High-Performance Demineralization:

A Case Study

By Filip Rochette

Introduction

In a world that is constantly changing, companies are being forced by multiple authorities to control their wastewater and chemical usage. Older techniques may cost more to implement, due to high waste production as well as high energy and chemical consumption. This case study details how the optimization of an innovative demineralization unit evolved to overcome the limitations of previous systems.

Figure 1. Continuous counter-current demineralization unit

A multiport valve in the center

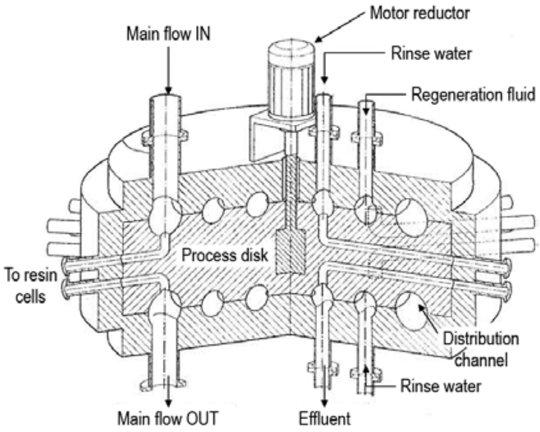
The technology is markedly different from other continuous, counter-current ion exchange systems that are available. The process disc within the multiport valve rotates and distributes the different flow streams to the cells containing ion exchange resin or other adsorption materials. During a full rotation, each resin cell is subjected to an entire sorption cycle. The process disk contains the process schematic and is used to index the process configuration to the next valve ports. The number of ports used depends on the process application; in this test case, the number of ports, and hence ion exchange vessels, is 18. The main process flow stream enters the valve from above the unit and leaves from an outlet on its underside (see Figure 2).

Once inside, distribution channels divide the process stream and make the connection to the valve's external nozzles, which feed the vessels that are filled with an ion exchange resin. The treated fluid collects in a lower channel and leaves the valve via the main outlet nozzle. As shown in the diagram, other external nozzles convey rinse water and regeneration fluid into the valve and effluent away from the system. Internal channels are separated from each other by two O-rings; a leak chamber or channel between these seals is used to detect and reveal a possible leakage. An encoder, which is interfaced with a controller unit and physically connected to the internal process disk by the system's central axis, generates pulses, or counts, while the disk rotates internally through 360°, from one outside port to the next, as an indexed movement or 'step time'. At the initial start-up of the installation, the controller receives the absolute encoder's 'zero point'. Once it has found this point, the internal position of the process disk is aligned with the outside nozzles by setting an offset parameter. After this has been set, the valve remains internally aligned. An LCD screen on the controller displays system information and data, including the position of the process disk, index time, offset to encoder 'zero point', remaining time until next index and possible position error.

An implemented unit

The subject unit was a continuous, counter-current ion exchange unit that featured the implementation of a patented ion exchange system based on true counter-current ion exchange, which resulted in the continuous production of demineralized water with a conductivity below 1.0 µS/cm. All steps in the process happened simultaneously. While a part of all columns were in production, some columns were switched in rinse, regeneration and/or preconditioning zones. A distribution valve in the cation unit, as well as in the anion unit, provided the concatenation of two passes through the ion exchange columns. The first pass flowed through partially exhausted columns that had already been used in the second pass. The second pass, in turn, flowed through freshly regenerated columns coming from the preconditioning zone. This ensured a very low conductivity with an optimal use of the regenerated resins. The working point almost touched the stoichiometric level, which led to very low chemical consumption.

Figure 2. Cross-sectional view of the multiport valve

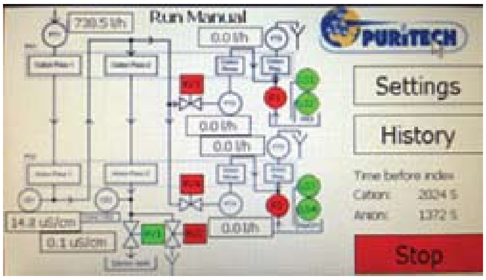


Plant design

The system consisted of two separate but connected basic units: one cation and one anion skid, consisting of different columns filled with ion exchange resins. An initial P&ID was made for both ion exchangers (see Figure 3).

The installation setup was equipped with a touch screen and was fully PLC-controlled. The demineralization unit was tooled with conductivity measuring devices after the first and the second pass. All valves opened and closed automatically. It was possible to control the machine from a distance via a modem with a mobile data card and assigned IP address. Data logging per minute was built in. This enabled the client to control all data without constantly controlling the machine. It was a data logger that kept an eye on the machine, minute by minute (see Figure 4).

Figure 4.
Data logging control interface

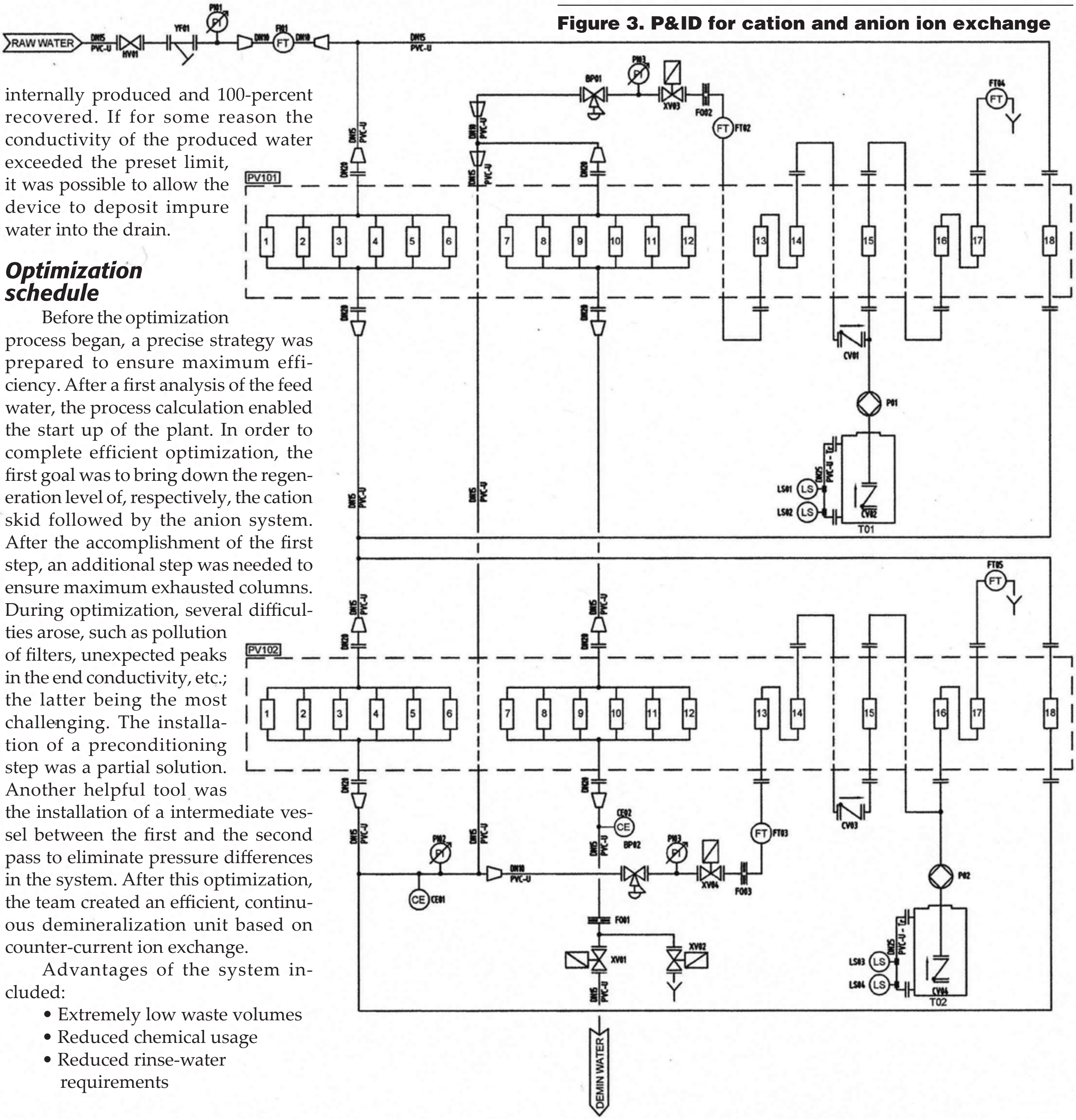


Time before index
Cation: 2024 S
Anion: 1372 S

Regeneration

When one of the cation or anion columns in production was exhausted, the corresponding distribution valve indexed and pushed the resin into regeneration. The cation resins were regenerated with hydrochloric acid, while sodium hydroxide was used for regeneration of the anion resins. The regenerant was dose-concentrated, then diluted with outgoing rinse water. All rinse water was internally produced and 100-percent recovered. If for some reason the conductivity of the produced water exceeded the preset limit, it was possible to allow the device to deposit impure water into the drain.

Figure 3. P&ID for cation and anion ion exchange



Optimization schedule

Before the optimization process began, a precise strategy was prepared to ensure maximum efficiency. After a first analysis of the feed water, the process calculation enabled the start up of the plant. In order to complete efficient optimization, the first goal was to bring down the regeneration level of, respectively, the cation skid followed by the anion system. After the accomplishment of the first step, an additional step was needed to ensure maximum exhausted columns. During optimization, several difficulties arose, such as pollution of filters, unexpected peaks in the end conductivity, etc.; the latter being the most challenging. The installation of a preconditioning step was a partial solution. Another helpful tool was the installation of a intermediate vessel between the first and the second pass to eliminate pressure differences in the system. After this optimization, the team created an efficient, continuous demineralization unit based on counter-current ion exchange.

Advantages of the system included:

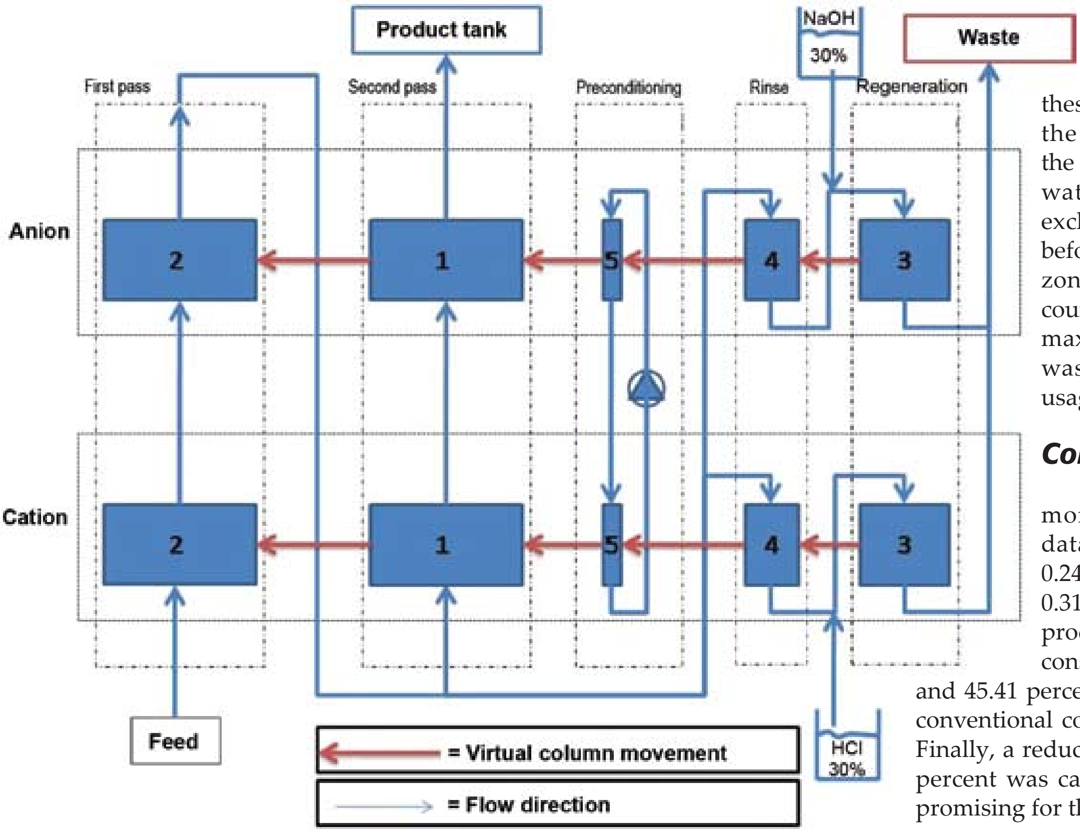
- Extremely low waste volumes
- Reduced chemical usage
- Reduced rinse-water requirements
- Simple, proven design
- Compact plant footprint
- Low electrical consumption
- Higher resin efficiency
- No compressed air needed

These advantages resulted in cost savings on chemicals, water consumption and energy. The system avoided unexhausted zones leaving the production zone, due to production zones being split up over several columns. A maximum utilization of regenerated resin was thus ensured.

Schematic overview and detailed information

The core system was based on a production zone in up-flow

Figure 5. Schematic overview and detailed information



combined with preconditioning, rinse and regeneration zones in down-flow (counter-flow principle). The counter current (see Figure 5) was established by the virtual movement of the columns (red arrows) in the opposite direction from the product flow (blue arrows). The internal process disk indexed to obtain virtual movement of the columns. All columns remained static in the installation.

The feedwater entered the multiport valve that divided the fluid over the first pass through the cation and anion exchanger. As the fluid left the first pass, a small amount of the partially demineralized water was tapped off for the rinse process, while the other part underwent a second pass through both exchangers before deposition in the product tank. As mentioned before, the second pass (1) flowed through a freshly regenerated and rinsed resin coming out of the preconditioning zone. The first pass (2) on the other hand, flowed through partially exhausted resins coming from the second pass production zone to ensure that all resins were fully exhausted after the production zone. In regeneration (3), the columns underwent a recovery step. The cation was regenerated with hydrochloric acid and the anion with sodium hydroxide. The chemicals were dose concentrated and dilution took place in the system by the outgoing rinse water.

Next, the columns entered the rinse zone (4) to wash away remaining chemicals and removed elements derived from the production zone. A big advantage was unused chemicals re-entering the regeneration step, which increased efficiency and resulted in a strong reduction of chemical usage. Lastly, a preconditioning zone (5) was implemented to remove remaining unwanted ions from the resins. Without preconditioning, these ions could, when entering the production zone, increase the conductivity of the produced water. In this way, maximum exchange capacity was ensured before going into the production zone, resulting in a continuous counter-current system whereby maximum efficiency, minimum waste and minimum chemical usage was assured.

Conclusion

The test lasted for three months and the performance data revealed an HCl usage of 0.246 kg/h and a NaOH usage of 0.310 kg/h. After up-scaling to a production of 15 m^3/h, the system consumes 57.52 percent less HCl and 45.41 percent less NaOH compared to a conventional counterflow, fixed-bed system. Finally, a reduction of waste of at least 75.93 percent was calculated, which is extremely promising for the future.

Figure 7. Comparison between continuous and conventional discontinuous counter-flow demineralization unit of 15 m^3/h

Regenerant usage:

- Counter-flow fixed bed system **HCl** Usage : 29,36 kg/h
  = 1.96 kg regenerant/m³ product
- ION-IX **HCl** Usage : 12,48 kg/h
  = 0.83 kg regenerant/m³ product

➔ ***57,52 % less HCl usage***

- Counter-flow fixed bed system **NaOH** Usage: 28,95 kg/h
  = 1.91 kg regenerant/m³ product
- ION-IX **NaOH** Usage : 15,80 kg/h
  = 1.05 kg regenerant/m³ product

➔ ***45,41 % less NaOH usage***

Cost saving due to lower regenerant usage/year:

Treated volume = 31.472 m³/year (8h a day / 5 days a week)

Regenerant price :

- HCl: € 0,2 /kg
- NaOH: € 0,35 /kg

→ ***€ 17.873,81 savings per year***

Waste stream:

- ION-IX : 1,77 %
- Conventional system : 7,34%

→ ***75,93% less waste***

Waste stream cost price : ± € 1,1 / m³
Savings waste stream : € 2.076,58 /year

TOTAL SAVINGS PER YEAR
€ 19.950.38

Figure 6. Performance data of test unit

Inlet conductivity (µS/cm^2)	Outlet conductivity (µS/cm^2)	Flow (l/h)	NaOH usage (kg/h) 100 %	HCl usage (kg/h) 100%	Waste stream (%)
348	< 1	1,000	0.310	0.246	1.77

About the author

◆ *Filip Rochette owns and operates PuriTech Ltd., located in Belgium, which he founded in 1996. He holds an electro-mechanical engineering degree and worked for 10 years in the pharmaceutical industry, designing high-purity water systems and clean-room production units. Additionally, Rochette operated as an independent freelance engineer for different pharmaceutical companies in Belgium. He holds US Patent 6,802,970 for the ION-IX process valve, issued in 2004.*

About the company

◆ *PuriTech, an international separation technology company, has more than 80 installations worldwide of its patented ION-IX technology used in nitrate removal installation; sugar treatment and hydrometallurgy applications. Flowrates of these ion exchangers range from 10 m^3/h up to 2,100 m^3/h.*

About the product

◆ *ION-IX systems are applied in a wide variety of ion exchange applications where very low waste or recovery of high-value components is required. Most applications are in water treatment, hydrometallurgy, sugar treatment and recovery of high-value chemicals.*