A Method to Reduce Adverse Gassing Effects in Hypochlorite Pumping Systems

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This article discusses a unique method to reduce adverse gassing effects in hypochlorite pumping systems, which delivers disinfectant to various water and wastewater treatment processes. The heart of this method is a peristaltic recycle pump installed in the feed pump suction that's downstream of the feed pumps. In use for several years, this installation has almost completely eliminated adverse gassing effects that often plague hypochlorite pumping systems. Adverse gassing effects include air binding, erratic feed pump output, and potentially dangerous buildup of high pressure in closed piping segments.

Water Chemistry of Gassing

In an aqueous solution, the relevant equations are:

$NaOCl + H_2O => HOCl + NaOH$ (1)

$HOCl => H^+ + OCl^-$ (2)

Where: NaOCl = sodium hypochlorite, H_2O = water, HOCl = hypochlorous acid, NaOH = sodium hydroxide, OCl^- = hypochlorite anion

As it pertains to disinfection, Equation (2) is of particular interest. As a function of pH, hypochlorous acid, a strong disinfectant, is in equilibrium with hypochlorite anion, a weak disinfectant. At a pH of 7.3, the two substances are about equally present. As pH increases, disinfection power decreases due to the hypochlorite anion predominating.

Sodium hypochlorite solution loses it strength by two decomposition pathways: chlorate ion formation and oxygen formation. The latter is the source of gassing.

The decomposition reaction is:

$OCl^- + OCl^- => O_2 + 2Cl^-$

Where: OCl^- = hypochlorite anion, O_2 = gaseous oxygen, Cl^- = chloride anion

Although the cited reaction is slow, it's catalyzed by the presence of certain transition metals, such as nickel (Ni^{+2}), copper (Cu^{+2}) and cobalt (Co^{+2}), that are present during the hypochlorite solution manufacturing process. As expected, decomposition increases with higher hypochlorite concentration and higher temperature. The latter is especially significant in Florida's high ambient temperatures.

In the presence of ultraviolet (UV) light, hypochlorite solution will also decompose to oxygen gas and chlorate ion, but this pathway is minimized and even prevented by constructing storage tanks of materials, such as fiberglass pipe (FRP), that do not transmit UV light.

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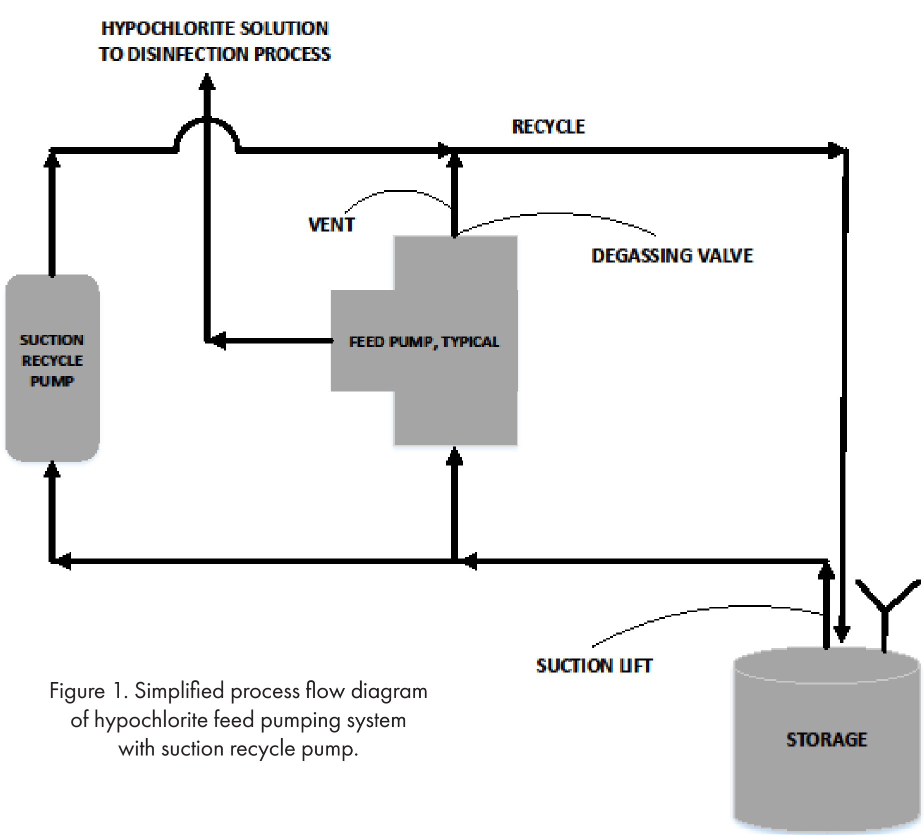

Figure 1. Simplified process flow diagram of hypochlorite feed pumping system with suction recycle pump.

Design Practices to Reduce Effects of Off-Gassing

Miller provides a thorough primer on how to design sodium hypochlorite feed systems, including advice on how to mitigate off-gassing. To prevent metal-catalyzed off-gassing, the installation of metallic components should be avoided, even for such small items as ball check spring valves and hose fittings. Diaphragm-type isolation valves are preferred. If ball valves are used, they can trap the off-gas, which can lead to high pressure and valve rupture. To prevent this, a hole that vents to the upstream side is drilled in the valve ball.

To partially reduce air binding of the pumps, the suction line should be upwardly sloped from the storage tank to a suction line vent that's usually located just prior to the pump skid. This vent is normally routed back to the storage tank. Other guidance is to keep the piping length between the pump and the application point as short as possible. Specifics include a maximum piping run of 500 ft, or a maximum detention time of four hours in the feed pipe. Pipe velocities should be kept as high as possible, but under 5 to 7 ft per second (fps). Such high velocities will tend to sweep oxygen bubbles along with the feed, minimizing accumulation.

Hydraulic diaphragm pumps are commonly used, but can be subject to air binding. If compatible, installing a "degassing" vent valve on the pump head is recommended. To prevent excessive agitation of the hypochlorite solution, low-speed and high-stroke settings are preferred over high-speed and low-stroke settings.

Hantelman and Zahller documented their commissioning of a sodium hypochlorite feed system, which is part of an advanced disinfection system that treats water supply from a reservoir. The system consists of two sodium hypochlorite solution storage tanks, three peristaltic pumps, and a carrier water system, which conveys the hypochlorite solution to a 30-in. water supply line.

During start-up, they observed the chlorine residual of the process water and attributed its erratic behavior to "air" (most likely oxygen gas) in the system. They iteratively tinkered so as to make the chlorine residual more stable.

For the first iteration, they plumbed the suction side to the vent (universally considered good practice) and disconnected the pressure relief line. Although improvement was achieved, it was insufficient.

For the next iteration, they made a concerted effort to remove locales where gas would accumulate and erratically discharge. This included removing horizontal pipe, removing the strainer, installing vertical wye fittings, and bypassing the flow switch. The chlorine residual was much smoother, but there was still room for improvement.

For the final iteration, the discharge pressure back pressure valve, a source of an erratic air pocket, was bypassed. The carrier water was also routed to the hypochlorite panel, reducing the length of the pipe that contains the concentrated hypochlorite solution. The chlorine residual was now stable—smooth and with no spikes.

The Plant Experience

The Water Treatment Plant

The City of Alachua (city) is located in north central Florida, has a population of about 10,000, and is the home of several burgeoning high-tech parks. The city operates its own water utility, and is fortunate to have a high-quality water supply. Three well pumps, the largest being 950 gal per minute (gpm), provide water to the treatment plant, where sodium hypochlorite solution is injected. After sufficient contact time, accomplished in two contact tanks, the treated water is ready for distribution. Required discharge pressure is typically 85 to 90 pounds per sq in. gauge (psig), which is relatively high for Florida, due to over 100 ft of elevation change within the distribution system.

Initial Installation and Start-Up Difficulties

The installed sodium hypochlorite feed system consists of three subsystems:

- Storage tanks and suction piping
- Pump skid
- Discharge piping

Nominal 12 percent sodium hypochlorite solution is stored in two 250-gal polyethylene storage tanks. These tanks are located outdoors under an overhang and thus away from direct UV light. The tanks are within 10 ft of the indoor pump skid. The ¼-in. nominal-diameter Teflon suction tubing enters through the top of the tank and is furnished with a filter/foot valve near the tank bottom. A larger vertical polyvinyl chloride (PVC) pipe within the tank simply holds the tubing in place.

Inside the skid room, the tubing transitions to a nominal ½-in.-diameter PVC pipe that connects to the skid, and suction is not flooded. Depending on the tank level, some suction lift is required of the feed pumps. There is no provision for a suction connection to the vent just prior to the pump skid. The suction piping routing may not be conventionally considered as ideal; however, vertical tank entry precludes the need for bulkhead fittings at the bottom side of the each tank. Such bulkhead fittings are a common source of leaks.

The sodium hypochlorite feed skid includes three solenoid-driven feed pumps that are doubly redundant. Although one pump is sufficient to supply the required solution, three pumps generally operate together at lower speeds. If one pump fails, the hypochlorite solution output from

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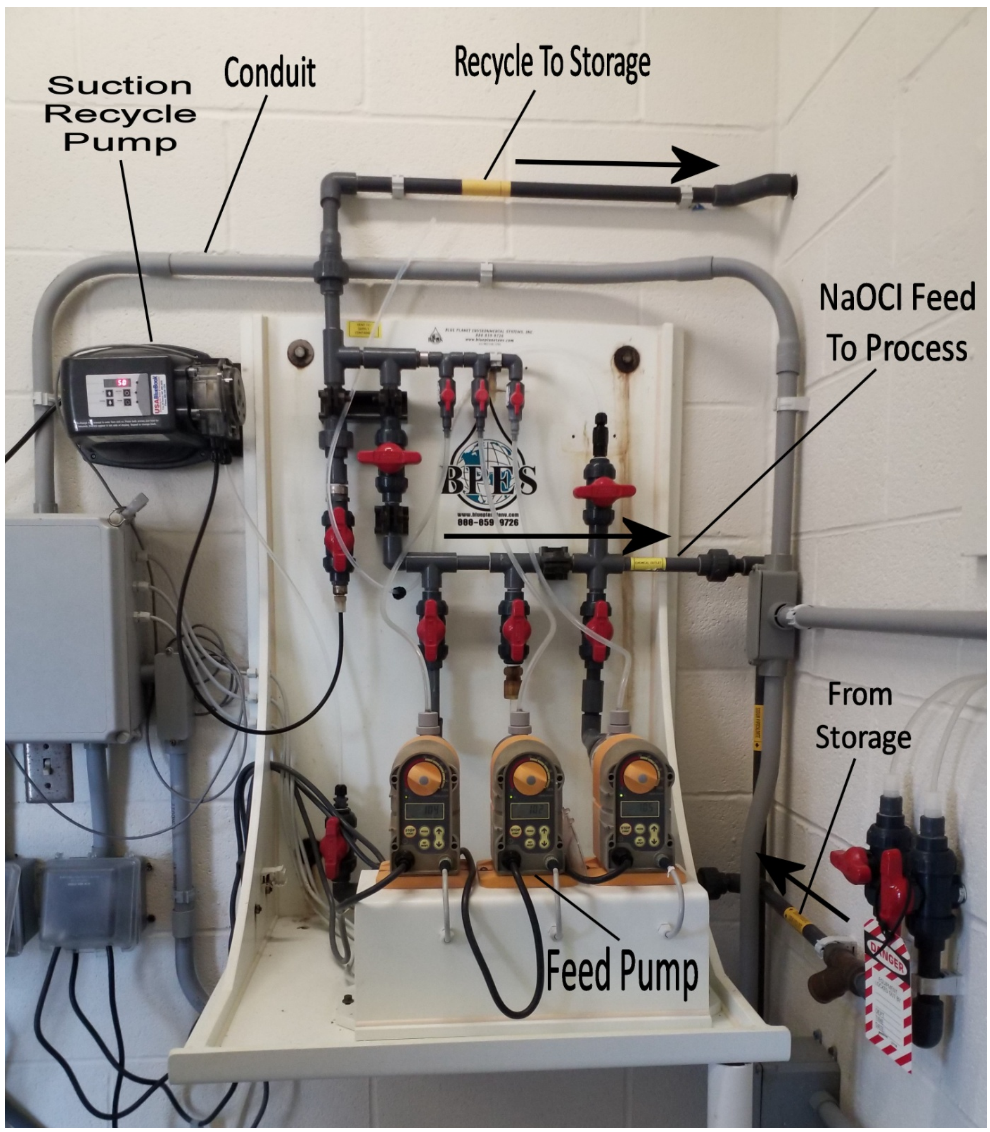

Figure 2. Hypochlorite feed pump skid and suction recycle pump.

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the skid is only reduced by 33 percent, which still maintains an acceptable dosing rate until repairs can be made. The capacity of each pump is 0.95 gal per hour (gph). Pump controls include speed and stroke adjustment; usually, stroke is kept at 100 percent. Open-loop flow pacing of pump speed is the normal control mode.

Each pump has been furnished with a degassing valve that vents back to the storage tanks. Solenoid-driven pumps, rather than hydraulic diaphragm pumps, were selected because required discharge flows are low and the required discharge pressure is high. This application is quite suitable for solenoid-driven pumps, and such pumps include an electromagnet that switches on and off, imparting stroke movement to the diaphragm head.

The discharge pipe is made of ½-in. PVC piping and is about 60 ft long. It connects to a feed quill inserted into the process pipe.

During start-up, it soon became evident that feed pumping was problematic as gas binding of the pumps frequently occurred and pump output was erratic. It was obvious that gassing in the suction line was the culprit.

The Modified System

See Figures 1 and 2 for a simplified process flow diagram and a photo of the modified system.

To remove the unwanted gas, the city's water system supervisor hypothesized that a pump installed on the downstream suction line, and its discharge recycled back to the storage tank, would be effective. The concept is that increasing suction header velocity would increase fluid dynamic drag so that gas bubbles would move along with the liquid flow. This recycle pump also has the advantage of providing additional suction lift.

The selected recycle pump is the peristaltic type, which is suitable for pumping liquid/gas mixtures. Such a pump includes flexible tubing with a rolling mechanism that imparts pumping action to the liquid air mix. Required discharge pressure is low, another point in favor of a peristaltic pump. The capacity of the recycle pump is 1.67 gph at a discharge pressure of less than 2 psig.

After commissioning the recycle pump, the appearance of visible gas bubbles was greatly reduced in the suction piping. More importantly, the sodium hypochlorite solution pumped output is stabilized, and continues to be so. Air binding and erratic pump behavior are now a thing of the past.

The initial nonflooded suction piping configuration has not been changed, as it doesn't impact successful pump operation and is not a source of tank leakage.

Typical Pumping Parameters

A typical treated water flow rate to the distribution system averages around 925 gpm. The associated sodium hypochlorite solution flow rate is approximately 0.5 gph, resulting in a chlorine residual on the order of 1.0 mg/l. Each feed pump delivers about a third of the total output, with a pump speed of about 80 to 100 strokes per minute and a stroke length of 100 percent. The suction recycle pump operates at 50 percent speed to deliver a flow rate of about 0.835 gph.

Flow rates entering and exiting the suction header are 1.335 and 0.835 gph, respectively, with feed pump takeoff accounting for the difference. With an actual suction header diameter of 0.526 in., flow velocities entering and exiting the suction header are 0.033 and 0.021 fps, respectively. Velocity in the recycle line is 0.36 fps, due to an actual inner diameter of only 0.125 in. for the nominal ¼-in. Teflon tubing. Although this suction recycle flow rate has been found to work, it's not necessarily the optimal flow rate.

Daily Degassing Protocol

Upon daily check of the sodium hypochlorite feed system, staff will increase the speed of the peristaltic recycle pump to 100 percent, or 1.67 gph, for about one to three minutes to increase pipe velocity and purge the suction manifold. This, in turn, increases fluid dynamic drag so as to clear any stubborn gas bubbles that may get lodged in a fitting, strainer, or other high-friction areas within the suction piping. Typically, staff will initially observe rapidly moving bubbles in the clear ¼- in. Teflon line directly connected to the peristaltic pump intake.

Once no bubbles are seen for at least 15 seconds, pump speed is reduced back to its normal 50 percent setting. Particularly effective in dislodging bubbles is closing the suction line for several seconds between the tank and the skid. The increased efficacy is likely due to the increased line suction.

In the event of a random gas binding issue, this procedure can be repeated, which clears the feed pump intake much faster than the degassing valve on the feed pump itself. This eliminates most, if not all, of the downtime during such an event.

Why not continuously recycle at 100 percent speed? Staff is of the opinion that running at only 50 percent speed during normal operations will extend the life of the pump tubing.

Discussion and Conclusions

A literature review of air in pipelines concludes that "there are no generally accepted formulae for the transport of air bubbles or pockets in pipelines and there is wide variation between the various prediction equations."

Corcos has authored a manual that emphasizes air removal in water pipes, which is of particular concern for gravity rural drinking water systems. He presents an equation that applies to air pockets that are long compared to pipe diameter, but not to bubbles. This equation calculates a critical velocity, above which the air pocket begins to move in a horizontal pipe. In this equation, the critical velocity is proportional to pipe diameter to the 2.5 power. The equation constant assumes the liquid to be water and includes factors for both surface tension and the velocity profile, including the Reynolds number. At the higher supercritical velocity, air will definitely be swept along with the liquid. For ½-in.-diameter pipe, the supercritical velocity is about 0.6 fps.

In the ½-in. hypochlorite suction manifold, velocities range from 0.01 to 0.05 fps, the latter being the purging velocity with the suction recycle pump at full speed. Thus, the velocities typically experienced in the suction manifold are at an order of magnitude less than the supercritical velocity mentioned previously. It was concluded that the supercritical velocity predicting when stationary air pockets begin to move in pipes does not seem to apply here.

The Reynolds number characterizes whether a fluid is either in that laminar, transition, or turbulent flow regime. Below 2300, flow is laminar; above 4000, flow is turbulent. Knowing that the kinematic viscosity of 12 percent hypochlorite solution is 1.27 centistokes (cSt), the Reynolds number in the ½-in. suction manifold can be calculated for the maximum velocity purged condition (2.17 gph). For this condition, the Reynolds number is only 152, meaning that laminar flow is present over the entire flow regime.

Operations staff is very pleased with the top-entry suction lift piping configuration, and has no plans to change it. As for the feed pump skid itself, several improvements are recommended. For the suction manifold, it's suggested to provide a slight upward slope in the direction of flow, which will encourage gas to exit the system. As it's now constructed, takeoff from the suction manifold to each feed pump is via a tee with a horizontal branch; instead, it's suggested that the tee be installed in the manifold so its branch is vertically downward.

The suction (and recycle) lines consist of mostly horizontal and opaque PVC piping, and mostly vertical and translucent Teflon tubing, which is fortuitous as it allows the operator to visually observe bubble movement. Installed in the horizontal pipe is a filter with a clear plastic housing, which also allows viewing of bubble formation and removal. If bubble formation is anticipated in a to-be-installed hypochlorite feed system, it's suggested that at least a portion of the suction piping be made of either translucent of transparent material to aid in diagnosing the extent of problematic bubbles.

Recycling sodium hypochlorite solution from the suction header back to the storage tanks effectively removes the oxygen off-gas from the solution. Air binding of pumps and erratic pump output has been greatly reduced, making it almost a thing of the past. Recycling does introduce a degree of mechanical complexity to the system, as an additional pump is required.

Although this suction recycle approach has been developed for nonflooded (suction lift) supply, it's expected to also be applicable for flooded suction configurations. Where lift is required for the hypochlorite solution suction, note that it's not permissible to install a vent in the suction line just prior to the skid; otherwise, the suction prime will be lost.

For flooded suction systems, a vent on the suction line just prior to the skid is recommended if the layout allows. As noted by Hantelman and Zahller, such a vent helps to degas, but does not completely eliminate gassing. Installing a recycle pump on the downstream end of the skid's suction manifold could further degas the system.

As noted by Corcos, the supercritical velocity to cause movement of a long air pocket in a horizontal water line is 0.6 fps. As stated, velocities in the ½-in. suction manifold are an order of magnitude less; note, though, that certain segments of the suction line from the tank to the skid consist of ¼-in. Teflon tubing (⅛-in. internal diameter [ID]). Similarly, the recycle line from the skid to the recycle pump, as well as the pump discharge line, consists of the same ⅛-in. ID-size tubing. Under a typical feed rate, and with the recycle pump at its purge velocity, flow rates entering and exiting the skid are 2.17 and 1.67 gph, respectively. Corresponding velocities in the associated ⅛-in. ID tubing segments are 0.94 and 0.73 fps, respectively. Such velocities exceed the supercritical flow rate to move long air pockets. This is considered a coincidence, as the ½-in-diameter suction manifold is the salient pipe segment for bubble behavior.

The recycle suction pump method should seriously be considered to mitigate off-gassing effects, especially if other methods are not sufficiently effective. The recycle suction pump method provides the designer with another tool to address the sometimes quite frustrating effects of sodium hypochlorite solution off-gassing.

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