

Not just for milk anymore

Pasteurization for disinfection of wastewater and reclaimed water

Andrew Salvesson, Nitin Goel, and Greg Ryan

What's the best disinfection method? Where chlorine was once the ultimate (and immediate) "go to" disinfection method, the challenges of reduced pathogen kill and the formation of disinfection byproducts and N-nitrosodimethylamine require a better answer. The industry is responding with innovations in ultraviolet light (UV) technologies, the re-emergence of more-efficient ozone, and now pasteurization.

Pasteurization overview

Pasteurization has been around since the 1860s. This simple treatment process, originally developed to disinfect beer and wine in France more than 150 years ago, is now commonly used to disinfect milk and juice. Recently, the Pasteurization Technology Group (San Leandro, Calif.) contracted Carollo Engineers (Walnut Creek, Calif.) to independently validate the pasteurization process, which was approved subsequently by the California Department of Public Health (CDPH), for reclaimed-water disinfection. The detailed performance testing required for CDPH approval is an exhaustive process that thoroughly documents the pathogen disinfection performance of a disinfection system over a wide range of operational and water quality conditions. The demonstration testing was done at the Laguna Subregional Water Reclamation Facility in Santa Rosa, Calif. To date, only UV, ozone, and now pasteurization have been approved based upon such detailed testing. Surprisingly, chlorination has not been approved by CDPH based upon the same testing rigor.

The economy of pasteurization is based upon the capture of a waste-heat source and the transfer of that heat to the water for disinfection. Economic analyses for utilities nationwide have shown pasteurization to be the lowest-cost system in all but a few locations, in terms of both energy use and total cost. In Ventura, Calif., the pasteurization system has been shown to potentially profit the city with a significant annual income from operating pasteurization, as opposed to an expense for operating UV disinfection.

Engineering concepts

The patented pasteurization system (see Figure 1, p. 44) consists primarily of plate-type (water-to-water) and stack-type (air-to-water) heat exchangers. The plate-type heat exchanger, or preheater module, transfers the heat from the already disinfected wastewater to the influent wastewater. The stack-type heat exchanger, or waste-heat recovery module, transfers the waste heat from the external heat source to the water. The external heat source

can be turbine-exhaust heat, burner- (flare-) exhaust heat, hot water, or other forms of heat. Following the waste-heat recovery module, in-line pumps are included to maintain a higher pressure on the effluent side of the system, compared to the influent side.

Many assume that pasteurization cannot possibly be cost-effective to heat wastewater to greater than 71°C (160°F). In fact, the use of the various heat exchangers keeps more than 96% of the reactor heat within the reactor. Therefore, only 1.7°C to 2.8°C (3°F to 5°F) of energy input is required on a continual basis. The secondary benefit of the capture and maintenance of the heat within the reactor is that effluent temperatures are typically within 1.7°C (3°F) of influent temperatures.

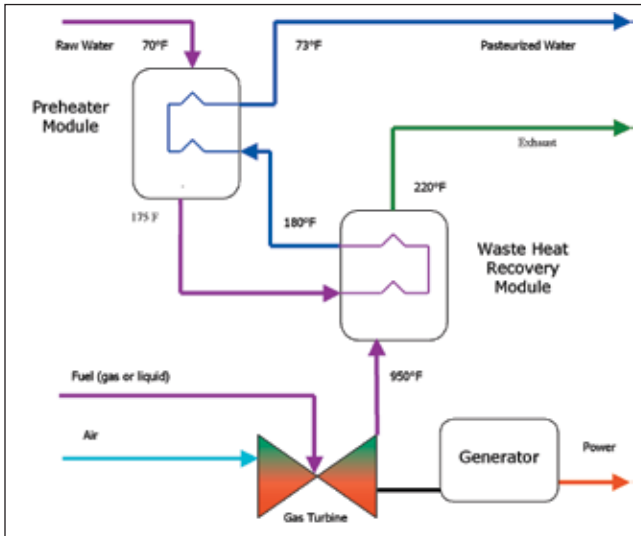
Title 22 research

Title 22 of the *California Code of Regulations* specifies methods to evaluate alternative reclaimed-water treatment technologies. The "tertiary recycled water" requirements under Title 22 call for rigorous determination of the "dose" needed to meet virus and bacteria disinfection goals of 5-log virus (based upon poliovirus) and 2.2 MPN per 100 mL total coliform bacteria, respectively. The research conducted by Carollo included a detailed literature review, followed by original pasteurization research. The goal of this effort was to define the dose needed to meet various disinfection targets over a range of water quality and system operations.

Literature summary. Pasteurization disinfection performance, as reported in the literature, is dependent on contact time and temperature. Low contact time coupled with high temperature is known as "flash pasteurization" and has proven to be very effective in the food industry.

The literature clearly indicates that MS2 coliphage is more resistant to heat than poliovirus (type 1) and various other enteroviruses. This is a critical finding that allowed for the Title 22 research to be performed with the nonpathogenic MS2 coliphage as a conservative surrogate for virus, with 4-log reduction of MS2 coliphage equivalent to the California-mandated 5-log reduction in poliovirus. The literature also demonstrates that coliform bacteria are less resistant to heat than enteroviruses. This second finding

Figure 1. Pasteurization system



demonstrates that the disinfection of an indicator organism does not always correlate to disinfection of a target pathogen.

The literature is mixed with respect to the relative impact of contact temperature and time. Some organisms, such as spore-forming and coliform bacteria, require contact times greater than 10 minutes at temperatures higher than 63°C (145°F). Viruses require higher contact times (at least 14 minutes) at temperatures of 71°C (160°F) but very short contact times (30 seconds) at 85°C (185°F) to attain complete disinfection. Protozoa are completely destroyed by pasteurization at temperatures of 70°C to 72°C (158°F to 161°F) at short contact times of less than 20 seconds.

Original research. The original research examined the relative impact of temperature variation, contact time variation, and wastewater quality.

Initially, 36 tests were conducted to determine the reduction in total coliform bacteria over a range of contact times (from <2 to 32 seconds) and temperatures of 52°C to 78°C (125°F to 173°F) on filtered secondary effluent. A statistical evaluation performed on the data set indicated that contact time was not a

Figure 3. Effect of temperature on reduction of MS2 coliphage

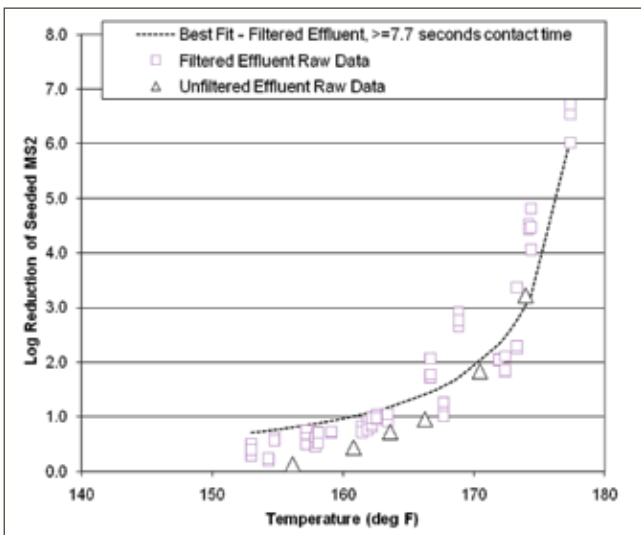
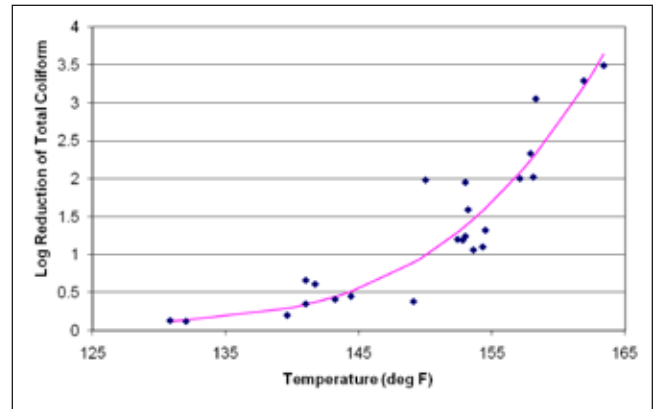


Figure 2. Effect of temperature on reduction of total coliform bacteria



significant variable within the range of times tested. Thus, within a contact time window of 8 to 32 seconds, only temperature affects disinfection of total coliform bacteria (see Figure 2, above).

Next, 18 tests were performed to determine the reduction in MS2 coliphage (the conservative virus surrogate) over a range of contact time (from <2 to 28 seconds) and temperatures ranging from 64°C to 78°C (148°F to 173°F) on filtered and unfiltered secondary effluent. A statistical evaluation performed on the data set indicated that contact time was a significant variable within the range of times tested, with times greater than 8 seconds required for virus disinfection. Interestingly, the results show that virus disinfection appears to have two-phase disinfection kinetics (see Figure 3, below).

Of critical importance to this project is the temperature required to result in proper virus disinfection – in this case, the temperature required to attain 4-log reduction of MS2. This temperature, based upon the results in this report, is 80.2°C (176.4°F), rounded up by CDPH to 82°C (180°F). The lowest contact time associated with this high-level disinfection is 7.7 seconds, rounded up by CDPH to 10 seconds.

In an attempt to address the question of water quality impact on pasteurization, the research team changed the water influent to the pasteurization pilot from filtered effluent to unfiltered effluent (see table, p. 45). Clearly, the water quality of the filtered effluent far exceeds the water quality of the unfiltered effluent.

A plot of the total coliform disinfection results in the unfiltered secondary effluent as a function of temperature is shown in Figure 4 (below). While one could argue that the unfiltered pasteurization

Figure 4. Total coliform disinfection results

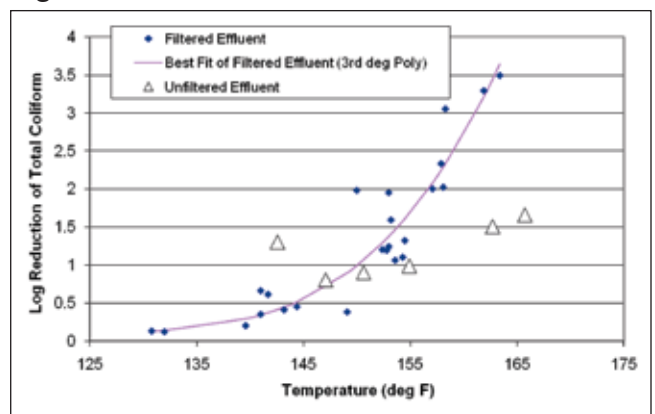
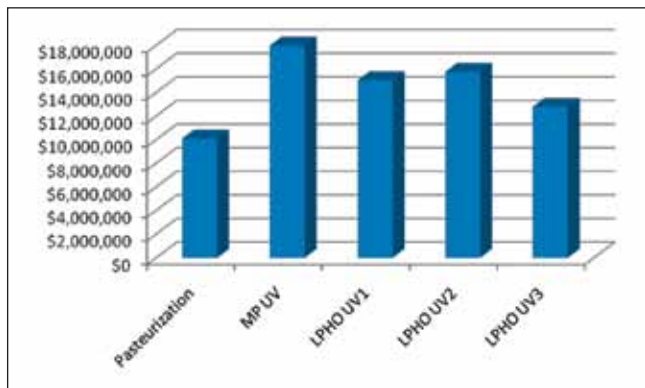


Figure 5. Net present worth for pasteurization and UV systems



UV = ultraviolet. LPHO = low-pressure, high-output. MP = medium-pressure.

results are within the variability of the filtered pasteurization results shown in Figure 2, it is more likely that there is some impact of water quality on pasteurization efficiency. UV disinfection effectiveness and efficiency is affected by suspended particles in wastewater and UV transmittance (UVT). Likewise, chlorine disinfection is affected by suspended particles, such nutrients as ammonia, and various organics. This impact can be readily quantified at future pasteurization sites through a limited bioassay.

Economics

The economics of pasteurization have been evaluated at numerous sites nationally. For the majority of these sites, pasteurization has been shown to be the lowest-cost system.

For example, the Ventura Water Reclamation Facility (VWRF) analysis is based upon an average flow of 45,000 m³/d (12 mgd) and a peak flow of 79,000 m³/d (21 mgd), with disinfection to California's tertiary recycled-water standard. Both UV and pasteurization disinfection were evaluated as potential replacements for chlorination/dechlorination at VWRF. General evaluation criteria included an energy cost of \$0.11/kWh, a labor rate of \$50/h, a duration of 20 years, and an inflation rate of 4.5%. For each process, one full train of redundancy is provided.

The running average for wholesale natural gas during the last 33 years is \$2.66 per million kJ (\$2.81 per million Btu). For this project, a conservative natural gas cost of \$4.27 per million kJ (\$4.50 per million Btu) is assumed.

Pasteurization design

The pasteurization research demonstrated that contact time was not a critical parameter for coliform disinfection but was critical for virus

disinfection. For sufficient virus kill, the contact time has been set by CDPH at a minimum of 10 seconds. For nonreuse applications, this contact time can be dropped to 8 seconds or less. The pasteurization research demonstrated a repeatable temperature response for disinfection of both bacteria and virus. For sufficient virus kill, the temperature has been set by CDPH at a minimum of 82°C (180°F). For nonreuse applications, this temperature can likely be dropped to 74°C (165°F) or less to meet coliform bacteria values.

For the VWRF evaluation, the waste heat could come from the combustion of either digester gas or an imported energy source. As this analysis shows, importing natural gas and burning it in turbines results in the generation of both electrical energy and waste heat for disinfection at a cost well below UV disinfection. Substituting digester gas for the natural gas further reduces costs.

For VWRF, the reactor has numerous possible designs. In the first design, natural gas would fuel a single turbine, providing 1.06 MW of power and the heat for disinfection of 53,000 m³/d (14 mgd). Less-expensive gas burners then would be used to create the additional heat to treat the remaining flow up to the peak of 79,000 m³/d (21 mgd). A second design has higher energy production (1.45 MW) and does not require the gas burners. In this design, the turbine will be using the digester gas along with the natural gas to create energy, with the excess heat going to disinfection of the wastewater. For both designs, a redundant flare is provided during emergencies or for regular maintenance of the turbine. The benefit of both designs is that most or all of VWRF's power needs can be met using the power from the turbines.

UV comparison

The project team compared the performance of the pasteurization system to four UV-disinfection systems. The UV systems were sized to meet the mandated dose of 100 mJ/cm² for tertiary recycled-water applications. The sizing also incorporated a design UVT value of 65% and an operational UVT of 70%.

The net present worth for the various UV systems and pasteurization is shown in Figure 5 (above). The costs of pasteurization will likely come down further, based upon a number of factors, such as the use of digester gas in combination with natural gas. In general, pasteurization was shown to be substantially less expensive than all of the UV systems analyzed, with an income of \$162,000/yr from operating pasteurization, as opposed to an expense of more than \$320,000/yr for operating UV disinfection. Because of these potential savings, Ventura and the Pasteurization Technology Group are now building a 1900-m³/d (0.5-mgd) pasteurization demonstration reactor, with assistance from Carollo, for a long-term performance demonstration.

Comparison of unfiltered effluent and filtered effluent BOD, turbidity, and TSS

Water quality	BOD, mg/L	Turbidity, NTU	TSS, mg/L
Filtered secondary effluent (average of 6 different testing days)	<2	<2	<1.5
Unfiltered secondary effluent (single sample)	7	3.8	7.9

BOD = biochemical oxygen demand.

NTU = nephelometric turbidity units.

TSS = total suspended solids.

Andrew Salvesson is water reuse chief technologist and wastewater disinfection principal technologist, and **Nitin Goel** is a project engineer in the San Francisco office of Carollo Engineers (Walnut Creek, Calif.). **Greg Ryan** is an entrepreneur and CEO of the Pasteurization Technology Group (San Leandro, Calif.).

The authors would like to thank the staff at the Laguna Subregional Water Reclamation Facility (Santa Rosa, Calif.) for their substantial assistance on this project.