Introduction

Although counter-currently regenerated ion exchange demineralizer (DM) plants have been widely available since the 1960’s, the past decade has seen the introduction of a new generation of demineralizer designs in North America and Europe. Promoted by several of the major resin manufacturers, these include UPCORE from Dow Chemical, PUROPACK from Purolite and AMBERPACK from Rohm & Haas. Although these systems have minor differences in design, they generally tend to share a number of common features. These include:

- counter-flow (i.e. counter-current) regeneration
- packed resin beds (i.e. no freeboard)
- fine/uniform particle resins
- short resin beds
- shorter operating cycles

The major advantages claimed for this technology are lower regenerant chemical consumption, higher demineralized water purity and smaller equipment. These systems have sparked renewed interest in ion exchange demineralization. The improved performance has reversed or slowed the industry-wide trend towards the use of reverse osmosis in lieu of ion exchange.

While these designs have advanced the state-of-the-art somewhat, they should be considered a evolution of the technology, with only incremental advantages. Advancement has been limited by traditional fixed-bed ion exchange design principles, which have been ingrained into the thinking of most water treatment professionals.
If one can step ‘out of the box’ of conventional thinking and extrapolate the same features outlined above into a new paradigm, a revolutionary ion exchange concept called Recoflo, becomes, in hindsight at least, quite obvious.

**The Principles of Recoflo Ion Exchange**

When comparing a conventional ion exchange demineralizer design such as the one shown in Figure 1 with the adjacent RecoFlo unit it is readily apparent that RecoFlo is indeed a dramatic departure from conventional thinking. The RecoFlo Demineralizer is much more (or less) than just another packed-bed, counter-current ion exchange system. The RecoFlo unit, which is equipped with resin beds only 15 cm in height can produce higher purity water with lower chemical consumption than the conventional unit which is equipped with 400 cm columns.

RecoFlo ion exchange principles date back more than three decades to the University of Toronto. Eco-Tec Inc. was incorporated in 1970 to develop and commercialize the technology. Although acceptance of the technology has not been universal, well over 1000 RecoFlo systems have been installed in over 45 different countries. RecoFlo can no longer be considered novel and is indeed now well proven and its advantages well documented 1,2,3.

While the process has been extensively used for chemical purification and waste recovery, the gradual but steady acceptance of RecoFlo in water treatment is at least partly a reflection of the more conservative nature of that industry.

Although a detailed explanation of the principles of RecoFlo is beyond the scope of this paper it can be appreciated by reviewing several of the major design features incorporated into the system.

1. **Short bed height/small resin volume** - The resin beds in the RecoFlo demineralizer are only 15 cm in depth and have approximately 10% of the resin volume of other conventional units. The height of the RecoFlo resin bed is actually just somewhat larger than the length of the mass transfer zone in the bed. Since a bed height in excess of the length of this exchange zone is of no advantage, there is no performance compromise in using such a short bed. The dramatic reduction in resin bed size makes it possible to pre-assemble and test the complete unit prior to shipment. This reduces space requirements and also reduces installation and commissioning time and cost.

2. **Low resin loading** - Unlike other demineralizers that load the resin to the maximum extent possible, the RecoFlo...
A demineralizer uses less than 20% of the total exchange capacity of the resin. By using only the most accessible exchange sites near the surface of the resin beads, the exchange kinetics are improved and regenerant usage is reduced. As shown in Figure 2, increasing the operating capacity of a resin requires more than a proportional increase in regenerant consumption. Conversely, by accepting a lower operating capacity the regenerant consumption is reduced by an even greater amount. As a result, it is possible to approach theoretical (i.e. stoichiometric) regenerant consumption at low resin loadings. In addition, the low resin loading appreciably decreases resin volume change each cycle and the resulting resin attrition that normally occurs.

3. **Fine mesh resin** - The size of Recoflo resin particles is approximately one fifth the size of the resin used in other demineralizers (see Figure 3). This reduces the distance that ions must travel through the resin particles. The reduced diffusion path length enhances the kinetics of the ion exchange process and allows use of dramatically higher flow rates. Fluid velocities in Recoflo systems are three to five times higher than in conventional systems. This reduces the required diameter of the resin vessels and the floor space to accommodate the equipment. In addition, fine resins are known to be much stronger and less susceptible to attrition due to osmotic shock than conventional, coarse resins.

4. **Counter-current regeneration** - To maintain the cleanest resin at the bottom of the resin beds after regeneration, the regenerant is passed through the bed in the opposite direction of the feed flow. Counter-current regeneration minimizes regenerant usage and maximizes product water quality.

4. **Compressed resin beds** - Resin shrinkage, even in a packed resin bed, can result in flow channeling (see Figure 4). This is perhaps even more of an issue in a short bed. By slightly compressing the resin inside the Recoflo bed, any flow channels that develop are immediately closed off by expansion of surrounding resin. The resin in the bed is truly immobilized so that exchange profiles move up and down the bed in a reproducible manner as it cycles, thereby fully realizing the potential benefits of counter-current regeneration.

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6. **Shorter cycle times** - The combination of high flow rates, low resin loading and short resin beds results in short cycle times, both in service and regeneration.
Pretreatment

With conventional co-current ion exchange systems, a small amount of solids accumulating within the resin bed can often be removed by regular back-washing. Often no pre-filtration is provided with these systems. It is not possible to back-wash a packed bed ion exchange system however, because there is no freeboard in the column to take up bed expansion. Moreover, to do so would obviate the advantages offered by counter-current regeneration. The fine resins employed in the Recoflo system increases the tendency of the resin bed to filter out any suspended material in the feed. Although various methods have been developed to help alleviate this situation, the general consensus is that packed bed ion exchange systems are more prone to fouling with suspended solids than conventional systems and must always be equipped with a pre-filtration system. It is fair to say that the level of filtration required for a packed bed ion exchange system such as Recoflo, is similar to that required for a reverse osmosis system.

To address this requirement, a number of new filter designs recently have been introduced. In some cases, ultra or microfiltration membranes have been installed. Eco-Tec has developed a new dual media filter called ‘Spectrum’. The Spectrum filter is equipped with a lower layer of very fine, high density ‘micro-media’. This unit provides lower average filtrate turbidities, can handle high turbidity feeds and gives generally more stable operation than conventional multi-media filters.

Recoflo Demineralizer Operation

The basic Recoflo demineralizer operating cycle is shown in Figures 6-8.

During the onstream or service cycle feed water is passed directly through the cation and anion beds in the usual manner. It has been found to be more economical to not use a decarbonator in most cases. If a decarbonator is used, additional caustic must be purchased to neutralize the acidic cation waste. If a decarbonator is not employed, the anion and cation waste usually self-neutralize.

The quality of the product water is most easily measured by measuring conductivity. For high purity water, the inverse of conductivity, resistivity, is a better measure. A typical onstream resistivity profile of the demineralized product water is shown in Figure 5. The length of the onstream cycle depends on the feed TDS. For example, for a feed water containing [TDS] = 150 mg/L the onstream time would only be about 10 minutes. This is indeed short compared to a conventional demineralizer, which may remain in service for a day or more.

To ensure that silica does not leak through into the product water, the onstream cycle must be terminated prior to the conductivity break. Where the feed composition is consistent, the duration of the onstream step can be pre-programmed into the PLC. Where there is significant variation in feed TDS, the feed concentration is continually monitored by conductivity. This value is then continuously read by the PLC and the ionic loading is totalized as the cycle proceeds. The cycle is automatically terminated, prior to breakthrough when the loading reaches the prescribed design level.

![Onstream Profile](image)

Figure 5: Onstream product water resistivity profile

The average water quality of the product water is also dependent on the feed TDS. For waters greater than [TDS] = 170 mg/L, average conductivities of less than 1 µs/cm can readily be achieved. For [TDS] = 50 mg/L, a conductivity of less than 0.1 µs/cm (>10 MΩ-cm) can be assured, while for [TDS] = 10 mg/L a conductivity of less than 0.067 µs/cm (>15 MΩ-cm) is obtained. Perhaps more significantly for boiler makeup applications, silica levels of less than 10 µg/L can be guaranteed. According to usual water treatment practice, a mixed bed polisher is
usually utilized to ensure purity of this level. By using Recoflo, the necessity of employing mixed bed ion exchange polishers is eliminated.

**Figure 6: Onstream step**

After the resins beds have become loaded, they must of course be regenerated (see Figure 7). The anion bed is typically regenerated by injecting 50% NaOH into a stream of warm, demineralized dilution water, which is directed up through the anion bed. The bed is rinsed by continuing the flow of water after injection of caustic has ceased. The cation bed is similarly regenerated and rinsed by injecting either concentrated commercial HCl or H2SO4 into demineralized water flowing up through the bed. The spent regenerant chemicals from each bed can be collected in a small tank where they self-neutralize. The complete regenerant dilution and feed systems are all located on the same compact skid as the resin beds.

**Figure 7: Regeneration steps**

Final rinse-to-quality is achieved by recirculating the contents of the two resin beds using the feed pump (see Figure 8). This minimizes the quantity of wastewater that is produced and ensures that the final product water quality is acceptable.

The total offstream time, including regeneration and rinsing of both beds as well as recirculation rinse, is only about 7 minutes. Because the total offstream time for a conventional DM plant is about four hours, a duplicate, standby unit is usually supplied to ensure continuous service. With the Recoflo system, a small water surge tank with only a few minutes residence time obviates the need for redundancy.

**Figure 8: Recirculation rinse step**
Triflo - Ultrapure Water Without a Mixed Bed

In order to produce demineralized water with a conductivity of less than 0.1µs (>10MΩ-cm) a mixed bed ion exchange unit is always used to polish the water produced by a primary two bed demineralizer. Conventional wisdom says that it is not possible to achieve this quality using separate beds, even using counter-flow packed bed technology. While mixed beds do the job they have a well-deserved reputation for being unreliable and maintenance intensive. According to a well known manufacturer of mixed bed systems, “statistically on a per capita basis, the call-out rate for problems on mixed beds was about 20 times higher than that for two bed plants.” He went on to say “...mixed beds were more liable to organic fouling and other wasting diseases and that automatic mixed beds in particular, needed an amount of tender loving care that seemed somewhat out of proportion to the results being achieved.”

The main limitation to water purity from a two bed demineralizer is sodium leakage. Because selectivity for sodium ions on cation resin is very poor, it is very difficult to remove the last little bit of sodium from the feed water. Moreover, rinsing the last traces of NaOH from the anion bed after regeneration is difficult, particularly as the resin ages.

By incorporating a second Recoflo cation bed immediately following the anion bed, it is possible to produce mixed bed quality water using a three-bed system called TriFlo. The cation polisher bed picks up sodium leakage from the primary cation bed as well as any residual caustic left in the anion bed after regeneration. In addition, any trimethylamine coming off the anion resin is also removed by this bed. Figure 9 shows the resistivity of demineralized water produced by the laboratory pilot plant after the primary cation/anion beds and then again after the polishing cation bed. The unit was fed tap water from the city mains at a feed concentration of approximately 170 mg/L. Also shown is the same data from multiple primary bed regenerations over the course of one day of operation. The polisher bed was not regenerated over this period.

Recently, two TriFlo units were installed at a power generation plant in the U.S. mid-west. The TriFlo units, one of which is shown in Figure 10, are equipped with 152 cm diameter primary beds and a 122 cm diameter cation polisher. The primary beds are 15 cm in height, while the polisher bed is 7.5 cm high. The onstream flow rate is 136 m³/h. Raw water is withdrawn from Lake Michigan and after filtration is fed directly to the TriFlo unit. The analysis of water from this unit as well as

Figure 9: TriFlo product water onstream profiles
the previous 2-bed demineralizer and the design specification are shown in Table 1. The feed water contains a TDS of about 160 mg/L and a total organic carbon (TOC) of 2000 mg/L.

The primary beds (cation and anion) of the TriFlo are regenerated approximately 4 times per hour as described above. The polisher cation bed is regenerated once per day.

**Summary and Conclusion**

Although ion exchange is considered a mature technology, a number of new demineralizer plant designs have been introduced over the past few years, based upon packed-bed counter-flow technology. While it can be qualitatively included with this group, Recoflo represents a major quantitative departure from other ion exchange designs and conventional thinking. As such, it offers a number of significant advantages. Aside from the dramatic size reduction, perhaps most importantly, Recoflo offers the ability to produce ultrapure water without employing a mixed bed. Like any packed bed ion exchange system or indeed any reverse osmosis system, proper attention to prefiltration is required to ensure reliable operation.

### Table 1: TriFlo field results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
<th>Typical TriFlo Results</th>
<th>2 Bed Demineralizer</th>
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<tr>
<td>Conductivity</td>
<td>&lt; 0.1 µS/cm</td>
<td>&lt; 0.06 µS/cm</td>
<td>10 µS/cm limit</td>
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<td>Sodium</td>
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<td>&lt; 1.2 ppb</td>
<td>20-100 ppb</td>
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<tr>
<td>Chloride</td>
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<td>&lt; 1.3 ppb</td>
<td>&lt;5 ppb</td>
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<td>Sulfate</td>
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<td>0.8 ppb</td>
<td>&lt;4 ppb</td>
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<tr>
<td>Silica</td>
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<td>20 ppb limit</td>
</tr>
<tr>
<td>TOC</td>
<td>&lt; 300 ppb</td>
<td>100 ppb</td>
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References


