REVERSE OSMOSIS PROJECT IN THE PHOSPHATE INDUSTRY

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INTRODUCTION

Reverse osmosis is a new technology being applied to water treatment at the New Wales Operations of IMC Fertilizer, Inc. Raw well water is being processed through reverse osmosis (RO) membranes to remove the bulk of the dissolved solids in the water. That water is then further treated through existing demineralizers to remove more of the dissolved solids. The result is a high quality boiler feedwater make-up for making high pressure steam in the waste heat boilers.

BACKGROUND

The initial New Wales complex was built in 1974 with four counterflow demineralizer units rated at 500gpm feed rate. Each unit consisted of a strong acid (H2S04) cation and strong base (caustic) anion bed. Typical run lengths were 120,000 gals before regeneration. From the beginning, boiler feedwater make-up capacity depended on condensate return from phosphoric acid evaporators. The demineralizers could not provide 100% make-up capacity.

In 1981 during the third train expansion, three more demineralizer units of duplicate size to the original four were added. At the steam requirements with all five sulfuric acid plants running at capacity, there was not 100% make-up capability from the seven demineralizer units.

Over time, the well water quality has deteriorated. Conductivity has gone from about 400 micromhos in 1974 to over 600 today. The cycle length on the demineralizers deteriorated to less than 100,000 gallons last year. The frequency of problems with the demineralizers increased. Whenever there were instances of extended contaminated condensate from the evaporators, make-up water levels would suffer. The demineralizers could not produce enough to make up the deficit, and we would invariably end up cutting sulfuric plant rates until the crisis was over.

The idea of reverse osmosis for roughing demineralization was first brought to our attention about four years ago. Shortly after that, a paper on the idea was presented at a Clearwater AIChE meeting (1). At that time New Wales was operating carbon columns for humic removal in the acid clean-up section of the Uranium Recovery Operations. Waste caustic from the demin anion bed regeneration was being recovered and used for neutralizing the carbon columns. Based on the price of caustic then and the value in the carbon columns, reverse osmosis could not be justified at our internal rate of return criterion.

CHANGING CONDITIONS

During 1990, several conditions had changed, causing us to re-evaluate reverse osmosis. The carbon columns had been bypassed, although the waste caustic from the demins was then used in wetrock grinding but at a lower value. The price of caustic had been increasing steadily and was expected to continue its increase. The frequency of contaminated condensate had increased. Treated water quality was also a problem, as increased silica breakthrough from the demineralizers had led to silica deposits on the 58-mw turbogenerator. That had caused reduced power output for a period of almost two years until the turbogenerator was opened and the blades blasted in November 1990.

The technology for low pressure brackish water treatment with reverse osmosis membranes had improved since the mid-80's. Thin film composites in spiral wound form had shown significant success in municipal water treatment in Florida for treating well water. This type membrane was recommended for roughing demineralization.

PROJECT DEVELOPMENT

In mid 1990, we solicited budget prices for a reverse osmosis system to produce 1500 gal/min treated water. This would provide some excess capacity over the current demineralizers. Requests were sent to approximately 12 suppliers of reverse osmosis systems. After receipt of the budget proposals, we discussed the proposals with some of the vendors and increased our understanding of reverse osmosis systems. From this initial review, we cut the list of bidders down to five.

At this point we did an economic evaluation based on the budget pricing and the projected performance of the RO system. The rate of return exceeded our internal criterion, and we decided to pursue funding for the project. A detailed bid specification was developed and sent out to the five pre-selected bidders. Since we did not have in-house expertise with this technology, we hired a consulting firm, Stone & Webster, to review and critique our bid specification and to perform a detailed bid evaluation for us.

In order to provide necessary data on the feed water to the RO system, we had silt density index tests run to characterize the suspended solids. The silt density index (SDI) is a measure of the tendency to plug a 0.45-micron millipore filter over a 15-minute period under 30 psig pressure on the water source. We found that, at our wellhead, the SDI was in a reasonable range of 2-3. From the well water storage tank, however, the SDI was in a high range of 6-7. The H_2S concentration was also measured and found to be 8-10 ppm at the wellhead but only 1-2 ppm from the tank. This data indicated that iron sulfide was being formed in the storage tank, and it was causing the SDI to increase.

Based on the SDI results, our system was specified to treat the well water directly from the well. Cartridge filters to remove suspended particles down to 5-micron were specified. Because of the carbonate and H_2S content of the water, a degasifier or decarbonator was specified downstream of the membranes. Most of these two dissolved gases, CO_2 and H_2S, would go through the membranes and be stripped with air from a positive displacement blower.

As we developed the project, the major equipment - RO trains, chemical feed systems, feed pumps, cartridge filters, instrumentation, and the degasifier - were bid as a supply package. IMC Fertilizer acted as the general contractor for the building and structural, the equipment and piping installation, the electrical, and tying the instrumentation to our existing distributed control system.

The bid required three RO trains of 500 gpm permeate (product water) and a minimum of 75% recovery. The building was laid out to accommodate a fourth train in the future. Three trains would give us flexibility needed for our current operation.

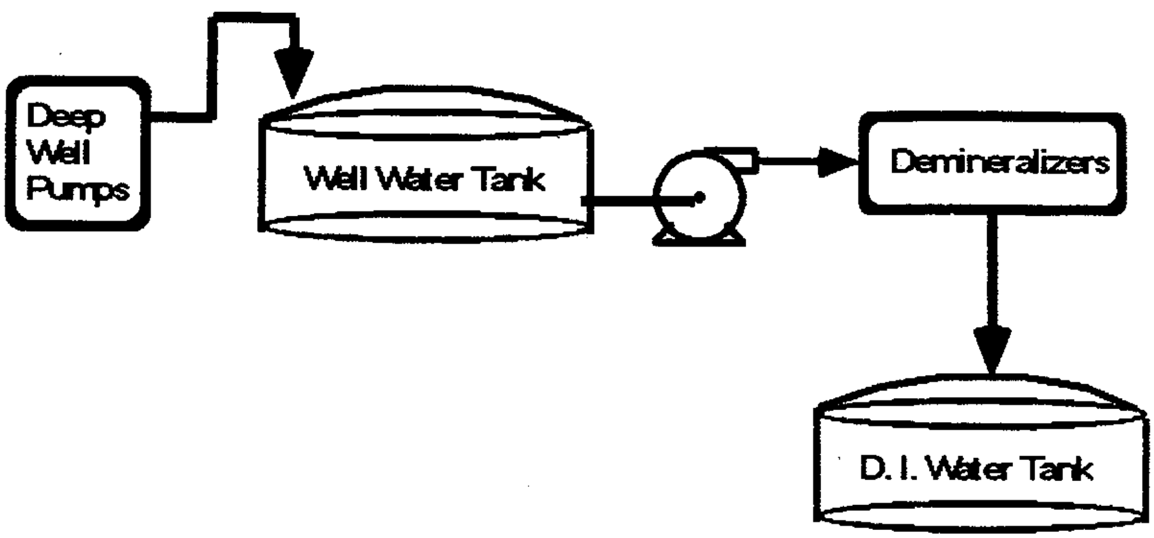
L*A Water Treatment was selected as the evaluated low bidder for the RO equipment supply package. The L*A proposal was 3 stages on each train with 80% recovery. With corporate approval of the appropriation request, a purchase order was issued in mid-February 1991. The scheduled delivery was 26 weeks. At a pre-award meeting, details of the RO system were reviewed with the vendor, resulting in some clarifications and changes. The cost impact of these was very small. During the next few weeks after award, design drawings and documents were reviewed and approved. Our Project Engineering Department also began design on the structural, building, and piping.

Construction on the building site began in early August 1991. When the RO trains arrived, they were set in place on concrete piers before the building was fully erected. The system was installed and checked out by mid-October. A vendor representative provided training for our operating, engineering, and maintenance personnel a week before scheduled start-up.

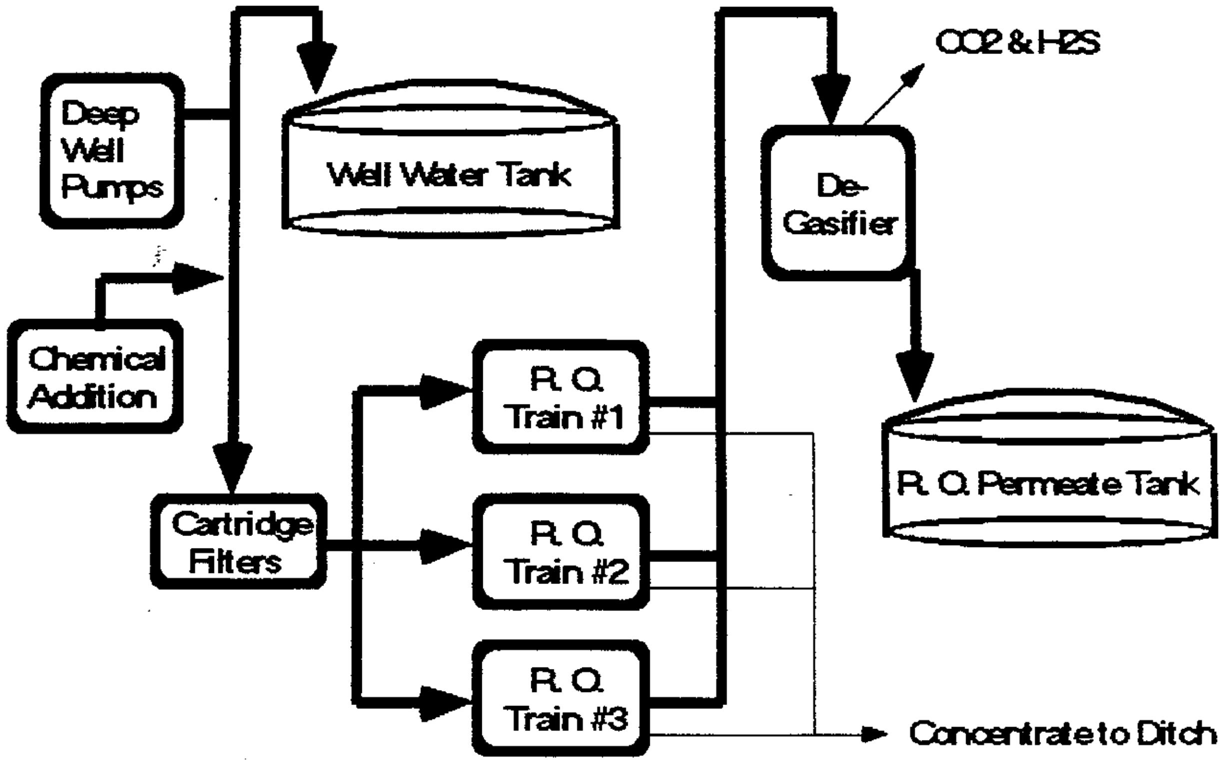
A start-up engineer worked with our maintenance personnel to install the membranes in the pressure vessels or tubes. Care had to be taken in preparing and installing the membranes. Each train had to be flushed and brought on at low pressure initially. Leaks were expected and did develop, requiring shutdown to repair.

The first train was put on line on October 23, 1991. On October 24, all three trains had been put in service.

Before Reverse Osmosis



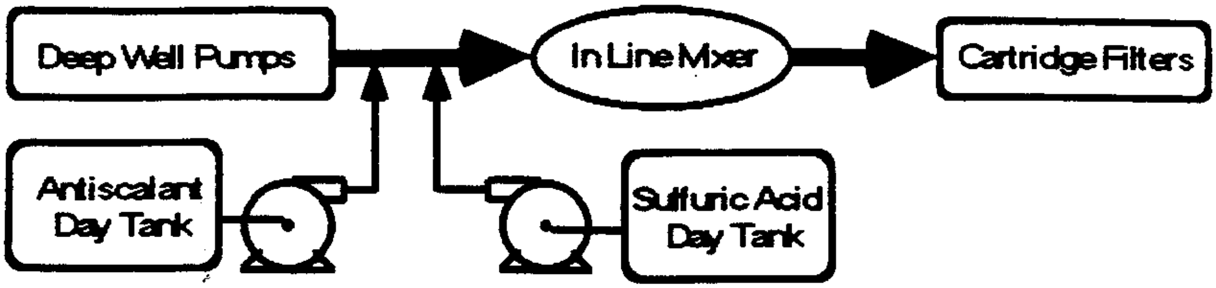
With Reverse Osmosis



PROCESS DESCRIPTION

Well water is delivered from the deep well pumps at 35-50 psig and 80°F through steel pipe to the RO unit. Outside the building the feed piping changes to 304 SS. Two injection points are provided where sulfuric acid for pH control and anti-scalant for increasing calcium ion solubility in the concentrate or waste stream are fed. Each chemical feed system consists of a day tank and two metering pumps. Just downstream of the injection point is an in-line static mixer to insure mixing of the chemicals in the RO feed water. The turbidity and conductivity are then measured before the water goes through three parallel cartridge filter units. Each cartridge filter unit consists of 37 spun polypropylene disposable filters 2.5" diameter X 30" long. They remove suspended solids down to 5 micron size. With clean filters, a pressure drop of about 8 psig is seen with three trains in operation. When the pressure drop increases to about 12 psig, the filters are replaced.

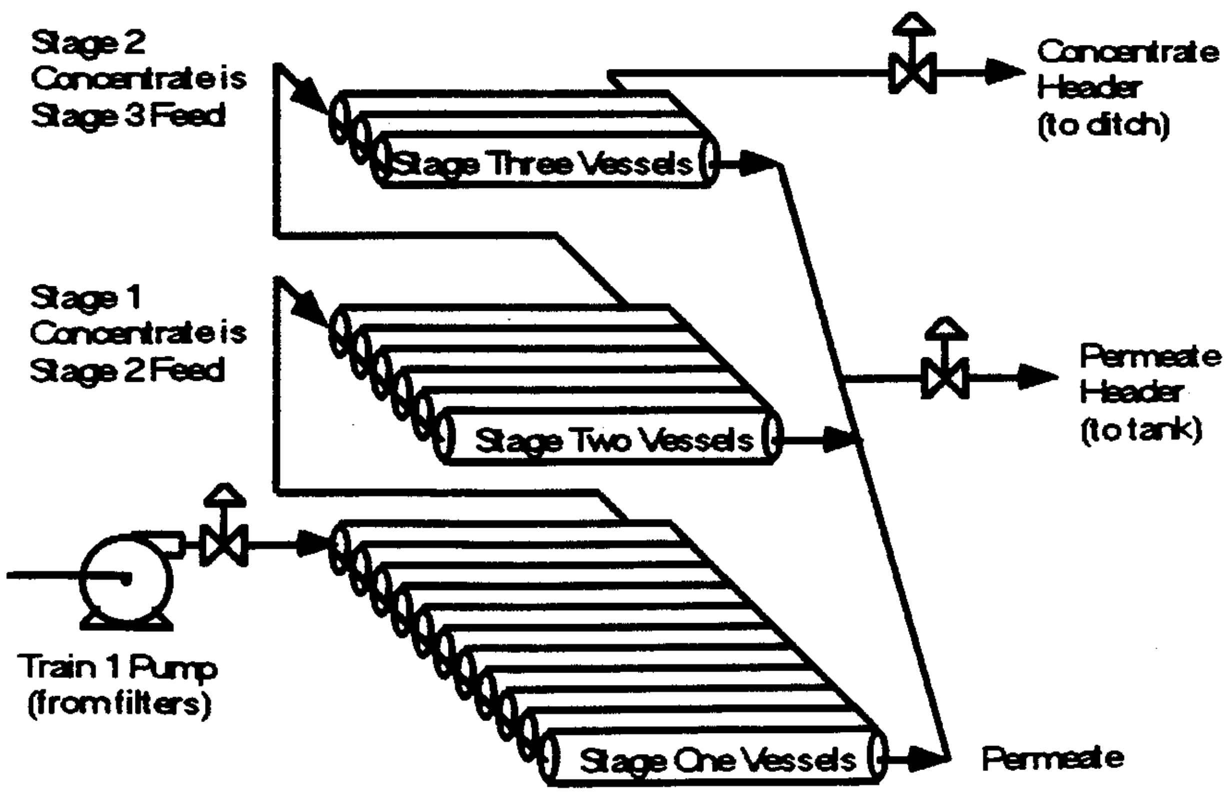
Well Water Pretreatment



After being filtered, the water is boosted in pressure by centrifugal pumps, one per train, to about 240 psig. The permeate water through the RO membranes of each train is controlled at 500 gpm by throttling the feed control valve. Concurrently, the concentrate flow is controlled at 125 gpm.

Each reverse osmosis train consists of twenty 8" diameter fiberglas (FRP) pressure vessels arranged in three stages. The first stage is comprised of eleven vessels arranged in parallel. The concentrate from the first stage is fed to the second stage which is comprised of six vessels in parallel. The concentrate from the second stage is then fed to the third stage which consists of three vessels in parallel. Typical feed pressures of the first, second, and third stages are 205, 180, and 155 psig respectively.

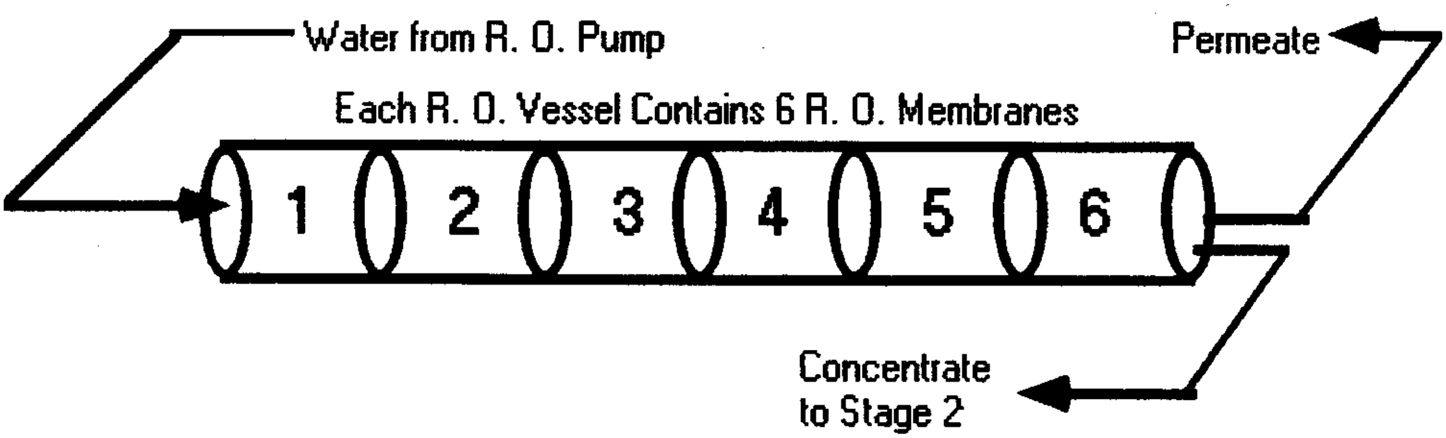
Reverse Osmosis Train #1



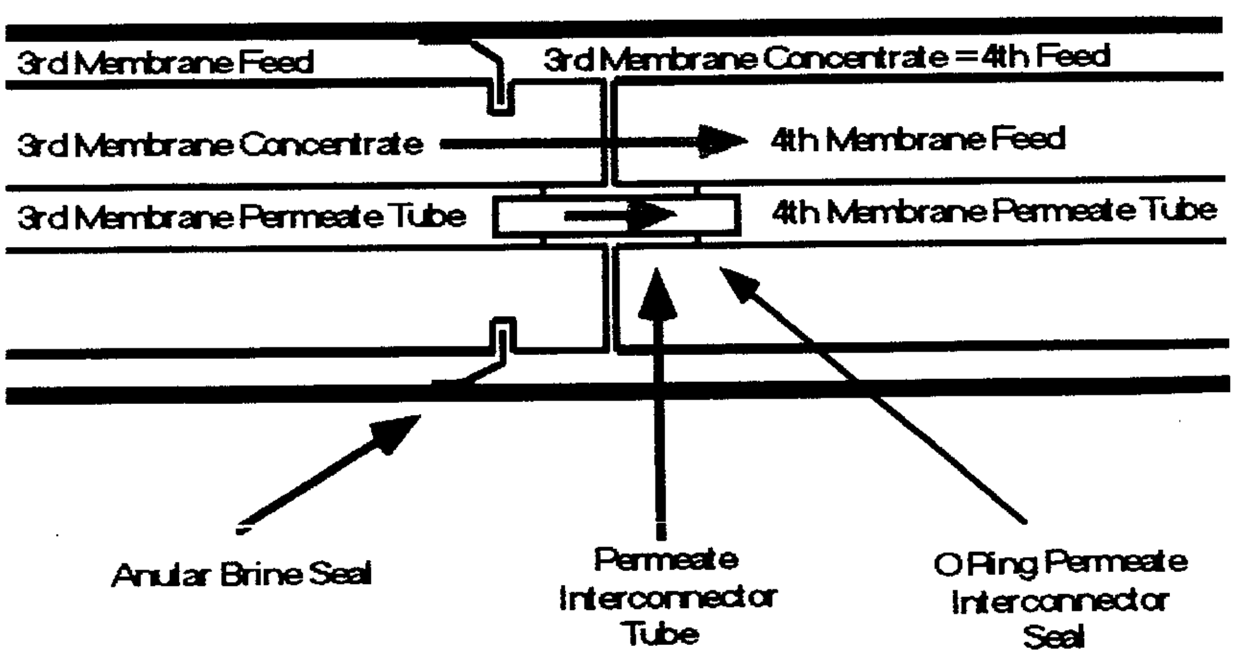
Carbon dioxide is formed when the pH of the well water is reduced by the addition of sulfuric acid. The reverse osmosis permeate contains approximately 51 ppm CO_2 and 10 ppm H_2S. The concentration of these gases in the permeate is reduced by removal with the forced draft degasifier. The degasifier permeate discharge contains ,<5 ppm CO_2 and <1 ppm H_2S.

The FRP pressure vessels contain six membrane elements connected in series with o-ring seals to prevent contamination. Each membrane element is spiral wound and is composed of multiple layers of polyamide, a microporous polysulfone support material, and a spacing fabric to act as a permeate channel.

Vessel Schematic



Membrane Junction



A membrane cleaning system consisting of an agitated FRP tank, a cartridge filter unit, and a low pressure centrifugal pump was furnished with the RO system. Chemicals such as citric acid or caustic will be used to clean the membranes whenever they become fouled. Cleaning has not yet been necessary but is expected about once a year.

SYSTEM CONTROLS

Operation of the three RO trains is controlled from the Westinghouse distributed control system (DCS). Permeate goes into a dedicated tank after passing through the degasifier. Based on tank level, one, two or three trains are brought on line. As the tank level increases, one train is dropped off line. Two trains are normally running with the third train coming on and shutting off intermittently. Each month a different train is used to control the permeate tank level.

A start-up and shut down purge is employed on each train in order to prevent air from getting into the membranes and to flush concentrate away from the membranes before shutdown. The start up sequence involves a two minute purge with filtered well water at its header pressure and the pump down. The permeate is dumped to a trench during this purge before pump start up. The shut down sequence is similar except it is a ten minute purge after the pump is shut down. Both are done automatically from the DCS.

SYSTEM TROUBLE SHOOTING

In December one of the trains showed an increased permeate conductivity. The individual vessel conductivities were measured with a portable conductivity meter. It was found that the three third stage vessels all had high conductivity. A length of poly tubing with connections to fit up to a vessel was then used to measure the conductivity of each of the membranes in those vessels. The last element in each of the three vessels was found to be the one with high conductivity on the permeate side. Those three elements were replaced.

The three membrane elements were found to be ruptured. This was determined to be due to a higher hydraulic pressure on the permeate side than on the concentrate side in those last three third stage elements during the start up and shut down purges. The height of the degasifier allowed the permeate pressure to be higher than the feed water pressure. Leakage past the permeate check valve permitted the pressure to be transferred to the membranes. To preclude this from happening again, the purges were modified to dump the permeate at each train so the permeate pressure can not be higher than the concentrate pressure.

RESULTS

The RO permeate water has been consistently under 20 micromhos conductivity since start up. Initially, the RO water as feed to the demineralizers gave run lengths of 1 million gallons before regeneration. That gradually increased to about 2.5 million gallons, which is the current run length. That compares to typical run lengths of 90,000 gallons on well water before regeneration. Needless to say, the amount of caustic for anion bed regeneration has been drastically reduced.

Silica levels in the boilers has been greatly lowered, also. Whereas we previously were bumping the 30 ppm maximum, we now typically are below 10 ppm.

REFERENCES

1 - Wethern, Mike, Mitco, "Reverse Osmosis for Roughing Demineralization" presented at the May 1988 AIChE Clearwater Convention.