(8) Substantially higher flux is achieved.

(9) Reduced overall capital cost, compared to conventional RO systems.

(10) Reduced overall operating cost, compared to conventional RO systems.

(11) The complexity of an ultrapure water system is significantly reduced.

The HERO brand RO system is highly site-specific. Individual process steps are customized to fit the specific feedwater at a specific site. Regardless of the difference in pretreatment process for different sites, one process parameter is common for all applications, namely that the RO system is operated at the highest feasible reject pH. Consistent with the highest allowable pH limit for currently available RO membranes (for example, pH 11.0 for FILMTEC(R) brand RO elements), a typical HERO brand RO system is designed to operate at pH of up to approximately 11, as measured in the RO reject stream.

Because of the very high concentration factors (i.e. percent recovery) allowed by my HERO brand RO process, the RO feed pH is correspondingly lower. For example, in a system operating at ninety percent (90%) recovery, a feed pH of 10.0 will produce a reject stream at an approximate pH of 11, provided that the RO feed is only slightly buffered by the presence of carbonate, phosphate, etc. Unlike conventional RO systems, typically operated at about seventy five percent (75%) recovery, a HERO brand RO system can be routinely operated at ninety percent (90%) or greater recovery, limited only by osmotic pressure of the RO reject. The pH increase from RO feed to reject is magnified at very high recoveries. Thus, the maximum allowable pH is specifically applicable for the RO reject conditions.

In order to operate an RO system with reject up to near pH 11, or at about pH 11, or above, several process conditions must be met in order to effectively eliminate the potential for scale formation on the RO membrane. Some of those process conditions are also necessary for operating an RO system at very high recovery rate. Such process conditions are as follows:

(1) Calcium, magnesium, strontium, and barium concentration in the RO feed must be substantially eliminated, preferably to near zero, and most preferably, to essentially zero.

(2) Aluminum, iron, and manganese content including organically bound species, as well as the presence of colloidal particles containing such materials, should be substantially eliminated, and preferably to near zero.

(3) Buffering anions (specifically bicarbonate, or carbonate, and/or phosphate species) should be reduced to as low of a level as can be practically achieved.

The selection of specific operations and control points to fulfill the above process condition requirements is influenced by the characteristics of each specific feedwater. The percent recovery needed (or desired for a specific application) also affects the operations and control point criteria as well. FIG. 2 represents a highly cost effective RO unit process sequence.

The first step is to adjust the hardness-to-alkalinity ratio of the feedwater, if needed. Optimizing this ratio, which is typically done by alkali addition, makes complete hardness removal feasible in the next process step.

The second step in the RO process train involves the utilization of a weak acid cation (WAC) resin (e.g. DOWEX (R) MAC-3, or Lewatit CNP-80, Amberlite(R) IRC-86). Operated in hydrogen form, the WAC resin removes hardness quantitatively, given the proper hardness-to-alkalinity

ratio of the influent. The hydrogen ions liberated in the cation exchange process react with the alkalinity and produce carbonic acid $(H_2CO_3)_2$, which is dissolved in the WAC effluent.

The third step involves adding acid to the WAC effluent to destroy the remaining alkalinity, if any such alkalinity is present. Total alkalinity removal at this step is important in order to achieve very high recovery across the RO system.

In a fourth step, the acidified effluent, containing virtually zero hardness and alkalinity, is then treated for carbon dioxide removal. This removal can be accomplished in a forced/induced draft decarbonator or in an existing vacuum degasifier of either packed bed or gas permeable membrane barrier design. The decarbonated, essentially zero hardness, essentially zero alkalinity water, is then injected with a soluble alkali, preferably for adjusting pH to 10.0 or higher, and most preferably to the pH as needed to achieve pH up to at or near 11.0 in the RO reject.

The next step consists of operating the RO system in such a manner that the pH of the reject is approximately, but preferably not appreciably higher than, 11.0. Note that this pH 11 limitation is applicable simply with respect to currently available RO membranes. An exemplary membrane, with the highest pH tolerance capability, is a FILMTEC type FT30 membrane. If RO membranes with a higher pH tolerance capability become available in the future, then the maximum allowable RO reject pH can be raised accordingly, with concomitant benefits from the higher pH, in excess of 11.0.

Feedwaters utilized for production of high purity water, as well as those encountered in wastewater treatment, include the presence of silicon dioxide (also known as silica or SiO_2) in one form or another, depending upon pH and the other species present in the water. For membrane separation systems, and in particular for RO type membrane separation systems, scaling of the membrane due to silica is to be religiously avoided. This is because (a) silica forms relatively hard scale that reduces productivity of the membrane, (b) is usually rather difficult to remove, (c) the scale removal process produces undesirable quantities of spent cleaning chemicals, and (d) cleaning cycles result in undesirable and unproductive off-line periods for the equipment. Therefore, regardless of the level of silica in the incoming raw feedwater, operation of conventional membrane separation processes generally involves concentration of SiO_2 in the high total dissolved solids ("TDS") stream to a level not appreciably in excess of 150 ppm of SiO_2 (as SiO_2). Typically, RO systems are operated at lowered recovery rates, where necessary, to prevent silica concentration in the reject stream from exceeding roughly 150 ppm.

Scaling due to various scale forming compounds, such as calcium sulfate, calcium carbonate, and the like, can be predicted by those of ordinary skill in the art and to whom this specification is directed, by use of the Langlier Saturation Index, as discussed above, or other available solubility data. Operating parameters, including temperature, pH, permeate and reject flow rates, must be properly accounted for, as well as the various species of ions in the raw feedwater, and those species added during pretreatment.

I have found that by reliable hardness and non-hydroxide alkalinity removal, to levels which effectively avoid formation of scale at a selected pH for RO operation, the concentration of SiO_2 in the RO reject stream can be safely increased to 450 ppm or more. This is accomplished by increasing the pH of the feedwater to the RO system, and without use of scale-inhibition chemicals. Moreover, even with this increase of silica in the RO reject, the level of silica