

The Use of Phosphates For Potable Water Treatment

The Phosphate Forum of the Americas has prepared this document as an educational resource for the general public.

I. Introduction

Phosphates have many uses in the treatment of potable (drinking) water. They are used to prevent "red" (from iron) and "black" (from manganese) water; to prevent and/or retard scale formation (from minerals depositing) and corrosion (from low pH and/or dissimilar metals) in the water distribution system; and to reduce soluble lead and copper in potable water delivered to the consumer's tap.

The Environmental Protection Agency (EPA) administers the Safe Drinking Water Act (SDWA), which provides for the enhancement of the safety of public drinking water supplies through the establishment and enforcement of nationwide drinking water regulations. Congress gave the primary responsibility for establishing regulations to the U. S. Environmental Protection Agency (EPA). Until 1990, EPA administered a certification process for chemicals, including phosphates, to be used for potable water treatment.

In 1990, the National Sanitation Foundation International (NSF) assumed responsibility for the total certification process. The process involves several steps. The toxicology database and impurity profiles are thoroughly reviewed by NSF's toxicology staff. NSF then audits all manufacturing locations. Samples are taken and analyzed to confirm impurity data submitted on certification applications. Raw materials used in the process are verified against submitted lists and any gaps must be filled. The raw material suppliers are also required to submit detailed information similar to the product application.

II. Selected Properties of Phosphates for Potable Water Treatment

This section discusses the selected properties of phosphates that make them suitable as additives for potable water treatment.

A. Sequestration

Sequestration is a chemical combination of a chelating agent and metal ions in which soluble complexes are formed. Hardness ions are metal ions commonly found in water and include calcium and magnesium. Sequestration is dependent upon pH; a given sequestrant works best in a particular pH range. Sodium hexametaphosphate (SHMP) performs very well at neutral pH ranges, while pyrophosphates and polyphosphates work best under alkaline conditions.

B. Threshold Activity

Many polyphosphates can accomplish the desired effect at levels far below that which would seem to be required for a stoichiometric (molar equivalent) reaction. For example, water containing 200 parts per million (ppm) hardness (as calcium carbonate, or CaCO₃) would theoretically require about 500 ppm of SHMP to sequester the available calcium.

Actually, only 2-4 ppm of SHMP is typically used to inhibit scale formation. This "threshold effect" of SHMP apparently occurs by interfering with early crystal growth.

C. Deflocculation

Flocculation occurs because small dissolved particles, typically those less than 10 microns in size, tend to attract one another due to the presence of regions of positive and negative charges on each particle. These groups of particles, which clump together due to the interaction of opposite charges, form hard deposits out of a water solution. To prevent this process, threshold levels of polyphosphates are added to the water. These threshold levels of polyphosphates tend to coat the small particles and reduce their attraction to each other by changing the surface charge distribution. These coated particles tend to repel rather than attract one another – hence deflocculation. Deflocculated particles are suspended in water and show little or no tendency to settle in standing water. This property is important for the removal of existing hardness scale deposits (CaCO_3) and iron oxides.

D. Chlorine Stability

Ortho- and polyphosphates are stable in the presence of chlorine at the levels found in chlorinated potable water. There are no interactions that reduce the levels or effectiveness of either the chlorine or polyphosphate. In addition, iron and manganese sequestered as colorless complexes before chlorination will remain colorless after chlorination.

E. Hydrolytic Stability

In solution, linear polyphosphates undergo slow hydrolysis. This process continues as the shorter chain phosphates break down further to yield still shorter chain polyphosphates, metaphosphates and orthophosphates. Under neutral pH and normal room temperatures, this hydrolysis is relatively slow. At 20°C and a pH of 7, about 50% of pyrophosphate (the shortest polyphosphate) will revert to orthophosphate in 12 years. At 50°C, the half-life is reduced to two months. Generally, lower pH and higher temperatures will increase the rate of hydrolysis. Because long chain polyphosphates will break down into shorter, but still functional chains, the overall step-by-step process should be considered in estimating shelf life and product stability.

F. Safety

In 1990, the NSF assumed responsibility for a certification program involving plant inspection, raw material certification and product labeling. The NSF certification process applies to all of a company's plants and products that could be used in treatment of potable water.

III. The Use of Phosphates and Phosphoric Acid in Potable Water Treatment

Phosphates for potable water treatment perform several functions that include: iron and manganese control, scale inhibition and removal, corrosion control and chlorine stabilization.

A. Iron and Manganese Control

In ground and well waters, iron and manganese are normally present in the bivalent form (Fe^{++} or Mn^{++}), which is soluble. Upon exposure to air, the forms are oxidized to the trivalent form (Fe^{+++} or Mn^{+++}), which is both insoluble and colored. Chlorination of water containing low levels of iron results in the formation of insoluble iron oxide or iron chlorides. Insoluble iron salts are the cause of what is commonly called "red water" and can cause a reddish-brown stain on laundry, porcelain, utensils and glassware. Manganese compounds undergo similar reactions to form "black water" and can result in brownish-black stains on contact surfaces. Other heavy metals can also react with chlorine to form similar insoluble materials. The discoloration of water is considered aesthetically unappealing and levels of 0.5 mg/l of iron and 0.05 mg/l of manganese result in objectionable flavors to the water.

The use of 2-4 ppm of a polyphosphate such as sodium hexametaphosphate (SHMP), sodium tripolyphosphate (STP) or tetrasodium pyrophosphate (TSPP) before chlorination results in the formation of colorless phosphate complexes of the heavy metal and elimination of the formation of insoluble compounds. Since calcium and magnesium salts of orthophosphates are relatively insoluble, water hardness can also be reduced by precipitation. The choice of which orthophosphate to use may be based on pH requirements.

B. Lead and Copper Removal

Lead and copper are found in drinking water largely due to leaching from piping and plumbing fixtures. Copper is restricted in municipal drinking waters to 1.3 mg/l, based on SDWA regulatory requirements. When excess copper is present, water has a metallic flavor (at 3 mg/l) and can leave a blue to green discoloration to surfaces. In adults, water containing copper in excess of 3 mg/l can cause nausea, vomiting and abdominal pain. Lead is restricted in municipal drinking water by the SDWA to 15 ppb. Lead in drinking water fails to leave a residue and can generally not be tasted.

Lead exposure can cause irreversible mental and physical development in the developing fetus, the infant and the young child. In adults, prolonged exposure can lead to damage to the brain, kidneys, nervous system and red blood cells. The use of lead-based solder was banned in the U.S. in 1988. However, lead may be present in older homes, dated municipal water systems, and brass fittings and plumbing fixtures. The leaching of lead into plumbing systems can be greatly reduced by introducing water-soluble orthophosphates into potable water distribution systems. At low levels, the phosphates react with the lead and copper and hardness ions (calcium and/or magnesium) to form an insoluble coating on the internal surfaces of the distribution system. Once this coating is formed, observed lead and copper levels in the drinking water drop rapidly. This effect can be maintained by continued metering of phosphates into the system.

C. Scale Inhibition and Removal

The formation of scale on surfaces in potable water systems is due to the crystallization of carbonates or sulfates of magnesium or calcium from solution. Very low levels of polyphosphates (1-10 ppm) interfere with crystal growth. This type of scale inhibition is referred to as a threshold property because it occurs at a level much lower than

would be required for a stoichiometric reaction.

Threshold inhibition by polyphosphates of calcium and magnesium carbonate formation is particularly effective at a pH range of 8-10 where carbonate scale in potable water is a major problem. Calcium sulfate scale is often a problem at lower pH ranges. The same mechanism of scale inhibition that can occur with calcium carbonate at a high pH range can also occur with calcium sulfate at a lower pH range at similar low (1-10 ppm) levels of phosphate addition.

Experience has shown that polyphosphates not only inhibit scale formation, but they can also help remove existing hard deposited carbonate or sulfate scale. Pipelines carrying potable water treated with polyphosphate for extended periods of time (several months) first show a gradual softening of the scale followed by disintegration and removal. The soft scale particles are deflocculated by the polyphosphate and carried away resulting in a clean piping system.

D. Corrosion Control

Water quality varies significantly throughout the U.S. The corrosiveness of water can be attributed to a low pH (acidity), high temperature, low total dissolved solids, a high flow rate, and the presence of dissimilar metals and dissolved gases (as oxygen and carbon dioxide). When these factors are combined, the corrosion is accelerated.

Polyphosphates, alone or in combination with orthophosphates, can effectively control corrosion on both ferrous and non-ferrous metals and alloys. Polyphosphates are particularly effective as corrosion control agents at lower temperatures and at a pH of less than 7.5. They have also been shown to be effective in brackish water (greater or equal to 2,000 ppm sodium chloride, or NaCl) with corrosion reductions of up to 90% being reported.

E. Chlorine Stabilization

Heavy metals such as iron are capable of catalyzing the decomposition of chlorine. Polyphosphates are capable of complexing with these heavy metals and greatly reducing their activity towards chlorine.

IV. Phosphate Products

Phosphate products for potable water treatment can be broadly classified into three groups: phosphoric acid, orthophosphates, and condensed phosphates. Phosphoric acid, orthophosphates, and condensed phosphates encompass a wide variety of chemical compounds having potential for potable water treatment applications. The application of each phosphate product depends upon the specific properties or treatment desired. Phosphates for potable water treatment along with their National Sanitation Foundation (NSF) designated maximum use levels are listed in the table below.

Phosphate National Sanitation Foundation (NSF) Maximum Use Level

Phosphoric Acids:

36% Phosphoric Acid 27.0 mg/l

75% Phosphoric Acid 13.0 mg/l

80% Phosphoric Acid 12.0 mg/l

85% Phosphoric Acid 12.0 mg/l

Orthophosphates:

Monosodium Phosphate (MSP) 13.0 mg/l

Disodium Phosphate (DSP) 15.0 mg/l

Trisodium Phosphate (TSP) 17.0 mg/l

Monopotassium Phosphate (MKP) 14.0 mg/l

Dipotassium Phosphate (DKP) 36.0 mg/l

Tricalcium Phosphate (TCP) 12.0 mg/l

Condensed Phosphates:

Sodium Acid Pyrophosphate (SAPP) 12.0 mg/l

Sodium Trimetaphosphate (STMP) 11.0 mg/l

Tetrasodium Pyrophosphate (TSPP) 14.0 mg/l

Sodium Tripolyphosphate (STP) 13.0 mg/l

Tetrapotassium Pyrophosphate (TKPP) 17.0 mg/l

Tetrapotassium Pyrophosphate, 60% Solution 29.0 mg/l

Sodium Hexametaphosphate (SHMP) 12.0 mg/l

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