Question of the Month

ADVICE FOR SMALL SYSTEMS

Does Chlorine Contact Tank Mixing Reduce Detention Time and THM Formation? BY JOEL BLETH

Water and wastewater utilities can account for nearly 40 percent of a small city's energy use. By more efficiently managing its energy use, a community can significantly affect operational costs and improve its financial sustainability.

Proper mixing increases detention time by adding a vertical plug-flow element to the flow of water through a chlorine contact tank. The increased detention time allows a plant operator to use a higher baffling factor used in contact time (CT) calculations, thus reducing the concentration of chlorine needed to meet CT treatment requirements.

Using less chlorine, in turn, reduces production of disinfection by-products (DBPs) such as trihalomethanes (THMs) and haloacetic acids (HAAs). Therefore, mixing a contact tank can be a low-cost way to achieve DBP compliance.

Chlorine contact tanks ensure disinfection effectiveness and compliance with the US Environmental Protection Agency (USEPA) Surface Water Treatment Rule for preventing waterborne diseases caused by cysts and viruses. Although chlorine's effectiveness partly depends on water temperature and pH, it primarily depends on the amount of time free chlorine is in contact with the water. Each state establishes a minimum chlorine contact time for various water sources, which results in a treatment parameter based on concentration × contact time, commonly referred to as the CT requirement.

DETENTION TIME

For example, if a treatment plant must achieve a CT of 120, free chlorine (in mg/L) multiplied by the time the chlorine and water are together in the contact tank (in minutes) must equal or exceed 120. Therefore, the plant can meet the CT requirement with 2 mg/L of chlorine contacting the water for 60 minutes in the contact tank or—during periods of higher flow through the plant—3 mg/L of chlorine contacting the water for 40 minutes in the contact tank. In each case, 2 × 60 = 3 × 40 = 120, the CT requirement is being met. The treatment plant must meet the CT requirement continuously, so the amount of chlorine that needs to be added can fluctuate significantly from hour to hour if the flow rate through the plant fluctuates.

Regarding time, USEPA and the drinking water industry have long known, through tracer studies, that the number of minutes that chlorine and water are together in a tank can't be accurately determined by merely dividing the tank volume by the flow rate. For example, if the flow rate is 1,000 gpm through a 500,000-gal contact tank, the calculated detention time is 500,000 gal/1,000 gpm = 500 minutes. However, in a simple tank, tracer studies have shown that—with just an inlet and outlet and no baffle curtain or mixing—the actual detention time is only 10 percent of the theoretical time, or 50 minutes. Therefore, this tank would be given a baffling factor of 0.10, meaning the actual detention time used for the CT calculation must be only 0.10 × the theoretical detention time.

If an operator doesn't conduct a tracer study to confirm detention time and baffling factor, USEPA assigns a chlorine contact tank a standard baffling factor based on its configuration. Standard baffling factors range from 0.1 (a tank with no baffles) to 0.3 (a tank with a single baffle) and up to 1.0 (perfect plug flow in a pipe).

HORIZONTAL LAYERS

In the example above, why is water in the tank for only 50 minutes? Water in reservoirs form thin horizontal layers of different densities, with the lightest layers at the top and the heaviest layers at the bottom (see Mix It Up! Solve Water Layering Problems, page 16).

Because of the high flow through a contact tank, temperature and salinity usually don't affect the formation of thin horizontal layers in the tank. However, the difference in density caused by pressure is present at every depth and is strong enough to cause layering of water that resists mixing from top to bottom.

Although the tank may have a 500,000-gal volume and an operating depth of 10 ft, tracer studies reveal that most of the 1,000 gpm enters at the tank's bottom, travels across the tank's bottom 1 ft, and exits the tank in only 50 minutes—instead of the theoretical 500 minutes. In other words, only about 1 ft of the tank depth (10 percent of the volume) is being used. With one baffle in the tank, only about 30 percent of the tank volume will be used.

A properly designed tank mixer continually pulls water from the tank's dense bottom layer and spreads it across the top of the tank, causing all other layers to move downward. When the tank's bottom layer of water moves to the surface, the only factor that made it the tank's most dense water is eliminated. The water floats evenly across the top of the tank because it's now the least dense water. If a mixer is of adequate size, all incoming water is continually transported to the surface and spread out across the top of the tank, creating a vertical plug flow that uses the entire tank volume for detention time.

After a mixer is installed, a tracer study can document the improved baffling factor, which should be about 0.5–0.9, depending on mixer size and design. Because many plants achieve CT compliance across specific plant sections involving several serial components and piping, the plants should conduct the studies regularly. Therefore, a

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Joel Bleth is president of Medora Corp. (www.medoraco.com), Dickinson, N.D.

process change in any section of a plant necessitates a new tracer study to be performed. Although some states may require a tracer study at just one flow rate, other states require studies for several flow rates, with as many as four flow rates required for some systems.

COMPARE SCENARIOS

Consider a treatment plant with a process rate of 1,000 gpm, a CT requirement of 150, and a 200,000-gal contact tank operating under the following conditions:

No Baffle or Mixer. The USEPA standard baffling factor is 0.1. The contact or detention time (T) = (200,000 gal/1,000 gpm) theoretical detention × 0.1 baffling factor = 20 minutes. To meet the CT requirement, the chlorine concentration that must be injected into water entering the tank = (150 for CT)/(20 for T) = 7.5 mg/L of chlorine.

Baffle Installed in Contact Tank. The USEPA standard baffling factor is 0.3. The contact or detention time (T) = (200,000 gal/1,000 gpm) theoretical detention × 0.3 baffling factor = 60 minutes. To meet the CT requirement, the chlorine concentration that must be injected into the water as it enters the tank = (150 for CT)/(60 for T) = 2.5 mg/L of chlorine.

Mixer Installed in CT Tank. Assume a baffling factor of 0.65 is achieved and verified with a tracer study. T = (200,000 gal/1,000 gpm) theoretical detention × 0.65 baffling factor = 130 minutes. To meet the CT requirement, the chlorine concentration that must be injected into water entering the tank = (150 for CT)/(130 for T) = ~1.2 mg/L of chlorine.

Chlorine Savings. The baffle and the mixer allowed for significant chlorine savings compared with using neither device. However, a mixer usually costs less than a baffle. If a treatment plant has high-THM levels, using less chlorine could save money.

PUTTING IT ALL TOGETHER

A chlorine contact tank with a properly designed mixing system can increase detention time and require less chlorine, resulting in lower levels of DBPs. After a mixer is installed, tracer studies can help establish new baffling factors at one or more plant flow rates. State regulators should be involved from the start.

In September 2013, Opflow ran an reader feedback article with the question “Does SolarBee / GridBee mixing create a CSTR (completely stirred tank reactor), or does it create a vertical plug flow?”

Read the feedback article as pubished , on the next page.

Feedback

LETTERS TO OPFLOW

Do you have a question, comment, or suggestion to pass along to *Opflow*? Please email feedback to opfloweditor@awwa.org.

TANK MIXING

I read with interest the July 2013 Question of the Month column, Does Chlorine Contact Tank Mixing Reduce Detention Time and THM Formation? (www.awwa.org/bleth13). The author concluded that adding mixing to a chlorine contact tank increases the baffle factor and improves contact time (CT). Although there are situations for which installing a mixer could increase the baffle factor, a general conclusion to that effect could mislead readers.

A mixed tank is a continuously stirred tank reactor (CSTR) or a completely mixed flow (CMF). The opposite of a CMF tank is a plug flow (PF) tank. In an ideal PF tank, the baffle factor is 1.0, and the T_{10} used in CT calculations is the same as the theoretical detention time (flow into tank divided by tank volume). This is the best possible CT—a 100 percent PF tank.

Regarding a 100 percent CSTR or CMF tank, fluid retention time in a CMF tank is determined by

1-F(t) = fraction of fluid retained in tank for longer than time, $t = exp^{-(t/T)}$

To find T_{10}, set 1-F(t) = 0.9, and calculate t/T to be 0.11. So, if you add a mixer to a tank and convert the tank to a CMF, the baffle factor is 0.11. To maximize CT, you'd want a PF tank, not a mixed CT tank.

Tanks are usually a combination of CMF, PF, and dead space. Tracer studies can help define percentages for a given tank. In general, adding mixing isn't desired. In fact, the better the mixing, the more the tank will approach a CMF and the more the baffle factor will approach 0.11.

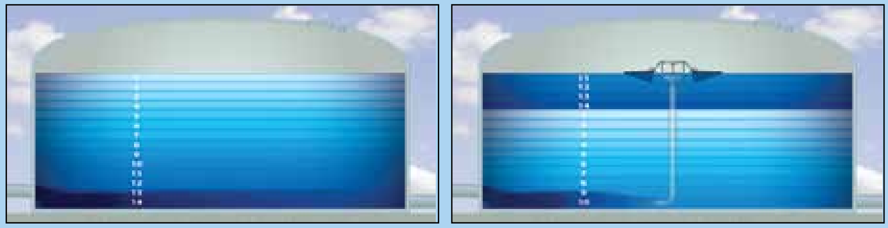
David Cornwell
Environmental Engineering & Technology
Newport News, Va.

Author's Response: *I agree. If a mixer created a perfect CSTR, the baffle factor would be 0.11. However, because of water layering into discrete horizontal layers, some mixers can create what amounts to a vertical PF effect within the tank. For that to happen, the mixer must pump influent water upward and constantly spread it across the top of the tank, not mix it totally or immediately with other water. The accompanying images may help clarify the process.*

Joel Bleth
Medora Corp., Dickinson, N.D.

Tank Baffling Factor

Water in reservoirs forms thin horizontal layers of different densities (left), with the lightest layers at the top. With no baffle or mixer, the standard baffling factor is 0.1. A properly designed mixer installed in a CT tank mixes layers of water (right), which essentially adds a vertical PF and increases detention time.



DIAGRAMS: MEDORA