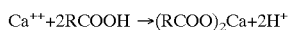


method, as illustrated in **FIG. 2**, are quite efficient in the removal of hardness associated with alkalinity. Such a reaction proceeds as follows:



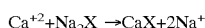
[0102] Then, the hydrogen combines with the bicarbonate to form carbonic acid, which when depressurized, forms water and carbon dioxide, as follows:



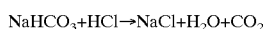
[0103] Regeneration of the resin is accomplished by use of conveniently available and cost effective acid. It is well known by those in the art that regeneration of WAC ion-exchange resins may proceed quite efficiently, at near stoichiometric levels (generally, not more than about one hundred and twenty percent (120%) of ideal levels). Preferably, hydrochloric acid may be used, since in such cases highly soluble calcium chloride would be produced, and the regeneration process would not pose the potential danger of formation of insoluble sulfate precipitates, such as calcium sulfate, even with high strength acids. However, by use of a staged regeneration procedures, i.e., by using a low concentration acid followed by a higher concentration acid, it is possible to reliably utilize other acids, including sulfuric acid ( $\text{H}_2\text{SO}_4$ ), while still avoiding undesirable precipitates on the resin. In this manner, hardness ions are solubilized to form soluble salts, which are eluted from the resin bed and are typically sewerred. Use of sulfuric acid is particularly advantageous in semiconductor manufacturing operations, since such plants typically use large quantities of such acid, and waste or spent acid may be advantageously utilized for regeneration of a weak acid cation exchange bed.

[0104] Other polyvalent cations, most commonly iron ( $\text{Fe}^{++}/\text{Fe}^{+++}$ ), magnesium ( $\text{Mg}^{++}$ ), barium ( $\text{Ba}^{++}$ ), strontium ( $\text{Sr}^{++}$ ), aluminum ( $\text{Al}^{+++}$ ), and manganese ( $\text{Mn}^{++}/\text{Mn}^{++++}$ ), are also removed by the WAC resin. Since the presence of even very small quantities of hardness or other species of decreasing solubility at increasing pH will result in precipitation of sparingly soluble salts under the process conditions present in my process, care must be taken to prevent precipitation on the membrane of the substances such as of calcium carbonate, calcium hydroxide, magnesium hydroxide, and magnesium silicate. One precaution that should be observed is that both hardness and non-hydroxide forms of alkalinity should be aggressively reduced in the feedwater, prior to upward pH adjustment to selected RO operating conditions. Once hardness and non-hydroxide forms of alkalinity have been removed, then the desired pH increase may be accomplished with any convenient alkali source, such as sodium or potassium alkali, or by anion exchange. Once this pretreatment has been thoroughly accomplished, then an RO system can be safely operated at very high pH levels, in order to take advantage of the aforementioned silica solubility.

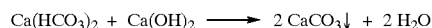
[0105] In cases where raw water composition is such that sodium zeolite softening is advantageous, as is depicted in **FIG. 3**, elimination of calcium hardness proceeds as follows:



[0106] Then, bicarbonate alkalinity is converted to carbon dioxide, with a selected acid, in a manner similar to the following:



[0107] For those waters where lime softening may be an acceptable or preferred method for initial hardness and alkalinity reduction, the addition of lime to the water reduces calcium and magnesium hardness, and associated bicarbonate alkalinity, as follows:



[0108] This process configuration is depicted as an alternate embodiment of my method, as illustrated in **FIGS. 3 and 4**. In the cases where lime or lime/soda softening is used, however, extreme care must be used in evaluating the performance of the remainder of the pre-treatment system, since the solubility of hardness ions remains appreciable in the softener 52 effluent stream 54.

[0109] For most feedwaters, particularly where lime or lime/soda softening is not employed, the use of a carbon dioxide removal step significantly enhances cost-effectiveness of the process when carried out prior to the pH increase. This also helps to maintain a lower total alkalinity level in the feed to the RO, thus providing a greater margin of safety against scaling due to hardness leakage from the cation removal step. Dealkalization by carbon dioxide removal also helps to enhance silica rejection, due to the lack of competing species. This is because the rejection of one weakly ionized anion is affected by the presence and concentration of other weakly ionized anions in the feedwater; this applies to weakly ionized anions such as boron, organic acids (TOC), cyanide, fluoride, and certain arsenic and selenium compounds.

[0110] Since the high pH operation also increases ionization of other weakly ionized anions, including borate, organic acids (TOC), cyanide, fluoride, and certain arsenic and selenium compounds, their rejection rates are enhanced in an RO membrane system. Consequently, in general, my method may be advantageously applied to reject across the membrane most weak acids with a pKa of about 7.5 or higher. Silica rejection can be increased to about 99.95%, or more, from a conventional baseline of about 99% rejection; this amounts to at least one order of magnitude decrease in the amount of silica escaping into the permeate, thus providing a ten plus ( $10^+$ ) fold increase in running life for the silica scavenging ion-exchange resin bed, namely anion exchanger 42 and the mixed bed units.

[0111] In the case of cyanide, rejections in a first pass RO of in excess of ninety percent (90%) can be attained, in contrast with a more typical range of about fifty percent (50%) or so with conventional RO processes.

[0112] Similar to the case for silica, boron rejection can be increased from a conventional baseline from a range of about 60-70% to 99% and higher, by operation at a suitably high pH. The beneficial effects on rejection percentage due to higher pH operation start at a slightly lower pH in the case of boron, since the pKa for boron is 9.14, roughly one-half pH unit higher than that for orthosilic acid, namely 9.7. The beneficial effects of high pH operation are much more pronounced in the case of boron, however, because orthosilic acid ( $\text{H}_2\text{SiO}_4$ ) in aqueous solution typically includes six