Premier’s Water Foundation Grant

Final Report

Clean-iX® Pilot Plant
for
Recycling Water
from
Woodman Point WWTP

14 October 2008

The Premier’s Water Foundation
"Fostering research and development that challenges boundaries and investigates innovative ways of managing our water resources."

An initiative of the Western Australian Government's State Water Strategy.
Executive Summary

A continuous counter current ion exchange technology, originally developed for minerals processing, also has performance characteristics which make it suitable for a range of water treatment applications.

In order to gain an understanding of the potential of the technology to help achieve Western Australia’s water recycling objectives, a pilot plant trial was conducted under the auspices of the Premiers Water Foundation and with the support of trial partners Water Corporation and Hlsmelt. The pilot plant was established at the Woodman Point waste water reclamation plant in Western Australia.

An independent engineering report describing performance achieved during the trial confirmed the capabilities of the system. The system demonstrated attractive cost characteristics and flexible performance attributes compared with current benchmark technology (i.e., micro filtration/reverse osmosis – MF/RO)

The performance of the pilot plant was derived from the following system attributes:

- Novel, robust ion exchange resins
- Continuous, counter current ion exchange process
- Compact plant footprint
- Low power requirements
- Low waste stream volume
- Low capital cost

The performance uplift exhibited by the pilot plant compared to standard (batch) ion exchange and membrane-based alternatives is principally derived from resin structure and robustness. A sustainable advantage derives from the synergies between more durable resins, the design of the processing vessels and novel methods of operation. The continuous counter current flows of resin and influent delivers a low capex, low power use, low waste stream volume, low footprint and a high recovery system compared to the micro filtration and reverse osmosis combination.

Table 1 shows a model of plant performance developed by independent engineering experts WorleyParsons for a 670 m³/h capacity plant, based on performance parameters demonstrated by the pilot plant during the trial.

<table>
<thead>
<tr>
<th>Units</th>
<th>Clean IX Water</th>
<th>MF/RO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Produced Water Flow</td>
<td>m³/h</td>
<td>670</td>
</tr>
<tr>
<td>Recovery</td>
<td>%</td>
<td>95</td>
</tr>
<tr>
<td>Waste</td>
<td>m³/h</td>
<td>24</td>
</tr>
<tr>
<td>Power</td>
<td>kWh/m³</td>
<td>0.22</td>
</tr>
<tr>
<td>CAPEX</td>
<td>$</td>
<td>$13,000,000</td>
</tr>
<tr>
<td>OPEX</td>
<td>$/m³</td>
<td>0.51</td>
</tr>
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</table>

The Clean-iX pilot plant trial demonstrated that a continuous counter current ion exchange water purification system has an array of applications in recycling and desalination of brackish waters to produce high quality water. In particular, the system demonstrated significant advantages over alternative technologies in the treatment of secondary effluent from the Woodman Point waste water treatment plant.
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1 Introduction
Under the auspices of the Premier’s Water Foundation a project was defined to test and trial an innovative water treatment technology.

The parties participating in the project were as follows:

<table>
<thead>
<tr>
<th>Organisation Name</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Department of Water</td>
<td>Government representative</td>
</tr>
<tr>
<td>Water Corporation</td>
<td>Premier water company in WA</td>
</tr>
<tr>
<td>HIsmelt</td>
<td>Potential technology customer</td>
</tr>
<tr>
<td>Clean TeQ</td>
<td>Technology owner</td>
</tr>
</tbody>
</table>

A pilot plant to test the capabilities of a continuous counter current ion exchange water treatment system was established. The plant was sited adjacent to the Woodman Point Waste Water Treatment Plant at the northern end of the Kwinana Industrial Precinct.

2 Outline Project
To establish whether the Clean-iX® WWTPWR flowsheet can be a cost-effective alternative to reverse osmosis for large scale recycling of water from municipal WWTPs.

3 Aim
The aim of the project was stated in the following terms:

*In partnership with HIsmelt Pty Ltd and the Water Corporation, Clean TeQ will design, build, operate and trial a pilot plant capable of processing 2m³/hour of WWTPW to industrial feed water standards.*

4 Method
As originally planned, the project was to be directed at performing three trials: waste water treatment plant effluent, scheme water and cooling tower blowdown water purification.

On consideration of the project steering committee a decision was taken to restrict the scope of the project to waste water treatment plant effluent. As a consequence, the project was directed solely to waste water treatment plant effluent purification.

The key activities of the project were as follows:

1. Resin preparation and QA.

   The pilot plant required 500 L of each of Clean TeQ’s strong acid cation resin (SAC) R101 and weak base anion resin (WBA) R502. R502 showed an unacceptable selectivity in long term operation and was subsequently replaced with R503 to provide broader selectivity and higher loading capacity per unit volume of resin. Resins were prepared in the appropriate ionic form and submitted to Clean TeQ’s standard QA analysis. This involved checking the resin’s particle size distribution, strength and loading capacity.

2. Detailed design of the process equipment

   Preliminary drawings were prepared as part of the Phase 1 work. A comprehensive engineering design effort delivered final versions of the general arrangement (GA) drawings, the process flow diagram (PFD) and the Process & Instrumentation diagram (P&ID) as well as detailed drawings for the major pieces of equipment and for the civils, electricals and
hydraulics. This work produced a final bill of materials (BOM) that was submitted for procurement. Safety assessments formed an integral part of the Clean TeQ design process.

3. Procurement and manufacture

Equipment and materials were sourced to meet design specifications, following consultation with the Water Corporation with respect to standard requirements for certain equipment categories. The manufacturing component consisted largely of pre-assembly and pre-commissioning. This allowed the project team to ensure that all components were in good working order prior to shipment to site.

4. Installation and commissioning

The pre-commissioned equipment were shipped to site and assembled in the designated location. The site was cleared and prepared to receive the pilot plant and various tie-ins (eg feed stream, power). Induction and briefing activities were also conducted.

5. WWTP effluent treatment

Three trials were conducted to test the central hypothesis that WWTPE can be treated to an agreed specification for industrial water reuse. The final trial was run for four weeks to allow sufficient time to achieve steady-state operation.

6. Decommissioning and demobilisation

At the end of the trials, the pilot plant was dismantled and removed from site, returning the location to its original state.

7. Documentation

Documentation was prepared throughout the project. In the early stages, design documents (drawings, lay-outs etc) and R&D protocols were produced. During the procurement and manufacturing stage, attention was focused on installation, commissioning and ongoing operating procedures. As the trials unfolded, a log book was kept and laboratory data tabulated and analysed.

An independent engineering report was prepared by WorleyParsons to review project results and interpret the project’s technical findings.

At the outset of the pilot plant project it was proposed that the project would be deemed to be successful if it resulted in a clear transition from R&D to commercialisation for the Clean-iX® WWTPER flowsheet. To that end, the specific technical objectives were to:

1. Deliver product water to specification in “steady-state” operation
2. Determine whether any, and if so, what type of pre-filtration is required before the feed stream can enter the first (R101) Clean-iX® unit without putting reliable operation of the system at risk.
3. Test the reliability of the proposed control system and hence the validity of the Clean-iX® WWTPER control strategy.
4. Optimise the desorption regime with a view to minimising reagent inputs to the system and reduce commercial-scale operating cost.
5. More accurately define the nature and volume of the by-product streams and establish the operating bands within which these streams can be expected to be managed at full scale.
6. Evaluate the resin attrition rate likely to be experienced in an operating plant.
7. Assess plant operability.

To facilitate a clear and impartial assessment of the degree to which the project delivered its objectives and obtained its measures of success, an independent engineering report was commissioned from WorleyParsons Limited.
5 Project Design
The pilot plant was designed as shown in the illustrations below.

Figure 1: Woodman Point Pilot Plant

Figure 2: Woodman Point Pilot Plant View from Above
Figure 3: Schematic of the Ion Exchange Water Purification Process

Figure 4: Photograph of the Woodman Point Pilot Plant – “In Situ”
6  Findings
The WorleyParsons report provided feedback on each of the technical objectives defined in
Section 4 above.

6.1  Product Water in Steady State Operation

The typical feed and product water specifications delivered by the Clean-iX® plant in steady
state operations were found to be as follows:

Figure 1: Typical Feed/Product Specifications

<table>
<thead>
<tr>
<th></th>
<th>UNITS</th>
<th>TYPICAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ppm unless otherwise specified</strong></td>
<td><strong>Feed</strong></td>
<td><strong>Product</strong></td>
</tr>
<tr>
<td>TSS-Particulates</td>
<td>55</td>
<td>5</td>
</tr>
<tr>
<td>Turbidity</td>
<td>6.0</td>
<td>2.2</td>
</tr>
<tr>
<td>Colour (@ 400nm) (TCU)</td>
<td>49</td>
<td>9</td>
</tr>
<tr>
<td>Total Hardness</td>
<td>160</td>
<td>2</td>
</tr>
<tr>
<td>TDS</td>
<td>670</td>
<td>14</td>
</tr>
<tr>
<td>Conductivity at 25C (µs/cm)</td>
<td>1071</td>
<td>18</td>
</tr>
<tr>
<td>pH</td>
<td>7.2</td>
<td>6.2</td>
</tr>
<tr>
<td>Na</td>
<td>159</td>
<td>2.3</td>
</tr>
<tr>
<td>K</td>
<td>25</td>
<td>1.3</td>
</tr>
<tr>
<td>Ca</td>
<td>28</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Mg</td>
<td>9.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Hardness as CaCO₃</td>
<td>109</td>
<td>0.1</td>
</tr>
<tr>
<td>Total Phosphorous</td>
<td>7.7</td>
<td>0.4</td>
</tr>
<tr>
<td>NH₄ as Nitrogen</td>
<td>7.3</td>
<td>0.3</td>
</tr>
<tr>
<td>NO₃ as Nitrogen</td>
<td>4.6</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>NO₂ as Nitrogen</td>
<td>0.7</td>
<td>0.01</td>
</tr>
<tr>
<td>Fe</td>
<td>0.1</td>
<td>0.04</td>
</tr>
<tr>
<td>Cl</td>
<td>185</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>SO₄</td>
<td>66</td>
<td>0.7</td>
</tr>
<tr>
<td>Total alkalinity as CaCO₃</td>
<td>140</td>
<td>7.0</td>
</tr>
<tr>
<td>SiO₂</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>BOD</td>
<td>&lt;5-10</td>
</tr>
<tr>
<td></td>
<td>COD</td>
<td>&gt;10-25</td>
</tr>
<tr>
<td></td>
<td>TOC</td>
<td>11</td>
</tr>
</tbody>
</table>

Legend:  
Physical  
Inorganic  
Organic

The pilot plant results indicate that the resin bed reduces total suspended solids from 55 to 5
mg/l and turbidity from 6 to 2.2 NTU. The total dissolved solids at the feed water inlet were
670 mg/l and the Clean-iX® pilot plant demonstrated the ability to reduce this to less than 14
mg/l. WorleyParsons commented¹ that in contrast to the Clean-iX® approach a reverse
osmosis system would require significant pre-filtration to ensure feed TSS/turbidity is
removed.

There is considerable room for improvement in the solids removal ability of the Clean-iX®
process through more stringent control of the removal of precipitated humic acid in the

¹  WorleyParsons Report Section 4.2.2 page 12
intermediate produced water. An outcome of less than 0.5mg/L and 1.0 NTU would be the target of the improvement.

All inorganic ions other than Fe were removed by the Clean-iX® plant with a very high percentage reduction. For Fe the Clean-iX® plant removed 60% of the load.

WorleyParsons report\(^2\) that by using the Clean-iX® system the BOD and COD of the product water can be reduced from 10 to less than five and 58 to less than 10 mg/l respectively. Macroporous ion exchange resins, such as those employed in the Clean-iX® plant, like activated carbon, have the ability to adsorb dissolved organic matter.

According to WorleyParsons\(^3\), the waste desorption solutions contained high concentrations of organics, thus demonstrating a highly reversible binding capacity thus minimising organic fouling. WorleyParsons observed\(^4\) that in reverse osmosis systems the TOC must be removed in pre-treatment as it causes fouling and reduces the water product flux and membrane element life.

### 6.2 Requirement for Prefiltration to Enable Reliable Operation

WorleyParsons observation\(^5\) indicated that the Clean-iX® system does not require rigorous pre-filtration. In contrast, according to the engineering report, a Reverse Osmosis system would require significant pre-filtration to ensure feed TSS/turbidity is removed.

### 6.3 Control System Reliability and Control Strategy Validity

The validity of the control strategy was addressed by the engineering report in Section 6 on pages 18 and 19. WorleyParsons addressed five key control system features:

- pH control
- Resin transportation
- Residence time
- Flow rates
- Acid/caustic pumps

WorleyParsons states\(^6\):

> From WorleyParsons site visit and observation, the Clean-iX® Woodman Point pilot plant has effectively demonstrated the ability for the process to operate with a high degree of automation with very little operator intervention.

Control system reliability was delivered principally through system design as illustrated by the major system control points highlighted below:

- The main control of the plant is based on the ratio between water and resin flow rates. Resin flow rates were continuously controlled via a programmable logic controller (PLC).
- The key quality parameters of the product water was delivered by monitoring the readings delivered a simple pH sensor which ensures the integrity of intermediate product water and the optimisation of chemical consumption during the resin regeneration process step.
- Robust level indicators measure and control the amount of resin transferred into and out of the sorption columns.

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\(^2\) ibid, Section 4.4.3 page 14  
\(^3\) ibid, Section 4.4.4 page 15  
\(^4\) ibid, Section 4.4.4 page 15  
\(^5\) ibid, Section 4.4.2 page 12  
\(^6\) ibid, Section 6 page 19
• Flow rates for each feed stream were controlled by pumps and meters mediated by PLC control.

The simplicity and robustness of the system and its control delivered reliable performance during the trial including the ability to operate the Woodman Point plant remotely from Melbourne.

### 6.4 Desorption Regime Optimisation

The pilot plant employed sulphuric acid and sodium hydroxide as desorption reagents.

We managed the flow rate of the desorption chemicals directly to the resin flow rate using resin to desorption chemical ratios selected based on plant performance and controlled this via PLC.

The desorption rate for the anionic circuit (sodium hydroxide) was set based on the theoretical required volumes and concentrations that were determined in the mini laboratory pilot plant trial performed before construction and operation of the pilot plant.

This method of operation proved to yield successful desorption results.

The cationic circuit desorption flow rate (sulphuric acid) was determined by the minimum required volume to ensure that the calcium and sulphate in the desorption stream did not combine to cause gypsum. This provided sufficient desorption reagents as it was in excess of what was theoretically required to desorb the resin if there were no issues with gypsum solubility.

### 6.5 By-product Streams – Nature and Volume

WorleyParsons reports\(^7\) that the plant demonstrated the ability to achieve recoveries of 95% and observed that the Clean-iX® platform is able to produce between 2 and 7 times less waste than reverse osmosis systems.

The actual recoveries achieved during the operation of the pilot plant were approximately 95%± 4%. Variation in recovery was experienced due to minimal automation being used in the wash water area of the plant to minimise capital costs. Despite this variation, the pilot plant successfully demonstrated the ability of the system to consistently achieve 95% recovery over extended periods of time.

### 6.6 Plant Operability Assessment

The WorleyParsons report states its assessment of the operability of the Clean-iX® process in the last paragraph on page 17.

“It is considered that the Woodman Point pilot plan effectively demonstrates the mechanical and operational simplicity of the Clean-iX® process.”

From observation of the Woodman Point Pilot Clean-iX® Plant, the mechanical reliability and operability of the Clean-iX® WWT process was a function of several variables. These include:

• **Hydraulic throughput**: Based on typical waste water salt loads, and a conservative structural design of columns, a single Clean-iX® train is capable of processing approximately 250 m\(^3\)/hr. In the event that volumes above this limit required treatment additional capital expenditure would be required due to column sizes reaching a limit and the requirement for parallel systems.

\(^7\) ibid, Section 1 page 5
• **Feed water ion concentration:** The cost of water treatment per unit volume is directly proportional to the salt concentration in the feed water. Higher salt loads in the feed water require larger volumes of resin, which in turn requires larger volumes of desorption solution reagents per unit volume of water treated. WorleyParsons observation indicated that the Clean-iX® pilot plant trials has demonstrated promising economic viability at salt loads seen in the Woodman Point waste water treatment effluent streams. Further developments in the area of desorption chemical concentration and reuse may put downward pressure on this operating cost. The ability to use the combined desorption solution as a value added product such as a fertiliser would reduce net operating costs and enhance the environmental effectiveness of the process.

• **Feed water turbidity:** the plant was able to continue to perform in the presence of particulates in the feed stream. The plant operated with a feed water turbidity of approximately 4 NTU, with no apparent impact on performance.

• **Power Requirements:** Pumps account for the majority of the power required for the plant. Therefore, the power requirements were a function of plant size and throughput. The Clean-iX® process is conducted at atmospheric pressure which means that there is a low power draw in operating the system.

• **Recovery:** The pilot plant data indicates that the recovery of the Clean-iX® system (ratio of product water to feed water) is about 95%. Product recovery is a function of the inlet salt concentration with recovery decreasing proportionally with increasing salt concentration.

• **Resin loading capacity:** the loading capacity dictates the achievable resin to feed water flow rates, which in turn dictates the system’s economic performance. Higher loading capacities allow the resin to be cycled through the system at a slower rate, which hence requires less desorption reagents. Further improvements in this area will lead to downward pressure on operating costs.

• **Resin Attrition:** the Clean-iX® process has very low resin attrition arising from the resin recirculating system. No resin loss was observed. Resin consumption records for the plant indicated no substantial loss of resin.

• **Efficiency:** the Clean-iX® plant was found to be capable of producing ultra pure water. The pilot plant trials demonstrated the ability to produce water of less than 20µs/cm conductivity when operating within its operating limits. Large economic gains may be realised if the columns were operated close to the sorption breakthrough parameters. Operating in this regime brings the following benefits:
  
  i. Resin is utilised to its maximum loading capacity.
  ii. Resin flow rates are reduced to lowest practical levels. This in turn minimises desorption solution requirements.
  iii. Product water quality can be controlled. Efficiencies are lost by producing water that is significantly cleaner than required specification.

The power requirement for the Clean-iX® system is less than 20% of the power needed for a similar sized Reverse Osmosis system. Further, the recovery of an RO system is typically between 75-90% compared to 95% for the Clean-iX® plant. The Clean-iX® pilot plant achieved similar ionic rejection to what would be expected from a reverse osmosis system.

The plant operated well with feed water much more turbid than a RO system could tolerate.
7 Conclusion

Pilot plant trials at Woodman Point waste water treatment facility have verified that the Clean-iX® ion exchange system has the ability to consistently satisfactorily treat secondary treatment wastewater and produce industrial quality water. Furthermore, it has demonstrated its capability of doing so with similar operating cost, lower power requirements and higher recoveries than MF/RO technology.

According to the trials and documentation, the flexibility and robustness of the Clean-iX® ion exchange process indicates that this technology will lend itself to a broad range of water management strategies and recycling applications.

Of particular interest is the potential for Clean-iX® to provide cost-effective solutions for wastewater treatment from large-scale metropolitan to small regional systems, reuse of WWTP effluent for industrial applications, treatment of aquifer water in remote communities, reduction of impurities such as nitrogen-containing ions (nitrates, nitrites, and ammonia), phosphates and sulphates, and capture and use of stormwater.