PREFACE

Singapore’s water consumption stands at 430 million gallons a day, with the domestic sector accounting for 45% of total water use, while the remaining 55% comes from the non-domestic sector. By 2060, Singapore’s water consumption is expected to double, with the non-domestic sector making up 70% of total water demand. Therefore, it is important that PUB’s partners in the non-domestic sector join us in the move to conserve water, and reduce water demand. This will help Singapore in its water sustainability journey.

The aim of this Best Practice Guide in Water Efficiency – Refineries, Petrochemicals and Chemicals Sector is to provide professional engineers, developers, plant owners and facilities operators involved in water management, with the basic knowledge of designing, maintaining and operating a water-efficient plant.
ACKNOWLEDGEMENTS

This guide could not have been possible without the participation, assistance and invaluable insights from the following organisations. Their contributions are appreciated and gratefully acknowledged.

- ExxonMobil Asia Pacific Pte Ltd
- JTC Corporation
- Mitsui Phenols Singapore Pte Ltd
- Petrochemical Corporation of Singapore (Private) Limited
- Shell Eastern Petroleum (Pte) Ltd
- Singapore Refining Company Pte Ltd
- Singapore Water Association
- Sumitomo Chemical Asia Pte Ltd
The Refineries, Petrochemicals and Chemicals Sector is one of the largest water-consuming industries in Singapore. They can be broadly categorised into two subsectors with the water usage breakdown shown in Fig. 1:

i. manufacturers of petrochemical and chemical products,
ii. petroleum refineries

Compared to the other industrial sectors in Singapore, the refineries, petrochemicals and chemicals sector is considerably heterogeneous. From upstream refinery to downstream refining and petrochemical, both process water and wastewater are key factors in successful plant operations for the industry. In general, each facility uses non-identical processes to manufacture different ranges of products, producing wastewater of varying qualities. On Jurong Island where many of such manufacturing facilities reside, third-party providers offer a wide range of water supply including supply of treated water (such as demineralised water, high-grade industrial water, etc.), cooling water, steam and even provide wastewater treatment services. Some manufacturing facilities could be using supplied cooling water instead of operating their own cooling towers or obtaining steam instead of operating their own boilers from third-party providers. As such, opportunities for water efficiency improvements can vary significantly and solutions should always be site-specific and tailored to the needs of the individual site.

Nonetheless, this best practice guide seeks to provide practical guidance for efficient water management in refineries, petrochemicals and chemicals sector. It is not intended to be prescriptive nor does it set an industry standard.

Companies are recommended to read this guide in conjunction with the following standards/references:

- SS577:2012 Water Efficiency Management System
- SS627:2017 Specification for Different Grades of Industrial Recycled Water from Refineries, Petrochemical, Chemical and Utility Plants
- Technical Reference for Water Conservation in Cooling Towers
Based on the reported data, the plant recycling rate\(^1\) of the sector varies, with recycling rate of 0% to 44%. The variation in recycling rate is mainly due to non-identical processes among the plants with different quality of wastewater generated. Nevertheless, manufacturers from the refineries, petrochemicals and chemicals sector are strongly encouraged to reuse and recycle water wherever and whenever possible. This will not only help companies to ensure water sustainability and to reduce reliance on external source of water but also lower the needs for future investment in expanding water infrastructure.

A facility operating their own cooling tower, boiler or demineralisation unit can have multiple options for water recovery and reuse. Fig. 2 shows the typical streams that can be recycled and possible areas where the recycled stream can be suitably reused at.

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\(^1\) Recycling rate is calculated as follows: total water recycled / (total water recycled + total water consumption).

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![Fig. 2 Water Recycling Opportunities in a Typical Petrochemical/Chemical Facility](image-url)
### RECOMMENDED WATER EFFICIENCY PRACTICES

**Cooling Towers**

<table>
<thead>
<tr>
<th>Method</th>
<th>Water Efficiency Opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reduce</strong></td>
<td><strong>New/Existing Plants</strong></td>
</tr>
<tr>
<td></td>
<td>Improve cycles of concentration (COC) to minimum 7 and 10 for cooling towers using potable water and NEWater respectively</td>
</tr>
<tr>
<td></td>
<td>Install a side-stream filter</td>
</tr>
<tr>
<td></td>
<td>Install a makeup water or side-stream softening system when hardness is a limiting factor on COC</td>
</tr>
<tr>
<td></td>
<td>Reduce cooling load by minimising waste heat generated and/or using waste heat for other purposes in the facility</td>
</tr>
<tr>
<td><strong>Reuse</strong></td>
<td>Reuse of harvested rainwater at cooling tower</td>
</tr>
<tr>
<td><strong>Recycle</strong></td>
<td>Recycle cooling tower blowdown back to the cooling tower or to processes, via a combination of microfiltration (MF)/ ultrafiltration (UF) and reverse osmosis (RO)/ nanofiltration (NF) processes</td>
</tr>
</tbody>
</table>

For water quality requirements, please refer to [Technical Reference for Water Conservation in Cooling Towers: Annex C - Typical Parameters of Potable Water, NEWater and Industrial Water as Makeup Water for Cooling Tower](#).
### Boilers / Steam Generation

<table>
<thead>
<tr>
<th>Method</th>
<th>Water Efficiency Opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>New/Existing Plants</td>
</tr>
<tr>
<td><strong>Reduce</strong></td>
<td></td>
</tr>
<tr>
<td>Minimize vented steam. Low pressure vented steam can be used to drive evaporation and distillation processes, produce hot water, etc. Thermocompressors can be used to increase the pressure and temperature of the steam if the pressure is too low for the intended application</td>
<td>Minimise over steaming of flares by having good controls in place</td>
</tr>
<tr>
<td><strong>Reuse</strong></td>
<td></td>
</tr>
<tr>
<td>Implement an effective steam trap maintenance program with regular steam trap survey</td>
<td>Minimise boiler blowdown by installing automatic boiler blowdown equipment which maintains a pre-determined level of conductivity in the boiler system</td>
</tr>
<tr>
<td>Minimise over steaming of flares by having good controls in place</td>
<td></td>
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</tbody>
</table>

For water quality requirements, please refer to **SS627:2017 Specification for Different Grades of Industrial Recycled Water from Refineries, Petrochemical, Chemical and Utility plants**: Table 2 – Water Quality Guidelines for Boiler Makeup Water Used in Different Boiler Applications.
## Process

<table>
<thead>
<tr>
<th>Method</th>
<th>Water Efficiency Opportunities</th>
</tr>
</thead>
</table>
| **Reduce** | Optimization of demineralisation unit throughput  
  - Carry out regular performance review to reduce water consumption as actual feed water quality could be better than design quality |
| **Reuse** | Reuse of regeneration rinse from demineralisation unit |
| **Recycle** | Segregate wastewater by total dissolved solids (TDS) levels (low strength: < 3,000 mg/L and high strength: ≥3,000 mg/L)  
  - Low strength used water can be treated to a higher quality, and reused at multiple areas  
  - Reduce quantity and strength of end-of-pipe wastewater effluent generated at site, making it less complex to treat and reuse effluent. Treated effluent can be used at areas demanding a lower water quality  
  - Setup recycling system that typically made up of biological treatment followed by membrane processes i.e. membrane bio-reactor (MBR) → UF/ NF  
  - Recycle of stripped sour water to desalters (for refineries)  
  - Recycle of condensate |

Water quality requirements subject to site requirements. Interested companies can approach independent consultants or PUB’s in-house Industrial Water Solutions Project Unit team to review the feasibility of water efficiency improvements at process areas.

## Additional Water Efficiency Opportunities

- Conduct water audit to prioritize opportunities for water efficiency  
  - Engage a consultant to perform thorough water audit to identify and prioritize potential areas of reuse and recycling. Interested companies may approach PUB for the contact of independent consultants

- Effective use of waste heat to produce water by using low temperature desalination  
  - Produce water internally is a fairly viable option in the petrochemical industry due to vast amount of low-grade waste heat available
1. Implementation of On-site Effluent Water Recycling Plant by Singapore Refining Company Private Limited

Singapore Refining Company (SRC) operates a refinery on Jurong Island, which is capable of processing 290,000 barrel of crude oil a day, has recently implemented an industrial water solution to further treat the effluent water and recover it for process use.

A water audit was conducted in 2013 over SRC’s refinery operations, revealing the potential of implementing a secondary treatment process for localised water recovery and reuse as the effluent discharged from SRC’s existing primary treatment was of fairly good quality. Back then, influent from SRC’s refinery processes underwent basic oil removal process, activated sludge process and clarification treatment before being discharged to the sea, within NEA’s guidelines. With the implementation of the secondary treatment process, effluent from SRC’s primary treatment is further treated using flat sheet ceramic membrane microfiltration (MF) and a two-step reverse osmosis (RO) process to remove suspended solids, dissolved solids, oil and grease and other contaminants to effectively reclaim NEWater grade product for process reuse, thereby reducing SRC’s uptake of NEWater from PUB’s piped supply.

Detailed Engineering revealed a design capacity of up to 2,500 cubic metres per day for reuse, and this facility allowed the refinery to reduce their NEWater consumption by potentially 30%. The key enablers for the success of this project were namely, strong commitment of SRC towards long term water sustainability, technical support from PUB during the implementation and operation of the secondary treatment process as well as technology advancements in the field of membrane materials that are robust enough to treat refinery effluent water.

With the success of this project, the technology of using ceramic MF-RO to treat and reclaim process water from refinery effluent has been tested and proven to be viable. The treatment process will be able to produce NEWater grade water quality and meet the quality requirements for SRC’s local process reuse. This process has a good scalability and viability for future full-scale implementation in a similar industry.
2. Implementation of MF-RO-ACF System to Recycle Trade Effluent by Petrochemical Corporation of Singapore (Private) Limited

Petrochemical Corporation of Singapore (Private) Limited (PCS) is a regional producer of ethylene and propylene, with the capacities of their two cracker plants totalling more than 1.8 million tonnes per year of ethylene and propylene. It was jointly established in 1977 by Singapore Government and Japan Singapore Petrochemical Co. Ltd (JSPC) led by Sumitomo Chemical. They also produce butadiene, 1-butene, MTBE, benzene, toluene, xylene among other by-products.

PCS has been pro-active in its water conservation journey and always look into opportunities to optimize water consumption within its plant. It recently embarked on a wastewater recovery plant using microfiltration (MF) - reverse osmosis (RO) - activated carbon filtration (ACF) system, to recycle treated trade effluent for process use.

After about one year of pilot testing to assess suitability of membrane technology and also to identify any potential issues, a full scale demonstration wastewater recovery plant with design capacity of 1,200 m$^3$/day has been approved for implementation.

Their existing industrial waste water treatment plant (WWTP) is made up of three stages, in order to treat oily and process waste water containing dissolved organics, oil and grease generated from upstream process units, to a quality suitable for direct discharge to the sea.

The demonstration plant, which is currently under construction and expected to be commissioned by second half of 2018, will treat secondary effluent from their existing conventional activated sludge (CAS) by using a treatment system that consists of microfiltration (MF) - reverse osmosis (RO) and activated carbon filtration (ACF). The treated water will be recovered for process reuse.

With the implementation of the wastewater recovery system, PCS’s uptake of NEWater can be potentially reduced by 10% when the recycling plant operates at its full capacity.
3. Leveraging MBR Technology to Reduce Process Cooling Water Needs at ExxonMobil’s Singapore Chemical Plant

ExxonMobil in Singapore is a manufacturing and marketing business with more than S$25 billion in fixed asset investments and a diverse workforce of more than 3,700 employees. The integrated manufacturing site in Singapore, comprising the Singapore Chemical Plant and the Singapore Refinery, is ExxonMobil’s largest in the world. The Singapore Chemical Plant (“SCP”), which was commissioned in 2001 and further expanded to more than double its ethylene production capacity in 2013, is also ExxonMobil Chemical’s largest integrated petrochemical complex globally. The world-scale petrochemical complex manufactures high performance products including olefins, polymers, specialty elastomers, aromatics and oxo alcohol.

As part of the 2013 SCP expansion, ExxonMobil deployed the membrane bioreactor (MBR) technology for the first time in the global ExxonMobil circuit to treat wastewater for process cooling, a primary use of water in petrochemical manufacturing. In using the MBR-treated wastewater for process cooling, ExxonMobil is able to significantly reduce water make-up to cooling towers. By 2016, continuous efforts to optimize the MBR technology have resulted in about 55% of MBR-treated water being recycled as cooling water.

The MBR system is designed to treat an average wastewater flow close to 450 m$^3$/h. Treatment occurs in two parallel biological treatment trains and four membrane operating system (MOS) basins. Biological nitrogen removal, carbonaceous Biological Oxygen Demand (BOD)/Chemical Oxygen Demand (COD) reduction via an active mass of microorganisms, as well as biomass and other suspended solids removal, is performed in this system.

Together with the upstream wastewater facilities such as Corrugated Plate Interceptor (CPI) and Dissolved Air Flotation unit (DAF), MBR is capable of treating wastewater from process units to effluent that not only meets the cooling tower make-up requirements for recycling back to cooling tower basin, but also the regulatory NEA specifications for discharge into the sea.

Fig. 5 shows the overall flow in the wastewater unit while Fig. 6 shows the pictures of aeration zone, MOS basin as well as compares inlet and outlet samples.

**What is MBR?** MBR is the combination of a membrane ultrafiltration (UF) process with a biological wastewater treatment process. The membranes are used to perform the critical solid-liquid separation function.
Opportunities to improve

Maintaining a stable cooling water chemistry can be a main challenge in increasing the recycling of MBR-treated wastewater. An upset in the MBR system would destabilise the cooling water chemistry significantly. Close monitoring and coordination between the two processes is necessary.

MBR effluent recycle can have much higher conductivity as compared to the usual water make-up. Components which contribute to high conductivity could risk corrosion or fouling in the heat exchangers and even microbiological growth in the cooling water circuit. Therefore, before increasing the MBR effluent recycle, tight specifications for the cooling water chemistry have to be determined, controlled and monitored. The MBR effluent recycle can then be increased to the conductivity limit in a step wise manner, ensuring healthy cooling water chemistry at all times.

For ExxonMobil, the MBR effluent recycle has increased over the years. As a result, water consumption has dropped significantly, and freshwater savings have grown by over 200% between 2015 and 2017 (from 60 ton/h to 200 ton/h as depicted in Fig. 7). In 2018, as part of ExxonMobil’s ongoing commitment to sustainable operations including responsible water use management, SCP is planning to further reduce fresh water consumption by increasing MBR effluent recycle and other projects to reduce the cooling water blow down rates.

![Fig. 6 Pictures of (i) Aeration Zone (ii) MOS Basin (iii) Wastewater Inlet (iv) Wastewater Outlet](image1)

![Fig. 7 MBR Effluent Recycle from 2015 to 2017](image2)
4. Reuse of Wastewater from Styrene Monomer (SM) Units as Feed for Water Wash Section of Propylene Oxide (PO) Production Units by Shell Singapore

SMPO unit in Shell’s Jurong Island chemical complex produces propylene oxide and styrene monomer. In the processing steps of PO production unit, a water wash section is included to remove salts. This is accomplished by injecting approximately 27 ton/h of cooled clean condensate (CCC) to the unit. The CCC added eventually ends up as waste water and treated as effluent.

In another section of the SMPO unit, styrene is produced by dehydration of alcohol. As the name suggests dehydration reaction results in generation of water at the outlet of SM reactors. This water is taken as overhead along with styrene in a distillation column. Styrene and water are separated in the overhead section of the column.

To reduce waste water treatment costs and to improve the performance of the wash train, a project was implemented in Shell Seraya to reuse the water generated from SM units in the wash train of PO units. This resulted in potential reduction of CCC usage in wash train section by 27 ton/h and a significant reduction in the load to effluent treatment units. Using SM reaction water also improved the efficiency of wash train section of SM.

The benefit realized is a 33% reduction in waste water generation from SMPO-2, which translates to 7 ton/h of steam savings in the effluent treatment unit and 0.17 ton/h of fuel gas savings in the incinerator due to reduction in feed to incinerator.
Support and Resources

PUB provides funding and technical support as part of PUB’s effort to encourage companies to explore ways to improve water efficiency.

For technical support, interested companies may contact PUB’s in-house Industrial Water Solutions Project Unit team at PUB_One@pub.gov.sg.

For information on funding available from PUB including Water Efficiency Fund and Industrial Water Solutions Demonstration Fund, please refer to PUB’s website at www.pub.gov.sg.
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