Paper No.
00314

CORROSION 2000

ADVANCES IN REVERSE OSMOSIS APPLICATION IN WATER REUSE

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ABSTRACT

Conservation of water resources and the minimization of discharges are paramount in today's industries. The reuse of process water effluents plays an important role in conserving water. This paper investigates the recycle of effluent process water from a metal finishing operation using reverse osmosis to provide make-up water for reuse. A case history demonstrates how membrane separation is used to produce water suitable for use and to minimize or eliminate aqueous discharges. This paper also examines the use of pretreatment chemicals to minimize membrane fouling.

INTRODUCTION

The use of reverse osmosis (RO) to remove salts and impurities from water has been a recognized technology to improve water quality. Design consideration of reverse osmosis systems is dependent on dissolved solids, organic, and suspended solids content. Naturally occurring ions comprise the total dissolved solids (TDS) of natural waters. RO design consideration must take into account the aount of TDS, or ionic strength, and desired water product quality. RO is used to produce a variety of high purity needs including industrial boiler feed, pharmaceutical waters, electronic industry supply, and other process industries.

RO is also used in food processing of milk, beverages, vegetable and fruit juices and meat by-products.(1) The RO proves is used in water consolidation and waste minimization either by itself or in combination with microfiltration (MF), ultrafiltration (UF), evaporation or other water processes. The use of RO in wastewater is a valuable application because permeate water and can be reused and wastewater stream becomes a resource in the process. The benefits include reduced discharge, reduced purchases, and conservation of water resources.

Reverse Osmosis Process

The performance of an RO system is largely controlled by the composition of the feed water. Feed water quality will determine the amount and the type of pretreatment necessary to make an RO an economical process. The balance is the primary limiting factor of most RO systems in operation today.

The major cause of RO system failure is membrane fouling, which results from the accumulation of foulants on the surface of the membranes. The fouling of an RO membrane is a complex phenomenon involving the deposition of several different but related types of foulants on the membrane surface. RO system fouling problems are becoming more prevalent as the use of low quality feed waters increases. In addition, surface water treated with cationic organic flocculants poses very different and challenging fouling problems. Operating costs increase when performance problems arise. These costs are those associated with membrane cleanup, replacement, and system downtime. The success of an RO system depends largely on three factors: system design, petreatment (including chemical conditioning), and operation and maintenance of the system.

The types of foulants most commonly encountered in an RO system include: inorganic fouling (scaling), colloidal fouling, biological fouling, and organic fouling. The high levels of dissolved scale forming ions in most feed water necessitate some form of pretreatment to control scale formation on the membrane surface. Colloidal fouling is typically controlled by mechanical filtration and/or the use of dispersants.

In RO, total solids are reduced through membrane separation. The concentrate, or reject, contains more highly concentrated ions than are found in the feedwater. The membranes typically remove 95 to 99 percent of the dissolved salts. The concentration of TDS, total suspended solids (TSS), and other water born contaminants can lead to fouling and decreased efficiency of the operation of a reverse osmosis system. The increase in TDS in the concentration can lead to fouling by scale forming species. These species typically include calcium carbonate, calcium sulfate, silica, and other species that exceed the saturation index. In the case of calcium carbonate, acid may be used to reduce the concentration of carbonate and bicarbonate, thereby reducing the potential for calcium carbonate scale formation.

The use of antiscalants and antifoulants has been documented to reduce the fouling potential of typical scaling species.(2) In the 1930s it was discovered that polyphosphates, such as sodium hexametaphosphate (SHMP), retard the precipitation of scale forming salts. SHMP, at low dosages (2 to 10 parts per million [ppm]), prevent precipitation through adsorption on scale crystallites, thus retarding their growth.(3) Although SHMP shows excellent threshold inhibition for calcium carbonate and calcium sulfate, it is easily hydrolyzed to form orthophosphate, which is inactive as a threshold inhibitor. Consequently, its use may lead to the formation of insoluble calcium phosphate scale deposits. In addition, the application of SHMP is limited because of its poor performance in suspending colloidal matter.(4)

The development of polyacrylate (PAA) based antiscalants to control scaling and fouling in RO systems was a significant step in making RO an economically viable process.(4) Although PAA based antiscalant was a significant improvement over SHMP in controlling some scales, it showed limited activity as a metal ion stabilizer or dispersant for suspended matter.(5)

Recently, a variety of polymer-based antiscalants have been developed and are used extensively as calcium phosphate precipitation inhibitors.(6,7) Studies have shown that the antiscalant performance strongly depends on polymer composition, molecular weight, and various impurities (soluble and insoluble) present in feed water. In addition, it has also been documented that the presence of soluble metal ions (i.e., iron, manganese, zinc, aluminum, etc.) in the feedwater can lead to scaling problems in industrial water systems. It is generally agreed that iron (II) and manganese (II) do not cause fouling problems as long as they remain in soluble form. It has been recently reported that iron (III), when present at low concentrations, can significantly reduce the performance of various calcium phosphate inhibiting polymers. As illustrated in Figure 1, a new co-polymer-based formulated product AQUAFEED® AF 1025Antiscalant[1] compared to other products show excellent performance especially in the presence of iron (III). Recent advances also include RO antiscalants that inhibit silica fouling.(8)

Reverse Osmosis and Wastewater

RO has been used in processing of wastewater. Wastewater can be from municipal or industrial sources. Water characterization of these waters may differ from naturally occurring water sources. These waters may contain a variety of contaminants and fouling species, which are not found in naturally occurring waters. These species may require create a fouling potential of species that require additional pretreatment or evaluation on a case by case basis. The use of technology

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[1] Registered trademark of The BFGoodrich Company, Brecksville, OH

to reduce fouling in these RO systems is required to maintain adequate performance. Recent developments in system simulation can facilitate scale prediction of scale potential. (9) The use of predictive models and the advances of improved antiscalant technology can improve RO performance in application where unusual scale formation may occur. These scales may include metal from manufacturing processes and other inorganic salts from cleaning processes (e.g., phosphates, silicates).

Reverse Osmosis Example

The metal finishing industry has been aggressive in implementing process changes to reduce consumption of water in the manufacturing process. A finishing plant's unit processes typically include metal forming, metal cutting, metal stamping, cleaning, phosphatizing, welding and assembly, and painting or coating. Most of the water is consumed in the cleaning and phosphatizing process. The focus of this paper is the water quality and the problems associated with the processing of treated industrial water using RO in a metal finishing operation.

A lawn equipment manufacturer located in the Southeastern United States contacted a wastewater pretreatment system supplier to evaluate the potential for converting the existing facility wastewater pretreatment to zero discharge/recycle system. The existing waste water system consisted of a physical/chemical system to treat effluent from the metals finishing section of the plant. The finishing plant's unit operations included alkaline bath cleaning, phosphatizing, several rinse baths, and a conditioner bath of the metal parts prior to painting. The existing wastewater treatment process, which was in place, included equalization, pH adjustment, coagulation, and precipitation of suspended contaminants in a conventional Lamella clarifier.

The addition of a membrane separation system was included in the new design criteria to treat the effluent from the existing wastewater process. This would provide the most cost-effective method to recycle the wastewater. Reverse osmosis membrane separation would be necessary to remove the metal ions and other contaminants contained in the wastewater and would provide the water quality, which would be suitable for reuse as make-up water supply to the rinse and bath tanks. The desired water quality could not be achieved by using Nano, Ultrafiltration or other membrane separation processes.

The new system was designed so that the effluent water from the existing treatment system could be pumped to the new recycle system instead of gravity flow to the municipal sewer system. A two-stage RO system was designed to treat an average of 10 gpm flow, with an average TDS of 3500 ppm. The typical expected feedwater analyses is listed in Table 1. RO permeate water was used for boiler make-up and plant makeup; the concentrate was reduced to a sludge through evaporation. Water, which was previously destined for discharge, would be recovered and reused.

The membranes used were a polyamide urea thin film composite (TFC) membrane with 31-mil spacers to increase the velocity across membrane. The first stage membranes were designed to process 7 gpm as permeate or product water and 3 gpm as reject. The first stage reject would flow to the second stage where the unit would process from 1.5 to 2 gpm as permeate and the remaining 1.5 gpm would be processed as reject. This would be sent to the evaporator for further concentration prior to disposal.

The existing wastewater chemistry was changed to provide maximum removal of contaminants without adding significant amounts of TDS or potential foulants in the membranes. The system was installed February 1997 and the membrane began treating wastewater. The membrane performance was carefully monitored. A significant decrease in performance was identified after a week of operation. The first stage permeate flow was reduced by 60% and almost 90% in the second stage. Investigation of the entire system showed that the alkaline cleaner used in the metal finishing process had been changed from a non-emulsifying type, where excess oil from the metal parts had been skimmed off, to a type where the oil was emulsified in the bath solution. The resulting carry-over to the rinse tanks was contaminated with a much higher amount of oil than was anticipated. An oil absorbent media was used to replace the media in the multimedia filters, the membranes were cleaned in place, and the system was reactivated.

The system performed well for approximately a month when a decrease in performance was again identified. The first stage permeate flow was reduced by 50% and 95% in the second stage Analyses of the RO feedwater and interstage precipitation products indicated that calcium phosphate was the persistent fouling species. The scaling potential of phosphate, which varies from 10 to 50 milligrams per liter (mg/L) in the feedwater, is significant. Figure 2 illustrates the predictive indices of tricalcium phosphate precipitation. The fouling potential for calcium phosphate is significant. The fouling potential as a function of pH and recovery is illustrated in Figure 3. In addition to calcium phosphate the potential for strengite or iron phosphate is also a potential foulant (Figure 4).

Amjad and Hooley et al documented the studies of antiscalants in the presence of divalent metal ions.(4) The use of polymer technology in the control of phosphate precipitation been studied by numerous authors. (6 and 7) The use of polymer technology to control both phosphate and phosphate in the presence of iron has been documented also.(7) Figure 1 illustrates the performance of polymer-based antiscalants in the inhibition of phosphate especially in the presence of high levels of iron. The conditions for these tests were: Ca concentration of 140 mg/L, PO_4 concentration of 9 mg/L, pH of 8.5, and temperature of 50°C.

After identification of the inorganic foulant, the system pretreatment recommendations of pH adjustment and the use of proprietary antiscalant that could reduce the potential for phosphate fouling was implemented. The control of this foulant was within the technology of antiscalants developed for high- stress RO applications.

The zero discharge RO recycle has been performing well since the pretreatment chemistry was initiated. A spare set of membranes was purchased to accommodate cleaning off site and reduce system downtime. The second set, which was installed in the first stage in July 1998, is still in production (November 1999) without the need for cleaning. Since the implementation of the antiscalant and pH control, the first stage has shown only a slight reduction (less than 5%) in capacity to date. The second stage membranes required cleaning every four to six months.

CONCLUSIONS

Reverse osmosis technology has demonstrated the capability of producing high purity water from a variety of feedwaters. The use of antiscalant technology has improved the operation and longevity of membrane systems. Careful analyses of feedwater data are necessary to determine pretreatment selection to protect membranes from scale forming species and other potential foulants. The use of wastewater in RO may contain fouling species, which are uncommon in natural waters. Careful consideration of the entire treatment system including a review of influent untreated waters as well as process chemistries involved are necessary for successful results. It is important to recognize and implement technologies that reduce the fouling potential and improve operation. Advances in antiscalant technology can improve performance in the presence of a variety of water process impurities.

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TABLE 1
FEEDWATER ANALYSIS PARAMETERS

Parameter	Result
Calcium (as CaCO3)	118 mg/L
Sodium	394 mg/L
Iron	0.1 mg/L
Chloride	573 mg/L
Sulfate	102 mg/L
Bicarbonate (HCO3)	54 mg/L
Phosphate (PO4)	33 mg/L
pH	7.2

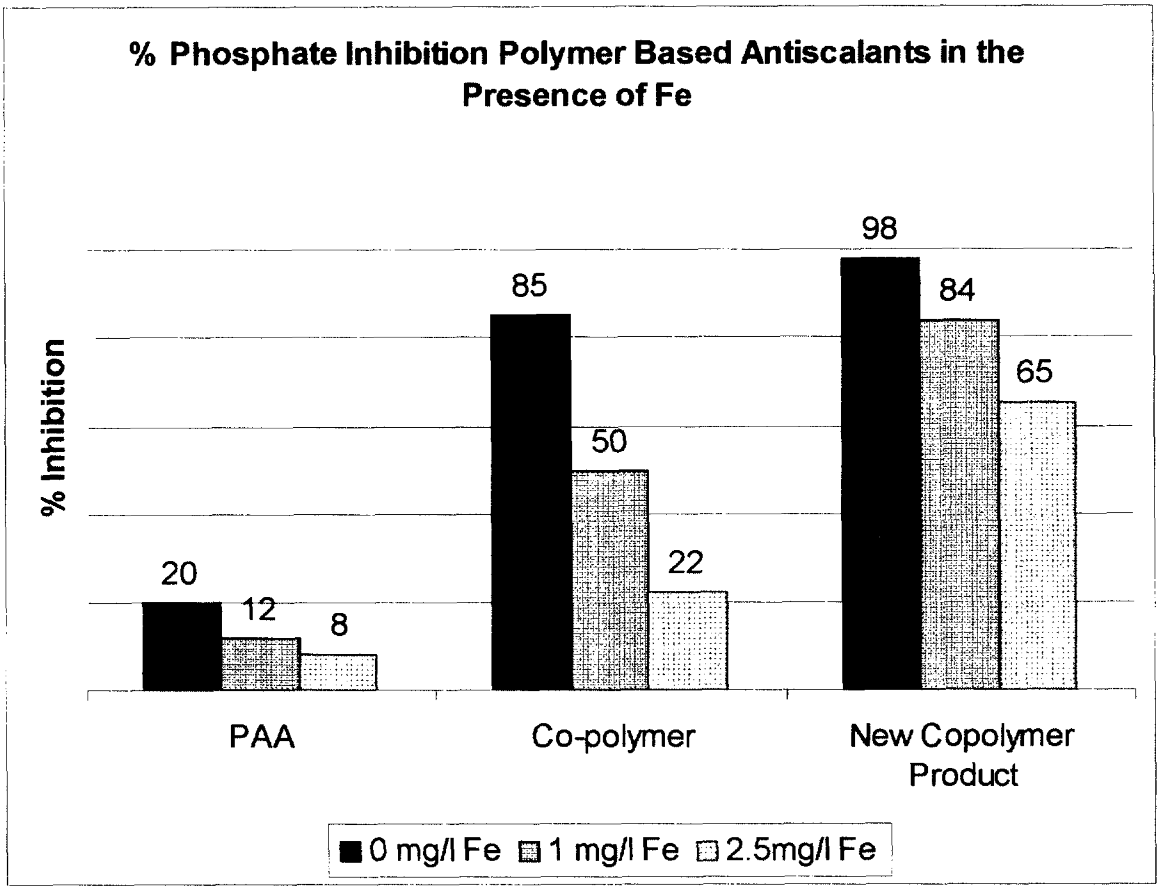

FIGURE 1 – Comparative Antiscalant Performance

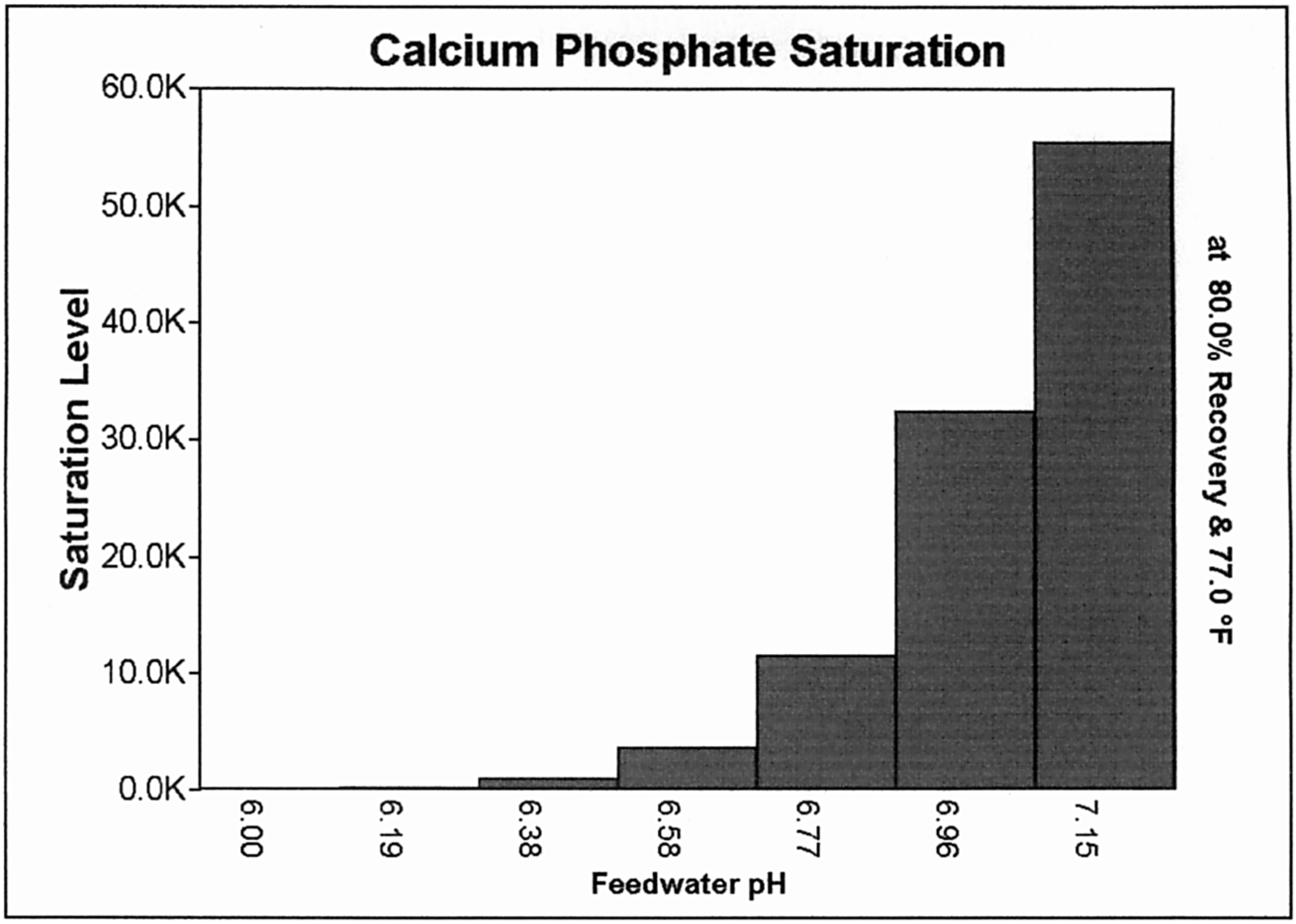

FIGURE 2 – Predictive Indices of Tricalcium Phosphate as a Function of Feedwater pH

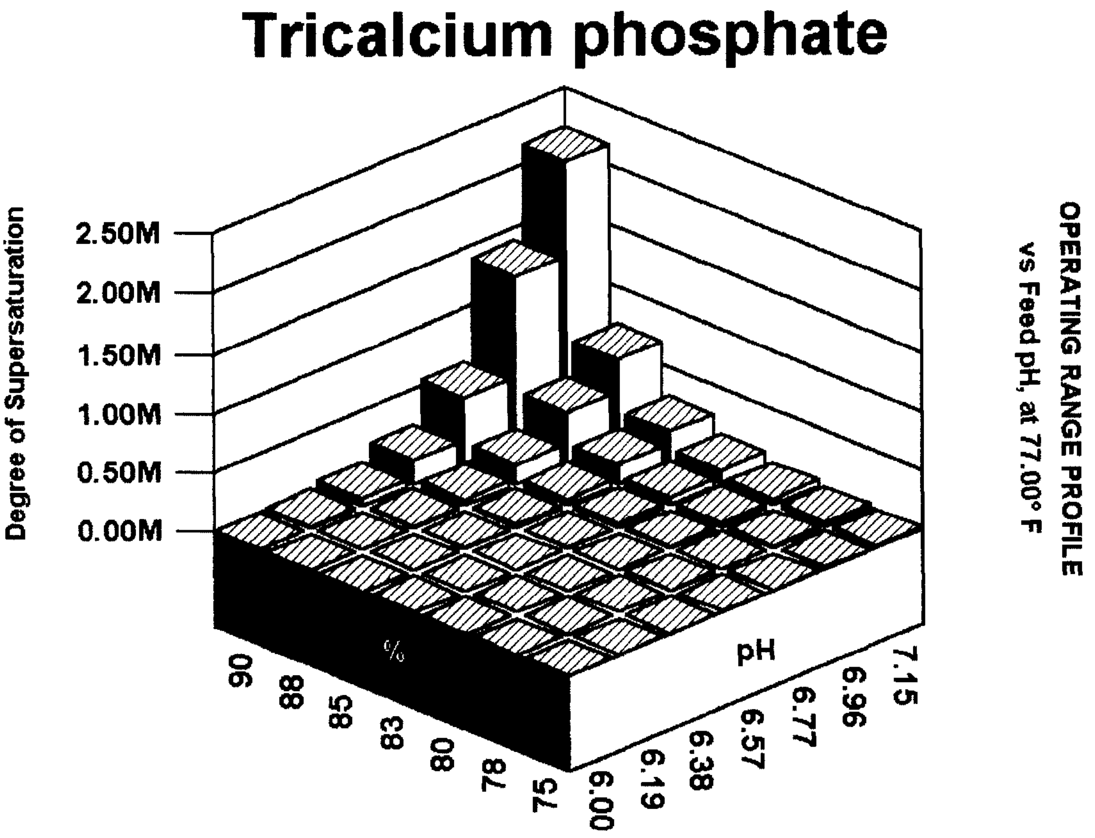

FIGURE 3 – Fouling Potential of Calcium Phosphate as a Function of pH and Percent Recovery

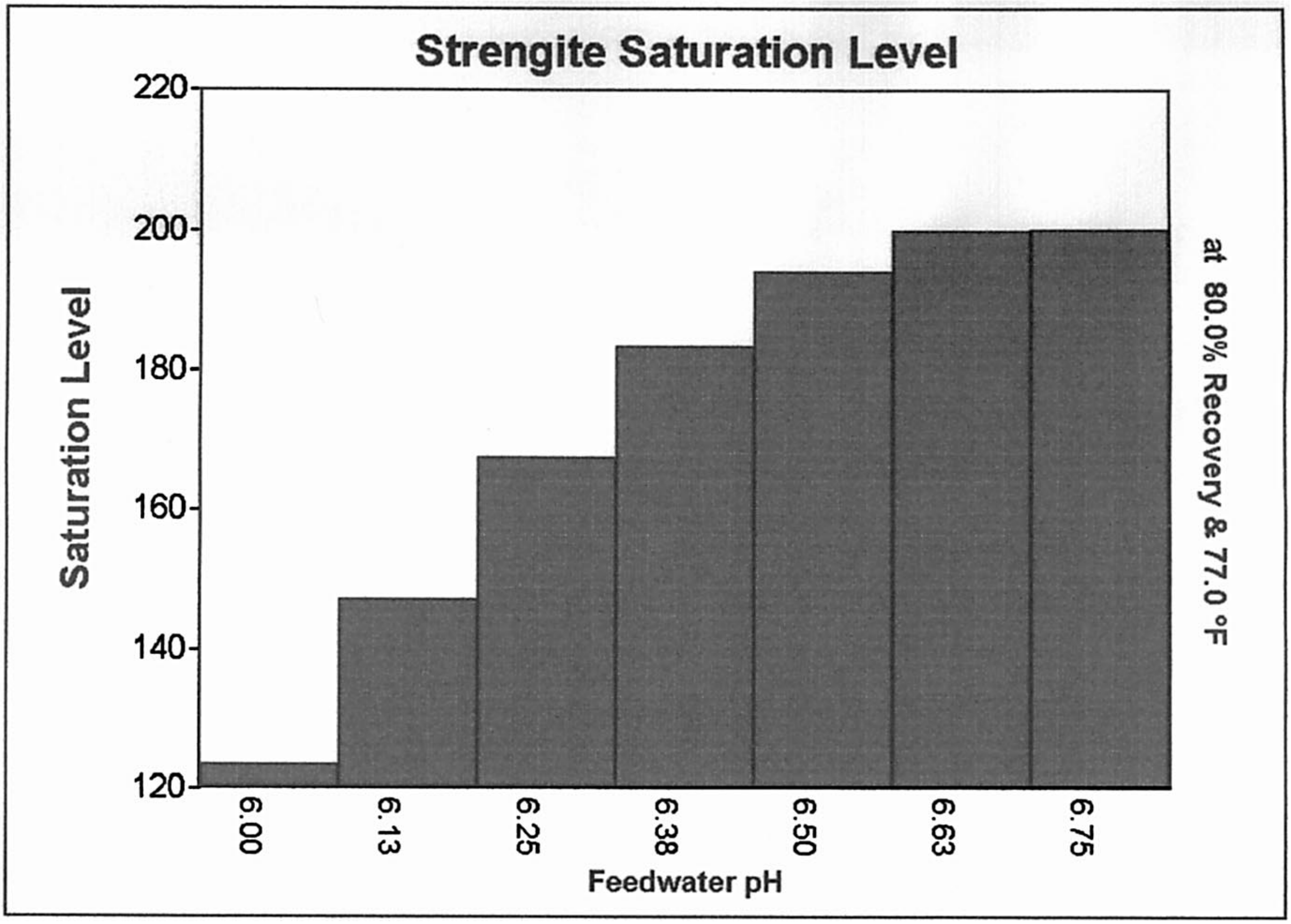

FIGURE 4 – Fouling Potential for Strengite