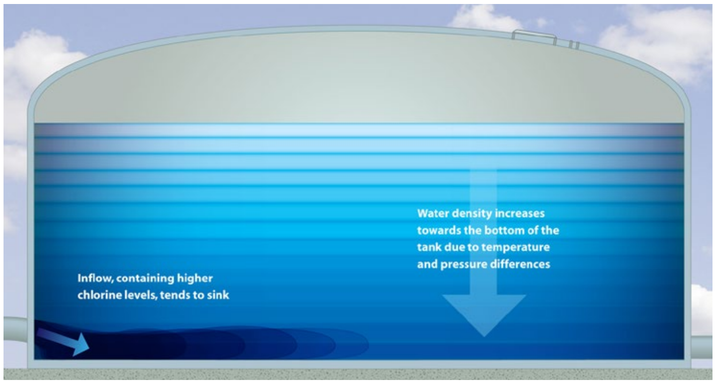
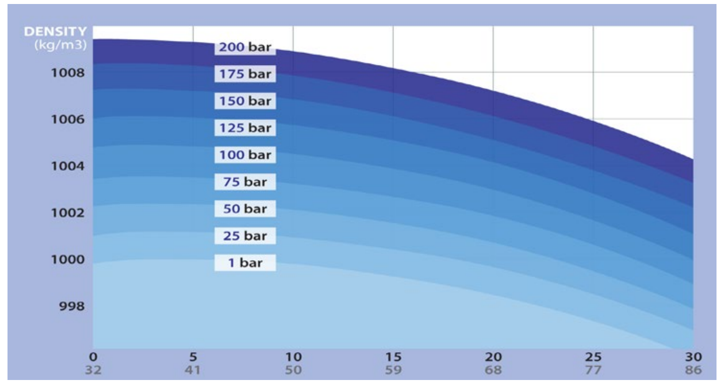


Water in reservoirs forms thin horizontal layers due to density differences of temperature and pressure. Inflow water, with its higher chlorine concentrations, usually plummets to the bottom of the tank.



Pressure and temperature both affect density: Increased pressure, from being at the bottom of the tank, increases water density. And cooler water has higher density than warmer water, down to approximately 4°C (39°F).

water is slightly compressed to higher density) or salinity (5–10 mg/l or less; salinity is not typically a factor in potable water). In a water tank, the heaviest, or most dense, layer is at the bottom, and each layer above it is progressively lighter. In the summer time, the lower water layers are usually cooler and newer, with higher chlorine residual. Upper and mid-depth water layers are usually warmer, older and have less chlorine residual because it has been used up in killing bacteria within the tank. In the world of tank hierarchy, gravity rules. A lighter layer cannot, by mild convective forces, displace a heavier layer—just as a layer of Styrofoam balls cannot displace an underlying layer of steel balls.

When the tank is being filled, the inflow water is carrying an important dose of new chlorine into the tank to help replace chlorine which has been lost in the process of destroying bacteria. But if the inflow water is cooler than the rest of the water in the tank, that density factor alone will usually overwhelm all other density factors, and gravity will cause the inflow water to stay at the bottom of the tank. Or, if the inflow water entered higher in the tank, it will fall to the bottom. As a result, the older tank water layers are "jacked up" by new inflow which enters the tank and levels out there. Neither baffles, check valves nor nozzles can change that result.

Even if a tank has little or no temperature difference from top to bottom, just the density differences between horizontal layers created by pressure, from the water above, creates a strong resistance to mixing of the layers. And regardless of whether the density differences are caused by temperature or pressure or both, the upper, lighter water cannot push its way into the outlet stream at the bottom of the tank (think of Styrofoam balls trying to push steel balls out of the way). As a result, the densest layers, from the very bottom, leave the tank first, one water layer at a time from across the entire tank floor.

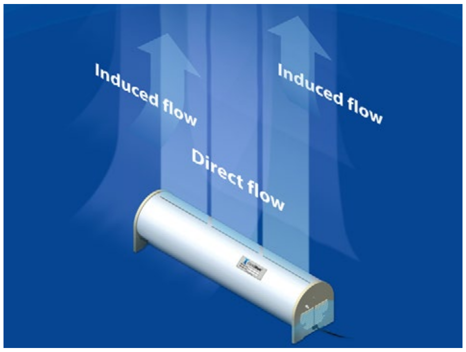
There is only one way to defeat the force of gravity holding the densest layers to the bottom of the tank, and that is with direct mechanical lifting. This "lifting" is done by a mixer that pulls water off the tank floor.

How mixing affects water layers

The job of a mechanical tank mixer is to mix the new inflow water throughout the entire water body, to keep the chlorine level, temperature and water age within the tank as uniform as possible. The layering effect of stored water has a significant effect on how well a mixer performs in tanks. The best approach is for a mixer to pull in water from the very bottom of the tank, where the densest layers are, and directly transport it toward the top of the tank. After a period of continuous mixing, the chlorine levels and temperature become nearly identical throughout the tank, and the pressure alone causes a slight remaining density gradient that inhibits mixing.

The effects of sheet-flow mixing

One solution to combat the layering of water is to use a mechanical "sheet-flow" mixer. This type of mixer sets on the tank floor and pulls water in from 1 to 2 inches of the tank floor. The water enters one end of the mixer, and is directed upward



The sheet-flow mixer pulls direct flow into the end of the machine and discharges through 3 long slots on the top of the machine. Direct flow leaves the mixer as a "sheet" of water while also dragging induced flow water up from the bottom of the tank.

through a long slot at the top of the mixer. This 31-inch long "sheet" of direct travels fast enough to reach the top of tall tank, even 150-foot standpipes, but slow enough to start dragging induced flow upward, from the bottom of the tank, immediately after water leaves the slot. With 31 inches of induced flow on either side of the mixer, that's a total of 62 inches of contact between the direct flow and the body of water, enough to create high induced flow just 8 to 10 inches off the floor. The bottom 1 to 8 inches of the tank is mixed because it is pulled into the mixer as direct flow. This leaves only the bottom inch—along with any sediment—unmixed. These mixers are capable of completely mixing tanks as large as 8 million gallons or more, depending on the water quality challenges the tank has, and can also be equipped with a chemical injection hose to boost the chlorine in the tank if ever needed.

Best practices for tank management

Develop a "Plan A" for each tank that addresses regular maintenance to prevent major problems. In addition, develop a "Plan B" for each tank that addresses how you would deal with a water quality crisis.

"Plan A" for each tank

To prevent major problems:

1. Clean the reservoir periodically;
2. Install a good mixer for 24/7 cleaning to the floor and all boundary walls;
3. Reduce water age by cycling the tank as much as possible (without affecting fire protection and other needs).

In warm weather (>55°F water), test frequently for temperature stratification and chlorine residual. For chloramine systems, test for free ammonia and nitrite. Although these problems are worse in the summer, they can occur year-round in warm states.

"Plan B" for each tank

Know how you will deal with a water quality crisis:

1. Make sure your mixing system works when the tank is off-line.
2. Install a chlorine boosting system.
3. Try "fast response early boost" (FREB) first. Often 1-10 gallons of diluted chlorine may be all that is needed to correct a water quality problem.

These steps avoid the need for crisis management meetings, dramatic drawdowns, fire protection problems, wasting water, or taking the tank offline. As a last resort, be prepared to breakpoint chlorinate the tank, which needs a very good mixing and boosting system.

Fast Response, Early Boost Program

At the first sign of trouble in a tank—within 1-3 days—boost the tank with a small dose of chlorine to correct the problem. For example, to boost a 500,000 gallon tank by 1mg/l of chlorine requires only 3.3 gallons of sodium hypochlorite 12.5% solution.

Small periodic dosing can reduce overall chlorine usage by 50 to 80%. A continuous mixer made for boosting is generally required (make sure your license allows boosting).

Remember that a mixer is not an absolute cure-all. A mixer can't manufacture chlorine or cure a water chemistry problem. The first month of mixing the tank can depress residual due to some chlorine being used up as the biofilm is being killed, but boosting is usually not required during that first month.

Also, the location of the sheet-flow mixer within the tank does not affect performance in most cases; the mixer works equally well placed under a hatch, for easy installation and maintenance, or in the middle of the tank. Since water is being pulled into the mixer from across the entire floor, due to the density-based layering of water, the discharge side of the mixer will also push water across the entire tank length and width just to keep the water surface level.

Mixers that pull from the bottom of the tank will show water of uniform temperature and chlorine concentration to within 1 to 2 inches of the floor. These mixers will sometimes cause residual chlorine to be depressed for several weeks after a new installation, because the bacteria in the sediment are finally being destroyed by the continuous flow of chlorinated water over the sediment. And these mixers are absolutely necessary to prevent problems of ammonia oxidizing bacteria (AOB) that cause nitrification in chloramine systems. Mixers that do not pull from the bottom of the tank will not exhibit these results.

Furthermore, mixers that pull from the bottom of the tank enhance the distribution of chlorine pellets or liquid 12.5% sodium hyperchlorite which some cities will drop into the tank from a hatch on top, to boost chlorine, in lieu of using a chemical injection system that injects chlorine directly into the mixer output flow. Without strong mixing that pulls directly off the floor of the tank, the pellets or solution will fall directly to the bottom of the tank and "roll" to the low spot, usually the sump. Most of the chlorine solution will then go right out with the first water leaving the tank.

CONCLUSION

Most potable water quality problems occur in storage tanks, not in the pipeline. These problems occur because water in tanks forms thin horizontal layers due to differences in temperature and pressure. One solution with proven results is to mix the tank thoroughly, from tank floor to water surface. Well-mixed water delivers consistent sampling, consistent water age and consistent water quality.

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