

By Joe Fleck &
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MOVING FORWARD *in Filling*

*Feed forward
ozone control optimizes
spring water filling*

Virtually all bottled water utilizes ozone technology in some way during the makeup and bottling processes. Ozone, the triatomic form of oxygen (O_3), is formed naturally during lightning storms and by ultraviolet radiation in the upper atmosphere. Ozone is produced commercially by corona discharge and other technologies. A powerful oxidizer with twice the oxidizing potential of chlorine bleach, ozone is replacing traditional chemical oxidants in a number of commercial processes in industries around the world.

Bottled water is one of the most mature and widespread commercial applications for ozone; it is used broadly in makeup water purification, bottle and cap washing and final filling. A low concentration of ozone is dissolved into the makeup water at final bottling, providing final sanitation and extending the shelf life to about two years. Ozone dosing also fulfills a “polishing” function that eliminates tastes and odors that occur naturally in some spring waters.

Final bottling of spring water requires tight control of the concentration of ozone to ensure a consistent balance between sanitation and bromate formation. The ozone dose and contact time must be sufficient to completely disinfect the product during bottling. However, the ozone dosing parameters must be controlled to minimize conversion of bromide ions to bromate. Under certain conditions, naturally occurring bromide ions may be oxidized by chlorine, ozone and other oxidants to bromate, a suspected carcinogen.

Factors Impacting Ozone Concentration

Maintaining tight control of ozone dosing during final bottling presents unique challenges. Variables that impact the concentration of dissolved ozone include water temperature, flow

rate, ozone generator output and mass transfer efficiency.

Water temperature. The stability of dissolved ozone varies with water temperature; it is more stable at lower water temperatures. Seasonal and daily fluctuations in the temperature of the makeup water will impact concentration.

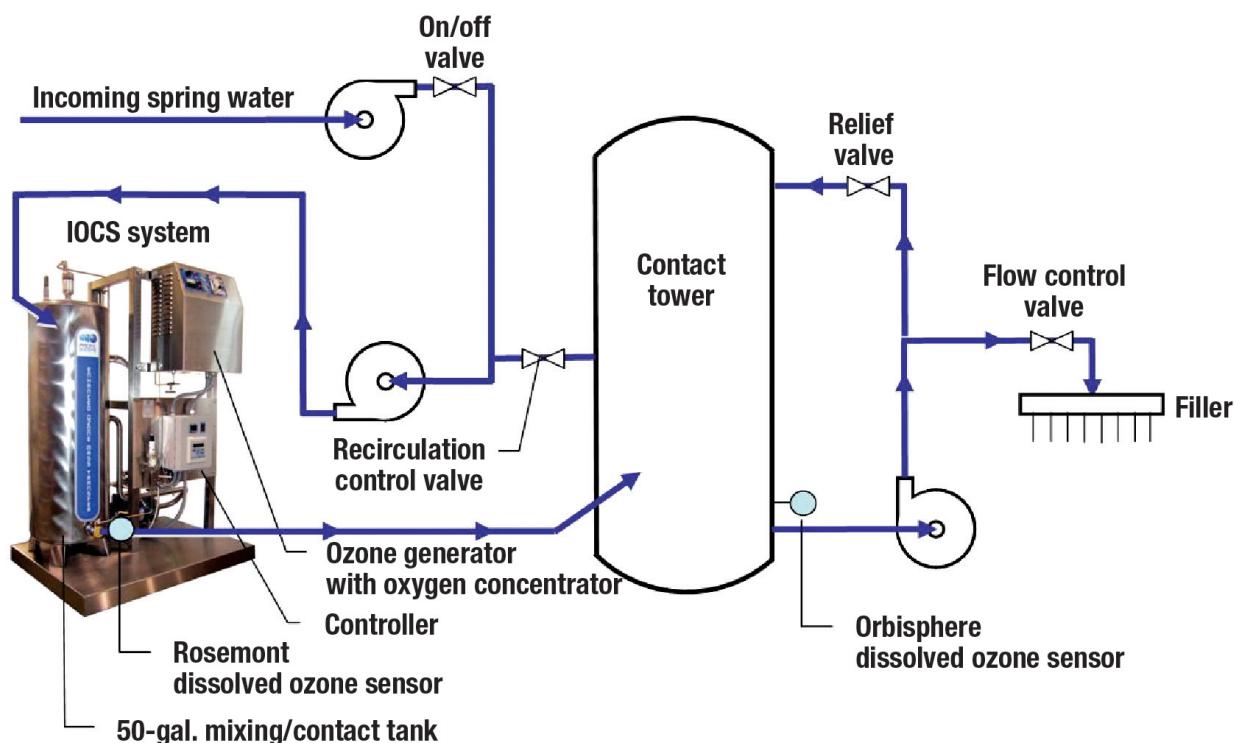
Water flow rate. The flow rate of the bottling process may be impacted by changes in pump velocities due to voltage fluctuations, as well as changes to pump parameters in the variable frequency drive that controls the pump motors. The flow rate may also be influenced by changes in water pressure that result from changes in the contact tank’s water level.

Ozone generator output. Changes in the electrical power, ambient temperature and air flow impacts the output of the ozone generator. Changes in the voltage applied to the ozone reactor cell influence the intensity of the electrical corona discharge. The flow of oxygen in the ozone reactor cell may vary due to fluctuations in the pressure of the source air or by contamination of the oxygen concentrator with oil or water. These factors influence the rate of conversion of oxygen (O_2) to ozone, thereby modulating the output of the ozone generator.

Mass transfer efficiency. Venturi injectors are typically employed to integrate the ozone gas into the makeup water. This process is generally 90% efficient as long as the pressure drop across the venturi is sufficient to draw the ozone gas into the water at a rate equivalent to the production of the ozone gas from the generator. If the rate of suction from the venturi is lower than the ozone gas production rate, a portion of the gas is forced through the venturi by pressure from the reactor cell and forms relatively large bubbles. The ozone in these bubbles will not dissolve into the makeup water. Rather, the undissolved gas collects in the head space of the contact tank and is periodically vented through a catalytic destruct at the top, which safely converts the ozone back to elemental oxygen before returning to the atmosphere.

Changes in the water level in the contact tank, which might result from tank filling in conjunction with water level sensors, cause fluctuations in the venturi exit pressure, eventually impacting mass transfer efficiency and the resulting concentration of dissolved ozone.

FIGURE 1. Ozone system for spring water filling line with feed forward control.



Spring Water Bottling Line

Pacific Ozone Technology recently developed an integrated ozone contact system (IOCS) for dosing ozone on a spring water filling line.

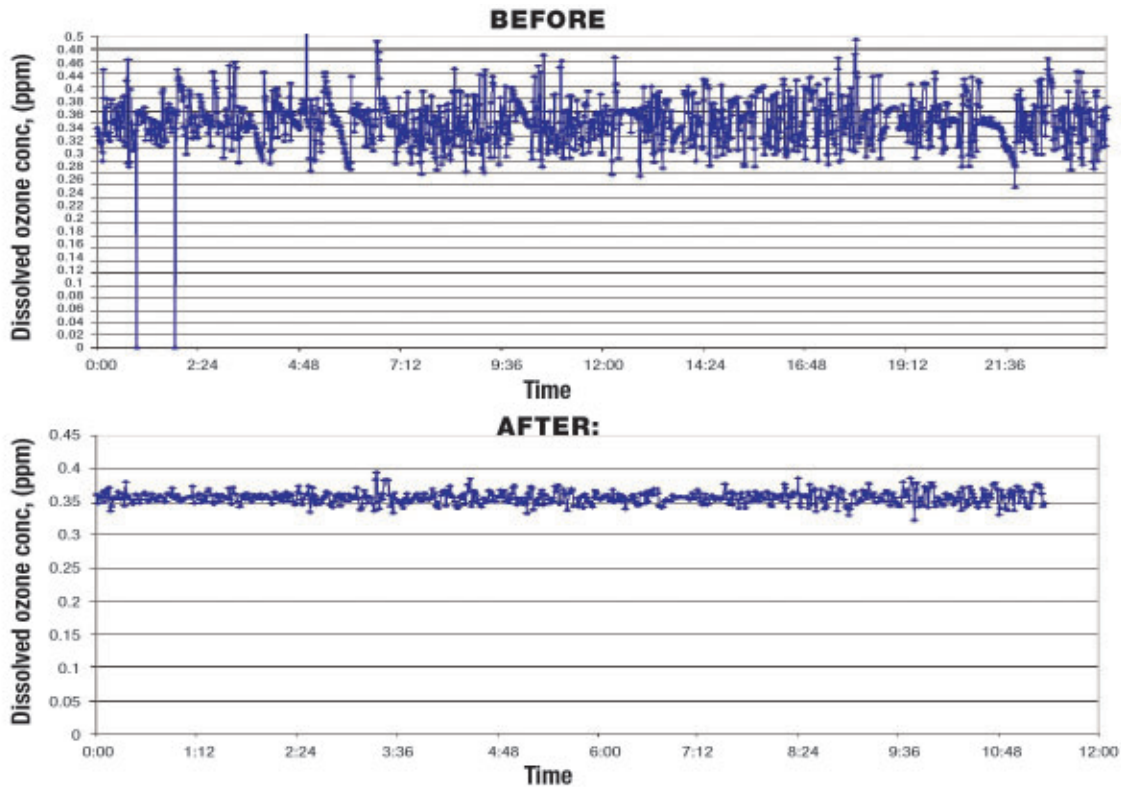
The system is diagrammed in Figure 1 and includes the following:

- Pacific Ozone IOCS05 integrated ozone contact system: This is built around a Pacific Ozone SGA21 ozone generator with a built-in oxygen concentration and ozone reactor cell capable of producing up to 1 lb of ozone gas per day at water flow rates up to 120 gal per minute (gpm). This skid-based system includes enhanced mass transfer (EMT) technology with venturi injector, recirculation pump and a stainless steel contact tank. The 50-gal contact tank serves as a mixing tank and reaction vessel with final contact provided by the client's contact tower. All ports are carefully positioned to optimize contacting and mixing and to prevent short-circuiting. Control is provided through the
- advanced DirectDrive process controls. The DirectDrive system integrates EMT technology with dissolved ozone sensors, liquid flow/pressure monitors and controls, ambient ozone gas detectors and valve position indicators using programmable logic controller-based process control. The entire process is controlled and monitored through touch-screen display.
- Stainless steel contact tower.
- Four process pumps. A pump mounted on the IOCS system provides motive flow for the injector. Other pumps direct product water from the client's contact tower to the IOCS contact system, transfer incoming spring water to the IOCS contact tank and deliver product water from the outlet of the client's contact tank to the filling equipment.
- A Hach Orbisphere model 313XX O₃ electrochemical sensor monitors the ozone concentration at the outlet of the client's contact tank.

The client's goal was to deliver the final product to the filling line with a dissolved ozone concentration of 0.36 to 0.40 parts per million (ppm) for a final target concentration of 0.15 to 0.20 ppm in the bottle. The client also specified that the variation in ozone concentration from the input to the filling line be limited to $\pm 10\%$ of the set point, a stringent ozone control requirement. The client further required that replicate systems provide consistent operation across several bottling lines and over a range of bottle sizes, including 1.5 L, 500 mL and 250 mL. This required the ozone contacting system to adapt to changes in bottle sizes and system flow rates.

Filling half-liter bottles on the initial filling line presented a challenge because it demanded a high flow rate of ozonated product water in conjunction with a relatively small existing contact tower. In contrast, filling smaller bottles or filling at lower flow rates dramatically reduces overall system flow rates. Lower flow rates result in higher system stability

FIGURE 2. The benefits of feed forward control are shown in the before and after plots of the ozone concentration recorded by the Orbisphere.



and longer contacting because smaller proportions of the overall capacity of the contact tank are required to meet the demands of the filling line.

Regardless of the volume and flow rate requirements, this application would be impossible to control with standard proportional integral derivative (PID) control systems because PID phase lag and the nonlinear response of the ozone dosing system. The PID phase lag results from the delay associated with calling for a change in the process and then measuring the effectiveness of that change.

The phase lag in this application is significant because of the distances resulting from the placement of the ozone generator, injector, contact tank, contact tower, associated plumbing and the process control monitoring device.

Nonlinearity in the dosing response results from the influences of the factors affecting the concentration of ozone. For example, while the PID algorithm may signal for a 10%

increase in ozone production from the generator, the myriad of factors affecting the eventual change in the concentration of dissolved ozone may be more or less than the prescribed 10% increase.

Feed Forward Control

The limitations of traditional PID control were overcome with a feed forward control system. The primary process control system administers ozone dosing instantaneously based on the requirements, the ozone concentration setpoint and the flow rate of incoming spring water. The primary control system monitors the dissolved ozone concentration delivered to the filler input line as measured by the Orbisphere and the feed forward signal, an on/off signal for the input of spring water at a fixed flow rate. These signals are fed to the PID algorithm of the primary controller, which compensates for process variables such as ozone generators, water conditions and pump speeds. The resulting output signal from the primary is fed to the secondary nested loop control.

Critical Factors

Several critical factors that may impact the stability of the control system must be considered to ensure the success of the overall ozone dosing and filling process:

Contact tower size, shape & design.

A well-designed contact tower provides a balance between the need for retention time and the good mixing necessary for ozone control stability. Careful consideration must be given regarding the placement of entry and exit ports and contact tower height and width proportions. These design parameters affect timing values associated with PID phase lag.

Filler flow demand. Contact tower capacity is a function of filler demand. Tower capacity should be five times that of the maximum filler feed rate as stated in gpm.

Contact tower "flywheel effect."

The contact tower adds dynamic stability, or stiffness, by absorbing influxes of water of varying ozone concentrations. The larger the contact tank volume with respect to water flow rates, the longer it takes to effect change to contact tank

ozone concentration.

Pump circulation rates. Because phase lag is caused by delays associated with the delivery, mixing and detection of ozonated water, careful consideration must be made regarding the sizing of pumps, piping lengths, component placement and contact tower design.

Dissolved ozone probe location. The dissolved ozone sensor system provides two important functions: It provides the primary control, input for process control and monitors the ozone concentration of the finished product—the water being delivered to the filler.

System running dry. As the contact tower level begins to fall as a result of running out of water, ozone control becomes unstable. Running the system dry will damage the pump seals. A contact tower low-level sensor signal sent to the process controller offers protection.

Contact tower water pressure. Electrochemical dissolved ozone sensor probes are sensitive to water pressure variation. Contact tower level sensors are necessary for the accuracy required by this application.

Results of the System

The results of the feed forward control system are shown in Figure 2. The plots of the concentration of dissolved ozone recorded by the Orbisphere sensor demonstrate the benefits of feed forward control. Before the implementation of the control system, the Orbisphere recorded broad swings in the concentration of dissolved ozone. Tighter control of ozone concentration, well within the client's requirement of $\pm 10\%$, resulted after implementation of the feed forward control system. *bw*

About the Authors

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