HIGH RECOVERY WATER TREATMENT FOR NON POTABLE REUSE USING AN INTEGRATION OF ION EXCHANGE AND REVERSE OSMOSIS

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I.INTRODUCTION

1.1 General Background

Water scarcity is a growing global issue, with half of the world's population expected to be living in water stressed areas by 2025 [1]. The combined effects of growing populations, rising incomes, and expanding cities will see an exponential rise in water demand, while supply becomes more erratic and uncertain. Water scarcity, exacerbated by climate change, could cost some regions up to 6% of their GDP, spur migration, and spark conflict. [2]. A variety of water sources is required to ensure public health and social, economic, and environmental sustainability. There is a growing need to adopt non-potable reuse solutions as potable water supplies deplete, increasing the water security of businesses and people. Advanced wastewater treatment methods are a key enabler for non-potable reuse, further removing impurities beyond what is possible with conventional wastewater treatment methods and reaching the strict quality requirements that are often required for potable or industrial reuse.

Reverse osmosis (RO) is widely used to treat wastewater for non-potable reuse schemes. It is a widely used and well understood water treatment method which can be employed to remove a range of contaminants from water and wastewater [3]. RO membranes are prone to scaling during operation, often due to calcium, magnesium, and silicate in the feed. Membrane fouling can also occur due to strontium, barium, aluminum, iron, and manganese. Sulphate, phosphate carbonate or silicate scaling associated with calcium and magnesium of limit water recovery to below 80% during treatment, resulting in large brine volumes. Scaling and fouling of membranes also results in shorter RO membrane life, with more frequent replacement resulting in higher costs. Additional downtime is also required for CIP (clean in place), and additional chemicals are required to be used.

To combat low recoveries and shorter membrane life, Clean TeQ Water has developed a high recovery water treatment solution which uses a combination of continuous ion exchange and reverse osmosis.

1.2 Continuous Ion Exchange

Clean TeQ Water's CIF® (Continuous Ionic Filtration) technology is well suited to treat difficult mine water streams. It can selectively remove contaminants through ion exchange while simultaneously performing physical filtration, tolerating suspended solids in the feed. The ion exchange resin is periodically moved around the system for reconditioning. Additional information about CIF can be found in the Appendix.

1.3 HIROX® Technology

Clean TeQ Water's HIROX® (High Recovery RO) technology is specifically designed to remove di and tri valent cations that cause fouling and scaling before water proceeds to RO. The first part of the process uses CIF to remove ions like calcium, magnesium, iron, and manganese from the water to very low levels. The softened water then proceeds to RO, which can be operated at its designed pressure limit due to the reduced scaling and fouling risks. The RO concentrate is then used to regenerate the ion exchange resin, without the addition of any chemicals when there is sufficient sodium in the feed. A diagram of the HIROX system can be seen in Figure 1.

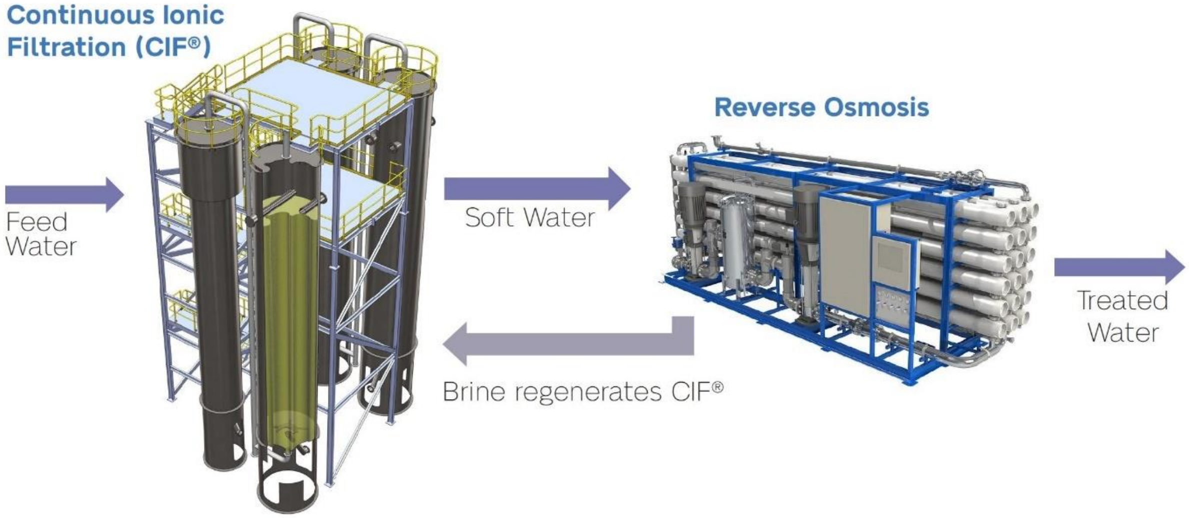

Figure 1. Diagram of a HIROX System

II.RESEARCH OBJECTIVES

The aim of the research conducted was to provide a proof of concept of the HIROX technology by confirming:

1. The CIF pre-treatment step performs sufficient softening to allow RO to achieve 92-95% recovery
2. RO brine can be used to regenerate the ion exchange resin in CIF without any reagent addition
3. The sodium in the RO brine will regenerate the resin regardless of whether the brine primarily consists of sodium chloride or sodium sulphate.
4. Gypsum precipitation can be tolerated in the desorption column during the resin regeneration process

Site and laboratory piloting were undertaken for a municipal effluent stream and a mining wastewater stream to test the viability of the HIROX system and the accuracy of in-house modelling tools. A desktop study was also undertaken for industrial wastewater to determine the effectiveness of using HIROX for process water reuse, and for groundwater to determine whether water treated by HIROX can substitute precious potable water resources.

III. METHODOLOGY

3.1 Municipal Effluent Piloting

3.1.1 Site Piloting

The pilot plant was located in Northern Australia and was designed for high recovery desalination of an MBR effluent for industrial reuse. The piloting equipment consisted of a CIF adsorption column operating with manual resin transfers, and a pilot scale RO system, as seen in Figure 2. The RO system was operated in batch configuration, with water softened by CIF fed to the system. Treated water exited the RO, and the brine was recirculated through the RO skid until the volume was reduced to 10% (i.e., 90% net water recovery).

Figure 2. Photo of Site Piloting Equipment for Municipal Effluent Reuse, CIF (left), RO Unit (right)

3.1.2 Laboratory Piloting

Further pilot work was undertaken in Clean TeQ Water's Melbourne laboratory to test the regeneration of ion exchange resin using the RO brine. Equipment consisted of a 2L CIF® packed bed column for adsorption, a 1L CIF® packed bed column for desorption, a 1L CIF® fluidized column for wash, and a commercially available SWRO membrane. A photo of the SWRO and one of the CIF® columns can be seen in Figure 3.

The RO was used to concentrate the brine to the achieve the expected sodium concentration required for desorption of the ion exchange resin. The concentrated brine was then used to desorb the resin that had been loaded on site on a 40mL batch system scale, and the subsequent re-adsorption capacity was analyzed by running the sample feed water obtained from site.

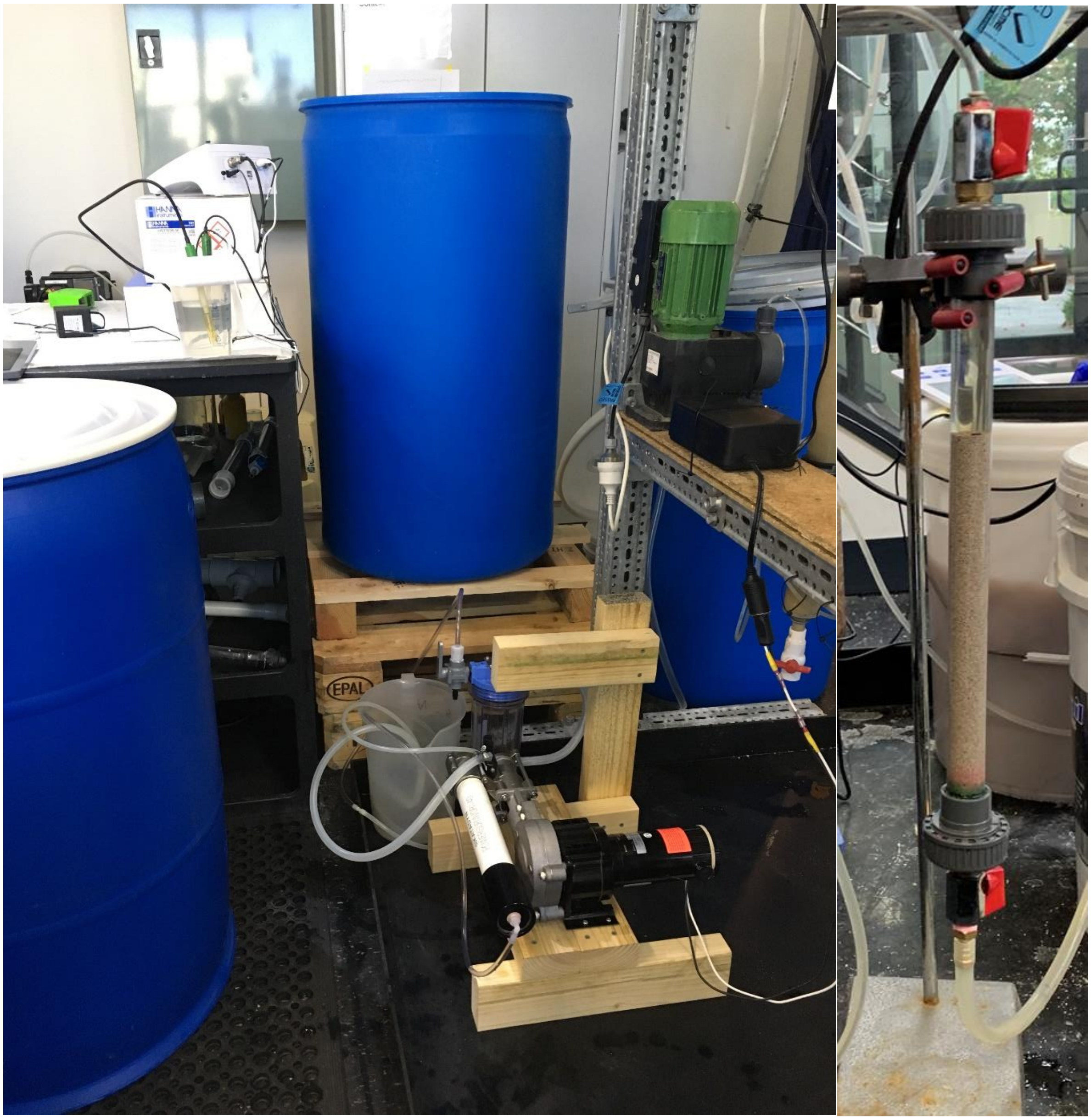

Figure 3. Photo of Laboratory Setup for Municipal Effluent Testing.

3.2 Brackish Mining Wastewater Piloting

The pilot plant was located in a factory near the mining site and water from a nearby coal mine was used as the feed. The water was from a mine tailings dam and largely consists of water generated from the dewatering of an open pit. Piloting equipment included an additional CIF® agitated pachuca column in the setup due to the high potential for gypsum formation during desorption. A photo of the site piloting equipment can be seen in Figure 4.

Figure 4. Photo of Brackish Mine Water Piloting Equipment

In this case the client was willing to accept the results of commercial simulation packages for RO, and as such an RO unit was excluded from the setup. LewaPlus® and DuPont®'s WAVE (Water Application Value Engine) were used to model the brine composition at 95% RO recovery (20 times concentration factor), and a synthetic brine was produced to match the composition.

During piloting, feed water was continuously pumped up through the adsorption column filled with approximately 75 L of strong acid cation (SAC) resin. The feed water was pumped from the feed drum into the adsorption column at a rate of 327 L/h (4.3 BV/h), with 300 L delivered each cycle. During the initial start-up of the column the resin was fresh and thus the column was run for 4 hours before starting transfers, aiming to reach steady state operation quickly. Once resin transfers began, water samples were taken every two hours and resin transfers occurred every hour. Water sample collection occurred immediately prior to resin transfers where resin at the bottom of the column is fully loaded, and the product water quality is expected to be poorest.

A small portion of the column's resin inventory (6 L) was transferred from the bottom of the adsorption column every hour, and 6 L of regenerated resin from the wash column was transferred to the top of the adsorption column. Resin was transferred automatically using pneumatic airlifts. The treated water exiting the column was stored in an intermediate water tank, representing the feed to the reverse osmosis unit.

The resin removed from the adsorption column was transferred to an agitated desorption/regeneration column for first stage regeneration. This agitated stage removed the bulk of the calcium and magnesium from the resin, while allowing for gypsum precipitation to occur. Second stage regeneration occurred in a packed desorption/regeneration column to allow for further polishing of the resin. The spent synthetic RO brine from the resin polishing stage was used in stage one regeneration, making the best use of the sodium content in the brine and reducing issues associated with gypsum solids generation. After regeneration, the resin is transferred to the wash column to remove any excess brine, allowing it to be transferred back to the adsorption column and continue treating water.

3.3 Desktop Studies

Two additional feeds underwent desktop studies to access the performance of a HIROX® system, one from an FMCG industrial manufacturing facility, and the second a well water for the oil and gas industry. The desktop studies aimed to determine the technical feasibility of the HIROX® process. The main parameters of interest are the calcium and magnesium removal efficiencies, and the maximum recovery that can be achieved by RO

The calcium removal extent for each feed stream was estimated to be 97%, and the RO recovery of the softened water was determined by simulation with either LewaPlus® or WAVE. The brine composition was used as an input to Clean TeQ Water's in house ion exchange model, which simulates the chemistry and kinetics of CIF's adsorption and desorption processes. Results obtained by the model were verified by small lab-scale batch tests and continuous lab testing over a wide range of feed concentrations. The RO recovery and CIF performance were updated iteratively until a steady state was reached, and the final calcium removal and RO recovery were obtained.

IV.RESULTS AND DISCUSSION

Piloting and desktop studies of the HIROX system were successfully completed, and all of the research objectives were met. The results obtained for each water type can be seen in Table 1. The total hardness value after treating with CIF was <10 mg/L as CaCO3 for the tertiary effluent, and 51 mg/L as CaCO3 for the mining wastewater. This is a 97% and 95% reduction in hardness for the tertiary effluent and mine wastewater respectively, allowing the high RO recoveries of 92% and 95% to be achieved.

Table 1. Results of Piloting and Desktop Studies

Feed Water	Resin Ratio	Average Feed to CIF®				Average CIF® softened feed to RO			RO Recovery
		Ca	Mg	Na	Total Hardness	Ca	Mg	Total Hardness	
	BV/BV	mg/L	mg/L	mg/L	mg/L CaCO3	mg/L	mg/L	mg/L CaCO3	
Tertiary Effluent Wastewater	100	39	62	519	350	<1	1	<10	92%
Mine Wastewater	50	115	208	443	1144	6	9	51	95%
Industrial Process Water	25	1010	-	4029	2525	30	-	75	85%
Oil and Gas Well Water	20	1000	510	5400	4590	50	520	2260	80%

For the tertiary effluent, the RO brine was concentrated to approximately 20g/L TDS and mainly consisted of sodium chloride. Despite the concentration of the brine being much lower than what is used for regeneration of ion exchange resin in conventional batch ion exchange systems, the brine provided enough sodium to regenerate the resin in CIF's desorption column without additional chemicals.

For the mining wastewater, the RO brine was concentrated to approximately 60 g/L TDS and mainly consisted of sodium sulphate. Upon desorption of the loaded resin with the RO brine, approximately 1% w/w gypsum solids were generated. These solids are managed easily using the agitated column, and the gypsum formed is removed with the spent solution during the resin transfer step. This is a process that cannot be achieved using conventional batch IX processes as solids block the system.

Both the RO brines were found to be highly stable, not forming any precipitates after storage for a long period, showing that an RO would not suffer from scaling, even without any antiscalant supplied. Projections made using vendor software packages confirmed that no scaling is expected with the RO operating with the CIF® pre-treatment, even without the use of antiscalant.

For both the industrial process water and oil and gas well water, the high concentrations of calcium in the feed were greatly reduced, from 1,000 mg/L to less than 50 mg/L. Removing the calcium form these feeds prevents calcium carbonate and sulphate scaling from occurring on the membranes, allowing an increase in RO recovery from 30% to above 80%.

Based on the outcomes of the oil and gas well water study, Clean TeQ Water is delivering its first commercial HIROX® installation, a 1.2 MLD HIROX® plant in the Middle East for NESR. The plant also includes a brine recovery circuit to recover salt, instead of adding imported salt, to achieve the water density required for well completions water. The reuse of salt will result in substantial operational cost savings for the end user. The plant is expected to achieve an overall system recovery of 90% recovery (RO recovery of 80%), compared to the 30% recovery that would be achieved by RO alone.

V. CONCLUSIONS

Two feed waters were softened using CIF® to a sufficient level to be able to achieve 92-95% recovery in an RO. The pilots prove that the RO brines can be successfully used to regenerate the ion exchange resin "free of charge" without any reagent addition, which is normally required in batch IX processes. The desktop studies confirmed that the HIROX® system can also be applied to allow non-potable reuse in the industrial water treatment sector, along with the oil and gas sector to achieve much higher recoveries than what would be achieved with RO alone. CIF® treated water has been shown to be able to meet a hardness discharge concentration of within 10-100 mg/L as CaCO3, which is sufficient to ensure that an RO system can operate downstream at recoveries of 92-95% or higher without suffering from scaling. The results of pilot tests and desktop studies performed achieve the research objectives and provide a proof of concept for Clean TeQ Water's HIROX technology.

These results have significant implications for high recovery desalination in non-potable reuse applications. Achieving higher recovery is pivotal in areas where water is scare, as the largest volume of water possible is required for use. HIROX® greatly reduces the scaling and fouling risks often faced by RO when not paired with adequate pre-treatment. Lower brine volumes are also a key feature of the technology, providing a significant reduction in the size of evaporation ponds or volume to be trucked off site, sent to sewer, or sent to disposal wells.

VI. REFERENCES

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VII. Appendix

Clean TeQ Water's CIF® (Continuous Ionic Filtration) technology is well suited to treat difficult mine water streams. It can selectively remove contaminants through ion exchange while simultaneously performing physical filtration, tolerating suspended solids in the feed, and allowing for cheaper reagents such as sulphuric acid and lime to be used. These usually cannot be used in conventional batch ion exchange systems since the precipitates that form cause the system to block up during desorption. CIF® is also more resistant to resin bed fouling compared to conventional ion exchange approaches since the ion exchange resin in periodically moved around the system. Higher removal efficiencies are also achieved in CIF® due to the counter-current movement between the feed solution and ion exchange resin. The system can also tolerate up to 150 mg/L of suspended solids in the feed and perform physical filtration if required.

In CIF®, ion exchange resin is continuously moved around the system for regeneration. Water treatment occurs in the adsorption column, which uses a moving packed bed of ion exchange resin. It can be likened to the continuous sand filtration process; however, the ion exchange resin continuously removes dissolved ions through ion exchange while simultaneously filtering solids if required. CIF® consists of a series of vertical columns, as seen in Figure 5, with one column treating the water, and the rest used to recondition the ion exchange resin as part of a continuous process.

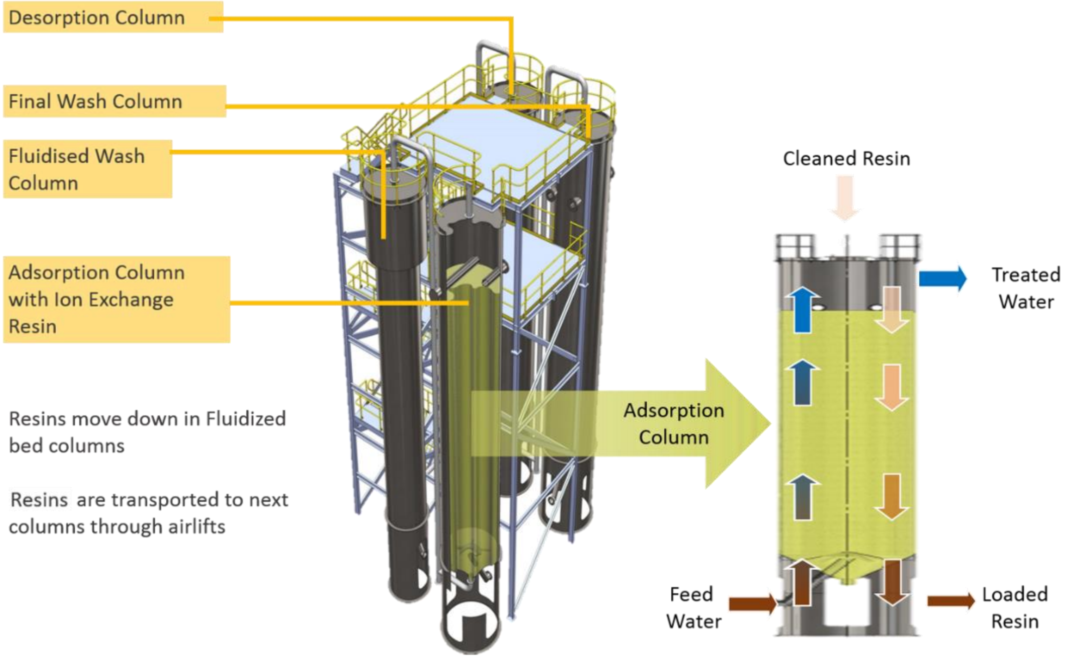

Figure 5. Diagram of a Typical CIF System