UPCORE System

Suspended Solids Removal for Countercurrent Ion Exchange Systems

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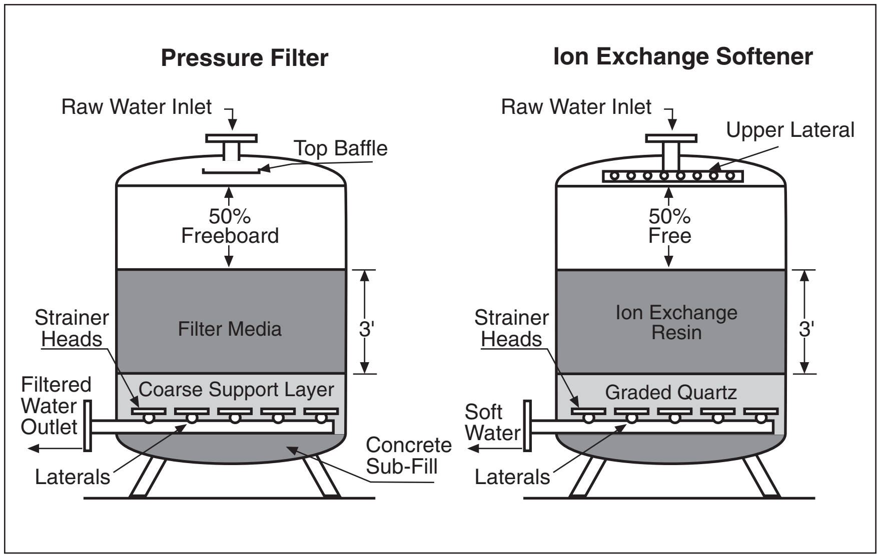
Introduction

Ion exchange demineralizers are designed and built to economically remove ionic impurities from water. Their design also makes them unintentional filters for any suspended solids left in the feedwater after pretreatment. The design and operation of any demineralizer system must include a mechanism for periodically removing trapped suspended solids from the ion exchange resin bed. This paper discusses the mechanism of suspended solids removal with traditional pressure filters and cocurrent ion exchange systems. It also reviews operational changes required to compensate for suspended solids removal in the operation of various countercurrent demineralizer system designs.

Background

Ion exchange resin development in the 1940's allowed the efficient removal of ionic impurities from water by reversibly exchanging "acceptable" ions for undesirable ions. The system design incorporated for these early cocurrent systems used downflow (in the direction of gravity) service and downflow regeneration. This design was simple and it worked effectively from an ion exchange standpoint. However, ion exchange vessels are also effective filters and will remove particulate matter that is present in the feedwater. To cleanse the bed of accumulated suspended solids, the resin was backwashed when it was taken out of service for regeneration. Incorporating a backwash step to the ion exchange regeneration procedure was a logical approach. The designs of pressure sand filters and cocurrent ion exchange vessels have a number of similarities and a backwash step was already being used for pressure sand filters.

Figure 1. Design Comparisons.
Pressure Filters and Ion Exchange Softeners



Comparison of Sand Filter & Cocurrent IX System Operation

The "rapid-sand" filter used in the early 1900's contained sand of 0.4 - 0.5 mm effective size in beds roughly 3 feet deep, and operated at a 2 - 4 gpm/ft^2 filtration rate.[1,2] Ion exchange systems, such as the softener shown in Figure 1, contained resin of 0.4 - 0.5 mm effective size in beds 30 inches or more in depth and operated at flowrates of 2 gpm/ft^3 (5 gpm/ft^2 for a 30 inch bed depth).

These sand filters were operated to a ΔP endpoint, typically around 12 psi. Run times normally ranged from 12 - 36 hours.[1] The material trapped in the filter was largely held in the top 1 to 4 inches of the bed. To clean this matter from the filter, a reverse flow of water was used to fluidize the filter media and wash the accumulated solids from the bed. The backwash time was 15 - 25 minutes at flowrates sufficient to expand the bed up to 50%.

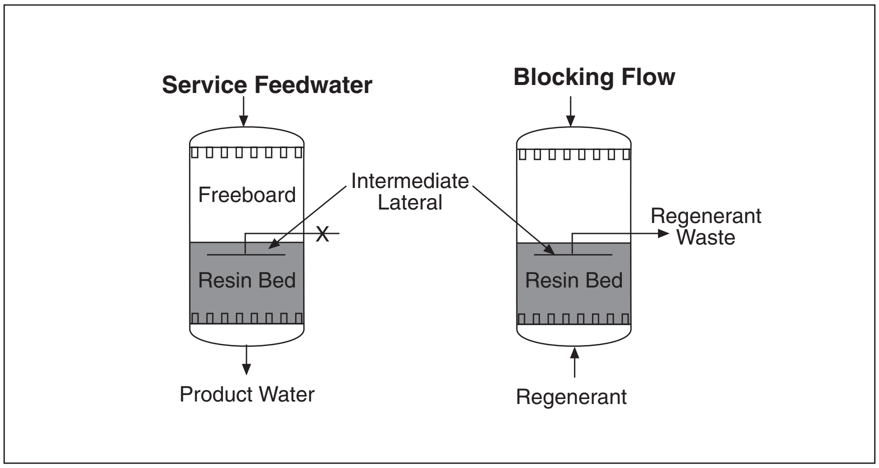
Ion exchange vessels were operated to an exchange capacity endpoint but also were designed to have run times of around 24 hours. Suspended solids present in the feedwater are also filtered out at the top of the bed. Backwash times of 10 - 20 minutes at flowrates sufficient to expand the bed 50% or more were used to flush accumulated solids from the bed.

Blocking Flow Countercurrent Systems

The chemical dosage requirements of conventional cocurrent ion exchange demineralizers are typically 200 to 400% of stoichiometeric. For every mole of ions captured, 2 to 4 moles of regenerant chemical is required. The dosage rates are normally elevated to these levels to meet the water quality constraints of the system.

Although an ion exchange system can be operated much more efficiently if the regenerant chemical is introduced to the ion exchange bed in the opposite direction to the service flow, countercurrently, it is more difficult from an operational standpoint. To achieve the advantages of countercurrent regeneration, the resin bed must stay classified. The most highly regenerated resin must stay at the service outlet end of the vessel. The resin most completely exhausted must remain at the service inlet end of the vessel.

Figure 2. Blocking Flow Countercurrent Systems



Blocking flow demineralizer designs solve this challenge by introducing a blocking flow of either air or water during regeneration that keeps the bed from expanding. An intermediate lateral placed several inches below the top of the resin bed collects both the regenerant chemical and the blocking flow (see Figure 2). Although both external piping and support equipment are different, the basic vessel design is the same as a cocurrent system. The direction of service water is downflow through a fixed bed of IX resins. Particulate in the feedwater will be filtered out at the top of the resin bed. When pressure drop becomes elevated, typically every 10 - 20 cycles, the resin bed is backwashed. The vessel contains adequate freeboard to allow the resin to be backwashed in-situ.

Resin backwash has been shown to be effective in removing particulate trapped in the resin bed if allowed to expand 50% or more. The backwash step also relieves bed compaction that results from the normal shrink-swell cycles that occur when a resin is converted from one ionic form to another. Regardless of whether the increased pressure drop across a resin bed is due to compaction or accumulation of particulate matter, the backwash step is effective at eliminating the cause and preparing the bed for continued use. However, performing a backwash disrupts bed classification. To prevent a decrease in water quality in a countercurrently regenerated ion exchange system, a double regeneration is required before returning the bed to service after every backwash.

Packed-Bed Countercurrent Systems

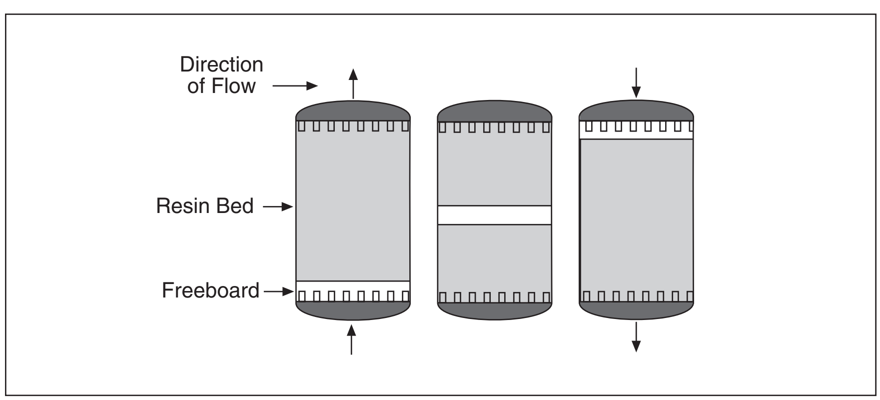
Another approach to achieve the advantages of countercurrent operation is to fill the entire vessel with resin. If a bed is "packed" full of resin, reversing the flow direction can't disturb bed classification.

In operation it isn't practical to keep a resin vessel filled at all times because resins change size during use. Another difficulty with packed bed designs is the elimination of freeboard space in the vessel makes it impossible to backwash (expand) the resin in situ. Cleaning particulate and resin fines from the bed must be addressed in some other way. The solution to these difficulties has been handled in two different approaches. The difference between the two approaches stems from the choice of whether to run service water upflow or downflow.

Upflow Service "Fluidized" Packed Beds

A small amount of void space is left in a packed bed to compensate for volume changes that occur when a resin is converted from one ionic form to another. The change in the size of the resin varies from a few percent for strong acid cation resin up to 20% or more for a strong base anion resin. Actual volume change depends on feedwater water composition, capacity utilization, etc. In all cases, some freeboard will exist in the vessel at some point in the service cycle. This freeboard space will move from one end of the vessel to the other when flow direction changes (see Figure 3). In a properly designed system, the movement of the freeboard is not significant enough to disrupt classification of the resin. The small amount of shifting in the position of individual resin beads has negligible impact on the ion exchange performance of the vessel. The shifting of the resin is actually a benefit in that it releases any compaction that exists in the resin bed.

Figure 3. Movement of Freeboard from Bottom to Top



These systems are commonly referred to as “fluidized” packed beds because the lower portion of the bed (the service inlet end) is partially fluidized during service. The percentage of the bed fluidized will vary dependent on a number of factors including flow rate, particle size, distribution of flow, water temperature, and vessel freeboard.

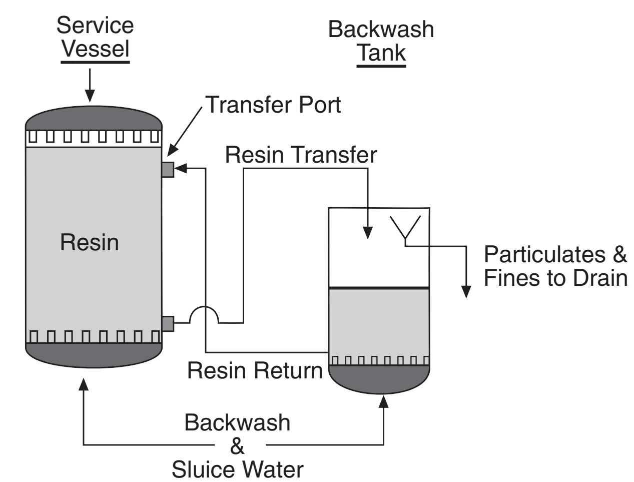
Upflow, fluidized bed systems are completely different from earlier IX system designs in how they filter/accumulate particulates in the feedwater. The resin beads at the inlet end of the vessel during service are fluidized. They do not have the ability to trap suspended solids in the pinch points between resin beads as earlier ion exchange systems had. Particulates are able to pass through the fluidized resins, deeper into the bed. As with blocking flow systems, the particulates will accumulate over time and the pressure drop across the bed will increase.

However, the increase in pressure drop is more gradual in the fluidized bed systems than in blocked flow systems. One reason is that suspended solids are partially washed from the bed during regeneration. Even at the relatively slow flowrates used in regeneration, and even with most of the particulates trapped deep in the bed, some suspended solids are removed during the initial minutes of regeneration. A recent IWC paper[3] reported the amount of suspended solids removed during regeneration was about 7% of the suspended solids collected during the service cycle. Most of the solids were removed in the first three minutes of regeneration. The second reason that pressure drop increases more gradually in fluidized bed systems is because deep bed filtration distributes suspended solids throughout the entire vessel. In blocking flow systems, most solids accumulate within the top few inches of resin, plugging the void space, and causing a more rapid increase in pressure drop.

However, the pressure drop does continue to increase. After a period that might be a few weeks or perhaps several months or more, the pressure drop reaches a point where the vessel must be removed from service. At this point, the resin is sluiced from the service vessel to the backwash vessel specifically designed for cleaning the resins (see Figure 4). The backwash step is effectively the same as a backwash in earlier system designs. The key difference is the suspended solids and resins fines are mixed throughout instead of being concentrated at the top of the resin bed. The backwash step is monitored (versus run for a preset automated time period) to determine when the bed is adequately cleaned and ready to return to service. The resin is then sluiced back to the service vessel.

As with the blocking flow system, the amount of regenerant chemical used is increased by 2 - 3 times the normal dosage for the first regeneration following a backwash. The elevated chemical dosage is required to return the polishing zone of the bed to a high degree of regeneration and ensure expected water quality is produced.

Figure 4. Fluidized Bed Backwash System



Downflow Service Packed Beds

The second approach for operation of a packed bed system is to run the service step downflow and regenerate the vessel upflow. This approach insures the bed remains classified during service. No fluidized resin zone exists.

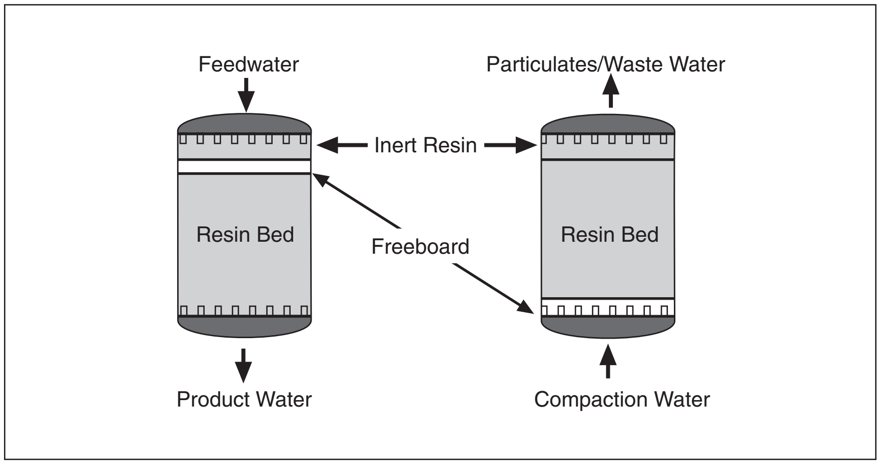
The challenge to operation with this design is keeping the bed compacted during regeneration. As mentioned earlier, packed beds all will have freeboard space left in the vessel. Typical regeneration flowrates are not sufficient to lift the resin to the top of the vessel and keep the resin classified. This problem is resolved in the UPCORE* system design, an upflow countercurrent regeneration system pioneered by The Dow Chemical Company, by incorporating a compaction step in the regeneration sequence.

Compaction

The first step in the regeneration cycle of an UPCORE system uses an upflow of water to compact the resin bed against a layer of floating inert beads at the top of the vessel. The flow rate needed for compaction is determined by the resin particle size, particle density, amount of freeboard, and water temperature. It only takes a few minutes for the bed to fully compact. Once compacted, the resin bed remains in place even if the flow rate is reduced. This allows regeneration to take place at the flow rate which achieves the best results in terms of regenerant contact time and concentration.

As this design operates downflow, through a fixed bed of resin, particulates in the feedwater are removed at the top of the bed as in a conventional cocurrent system. Penetration of solids into the bed is mostly limited to the top few inches of resin. During compaction, the resin is pushed to the top of the bed and compressed against a layer of floating inert resin (see Figure 5). This step prepares the bed for chemical injection. Compaction also flushes trapped particulate matter from the bed.

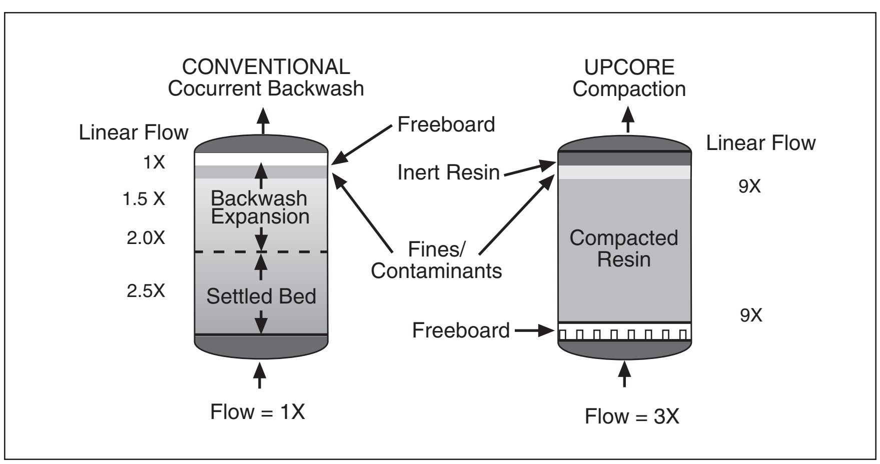
Figure 5. UPCORE System - Compaction



The size of the inert beads and the design of the upper laterals are critical variables in the compaction step. The inert beads must be small enough to prevent the resin beads from passing through, but large enough to allow free passage of particulates. The overall system is designed so particulates and resin fines can be freely flushed from the vessel.

The depth of the inert layer is also important. Too shallow of bed depth may allow resin to penetrate, causing lateral blockage. Too deep a bed depth could reduce the efficiency of particulate removal. Surprisingly, the proper inert resin depth is roughly the same as the amount of freeboard space left above the fluidized resin bed in a cocurrent system during backwash (see Figure 6). The distance particulates must travel from the top of the resin to the outlet of the vessel is effectively the same in both system designs.

Figure 6. Solids Removal Mechanisms



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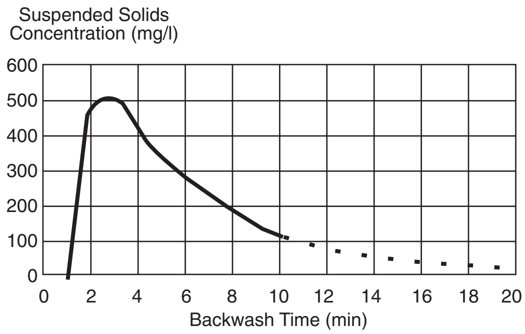
However, a key difference between the backwash of a cocurrently operated vessel and the compaction step of an UPCORE system is the flow rate of the “cleansing” flows. The flowrate used during compaction is significantly faster, as measured by gpm/ft^2, than used during a conventional backwash. The higher flowrates used during compaction result in substantial increases in the hydrodynamic shear forces across the resin surfaces. The compaction flow is effective at removing the particulates attached to the surfaces of the resin beads as well as the matter held in pinch points between resin beads.

Closer inspection of backwash and compaction shows the difference in hydrodynamic shear is more significant than the ratio of their respective flowrates. The void space between the resin beads is roughly 33% of the total bed volume. If the linear flowrate through an empty vessel is X gpm, the flowrate through a packed bed of resin will be (1 ÷ 0.33)X or 3X. The linear velocity through a resin bed during regeneration will have a linear velocity of 3X at the start of backwash. However, as the bed begins to expand, the void volume increases, and the linear velocity decreases. At 100% bed expansion, the linear velocity is 1.5X. There is always some freeboard space left above the expanded resin to prevent resin loss. The freeboard space above the resin will once again have a linear flowrate of X. The flowrate of X is the final velocity for flushing particulate matter from the vessel.

A packed bed vessel also has 33% void space. The percent void space remains constant during the compaction step because the bed is kept packed. The flowrate throughout the entire compaction step is three times the linear velocity through an empty vessel. It also has to be noted compaction flowrates are faster than used during backwash, up to three times faster. So the actual flow

Figure 7. Backwash Effluent Profile Suspended Solids vs. Backwash Time

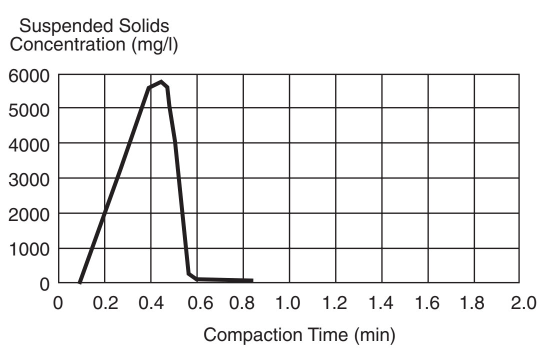


velocities at the top of the vessel where the solids are flushed from the vessel are up to nine times faster during compaction than during backwash (see Figure 6).

A profile of a backwash effluent plotting concentration of suspended solids versus time is shown in Figure 7.[4] This curve highlights two typical characteristics. First, there is always a time lag after the start of the backwash step that varies with both flowrate and percent freeboard. The greater the freeboard, the longer it will take to expand the bed sufficiently to allow particulate to begin to be flushed from the bed. Second, fluidization of the bed during backwash is responsible for the “tail” of the curve The total time for backwashing a cocurrent system where the resin is backwashed every regeneration ranges from 10 to 20 minutes. Suspended solids are not totally removed at any time, so the decision on when to stop the backwash is somewhat arbitrary. In practice, an occasional extended backwash may be required to more thoroughly cleanse the bed.

A profile of the effluent during compaction is shown in Figure 8. It plots the same properties as Figure 7 but the scale of units has been modified by a factor of 10X for suspended solids concentrations and by a factor 0.1X for time. The change in scale was required to adjust for the more rapid removal of suspended solids achieved during compaction. This profile differs in that the time lag before suspended solids begin to be washed from the vessel is much shorter. It only takes a matter of seconds for the resin bed to move to the top of the vessel because there is minimal freeboard space.

Figure 8. Compaction Effluent Profile Suspended Solids vs. Backwash Time



Compaction has one additional advantage over the conventional backwash that warrants note. Most systems are required to monitor the backwash temperature and adjust flowrate to compensate for the change in bed expansion at different water temperatures. In practice, adjustments are generally belated or ignored completely, resulting in inadequate backwash expansions and poor removal of suspended solids, or excessive backwash and loss of resin that is flushed to drain. In contrast, only resin fragments, if any are present, can be flushed from the UPCORE system during compaction.

Settling

Following compaction, regenerant injection, and slow rinse, the flow through the UPCORE system is stopped for a few minutes to allow the resin to settle to the bottom of the vessel. Settling does not occur all at once with the entire bed dropping to the bottom of the vessel as a plug. Instead, the resin "rains down" in a continuous fashion as a narrow zone of fluidized resins moves up the vessel. The movement of an individual resin bead, either up or down, is not significant enough to detract from the ionic stratification.

Settling has two critical affects on system operation. First, it relieves any compression of the resin created during the ionic cycling of the resin during regeneration. Secondly, it helps in cleaning the bed. The movement of the fluidized zone during settling allows any resin fragments or small particulates that are located within the bed to move upward. The movement in any one cycle is small but the continuous compaction and settling that occurs with normal operation has a significant affect. This has been demonstrated by injecting dyed resin fragments into a bed of resin several feet from the top. Over a series of six compaction/settling cycles, the fragments moved to the top of the bed where they were flushed from the system.[5]

Summary

The very nature of the way ion exchange resins are most efficiently used makes them effective filters of suspended solids. Removal of suspended solids from conventional cocurrently regenerated demineralizers have proven effective at continuously removing particulate matter.

The chemical efficiency and water quality of countercurrent regeneration is known to be superior over cocurrent designs but the mechanical aspects of operating countercurrently have certain barriers to overcome. Countercurrent system designs must compensate for bed compaction that occurs with use. They also must have some mechanism for suspended solids removal.

Blocking flow system designs operate downflow and rely on periodic in-situ backwashing to remove trapped particulates and release compaction. Stopping operation to backwash is roughly required every 10 - 15 cycles. Upflow service packed beds are regenerated downflow so using blocking flow during regeneration is unnecessary. The settling of the resin when direction of flow changes releases bed compaction. Deep bed filtration reduces the need for backwash to a period of weeks or even months. When backwash is required, the system is shut down and the resin is transferred to a separate backwash vessel.

The UPCORE system is a downflow service, upflow regeneration packed bed system. It utilizes a compaction step to compress the resin to the top of the bed as the first step in every regeneration cycle. Compaction effectively removes the suspended solids trapped in the upper part of the resin bed during the service cycle. A separate settling step relieves compaction of the bed. It also lifts any resin fragments or particulates located within the resin bed toward the top of the vessel where they can be removed during compaction. Suspended solids are continuously removed in every regeneration so a separate backwash operation is not required.

References

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[2]"Demineralization by Ion Exchange", Samuel B. Applebaum, Academic Press, 1968.

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[4]Pilot plant data shared with Dow by an equipment manufacturer.

[5]Internal laboratory test data, The Dow Chemical Company.

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Warning: Oxidizing agents such as nitric acid attack organic ion exchange resins under certain conditions. This could lead to anything from slight resin degradation to a violent exothermic reaction (explosion). Before using strong oxidizing agents, consult sources knowledgeable in handling such materials.

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