PUB SINGAPORE'S NATIONAL WATER AGENCY

Best Practice Guide in

WATER EFFICIENCY

Refineries, Petrochemicals and Chemicals Sector

Version 2

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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 accounting for the majority of the increased 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. We have also compiled best water efficiency practices in this publication to help you in your journey towards sustainable water use.

ACKNOWLEDGEMENTS

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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

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Introduction

The Refineries, Petrochemicals and Chemicals sector is one of the largest water-consuming industries in Singapore. They can be broadly categorised into two subsectors, namely:

i. **manufacturers of petrochemical and chemical products,**

ii. **petroleum refineries**

The bulk of water usage stems from boilers to generate steam and makeup for cooling towers in these sectors, accounting for 77% and 87% of water usage respectively. Water usage of these two sectors is shown in Figure 1.

Companies in these sectors have taken steps to raise the sustainability of their operations through the implementation of recycling measures. In view of the high evaporative losses from cooling tower and boilers, some companies have successfully reduced their overall water consumption through the adoption of alternative cooling technologies such as seawater cooling and air-cooling. As Singapore is a water-stressed country, PUB aims to work closely with industries to harness these water-saving opportunities, to support the growth and advancement of this sector in a sustainable manner.

Chapter 2 provides an overview of recycling opportunities in these sectors, while recommended water efficiency practices as well as seawater cooling can be found in Chapter 3. Chapter 4 offers a compilation of case studies that companies have successfully implemented to raise water efficiency, while reaping cost savings in the longer term.

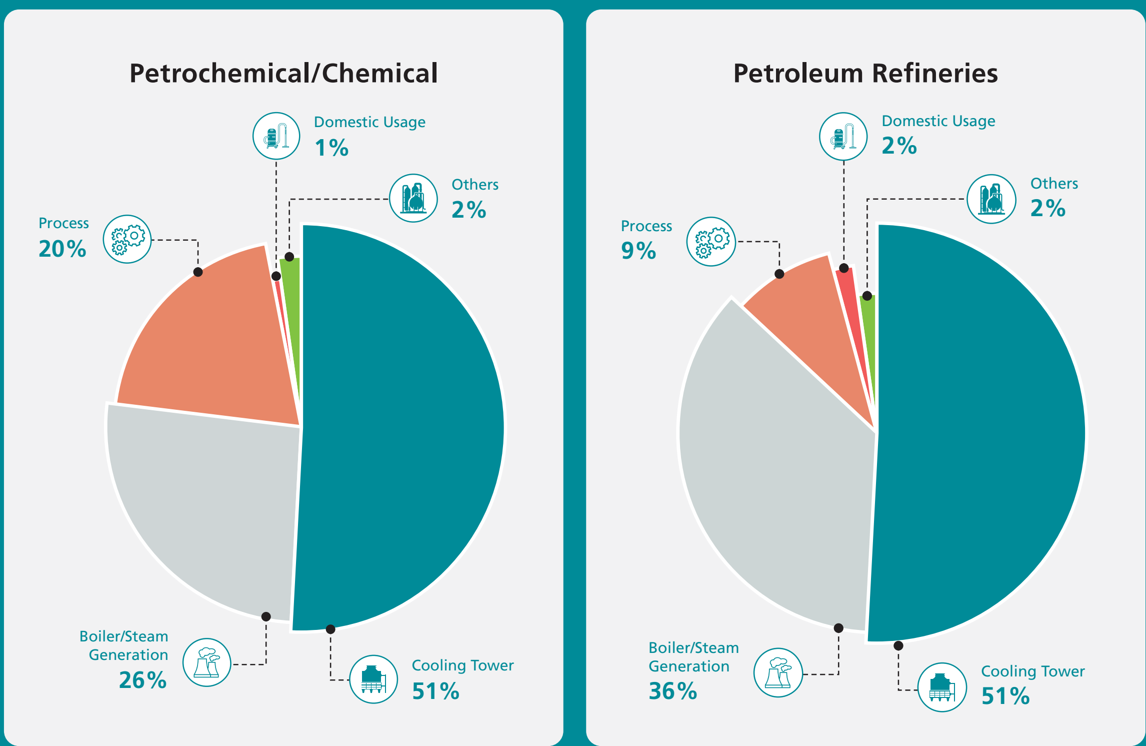


Figure 1: Typical Breakdown of Water Usage for Companies in the Refineries, Petrochemicals and Chemicals Sector

This guide seeks to share practical and cost-effective approaches, illustrated by actual case studies, to manage water usage in the 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:

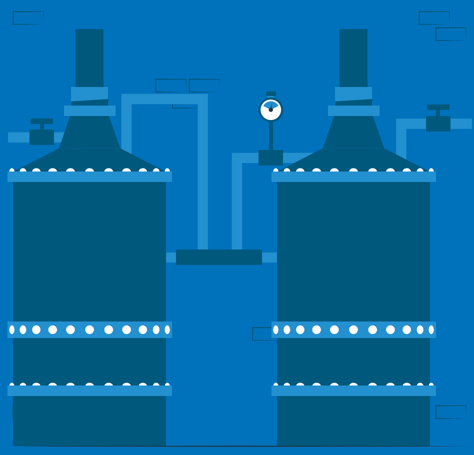
i. SS ISO 46001:2019 Water Efficiency Management Systems

ii. SS627:2017 Specification for Different Grades of Industrial Recycled Water from Refineries, Petrochemical, Chemical and Utility Plants

iii. Technical Reference for Water Conservation in Cooling Towers

02

Water Recycling Opportunities



A facility operating its own cooling tower, boiler or demineralisation unit can have multiple options for water recovery and reuse. Some of the low hanging fruits include re-using steam condensate as boiler feed as well as optimising the cycles of concentration (COC) of cooling towers. Steam condensate is ideal for re-use as boiler feed water as it will not only reduce the uptake of demineralised water but also reduce the energy required to pre-heat the boiler feed water, due to its heat content. Industries should also explore reclaiming blowdown from cooling towers and treat it with RO system, subsequently re-use it as makeup for cooling towers.

For refineries, companies are encouraged to route sour water to the sour water stripper and the stripped sour water can be re-used as desalter wash water. Locally, we have seen that re-use of stripped sour water contributes towards 4% to 11% of recycling rates in refineries.

Figure 2 shows the typical streams that can be recycled and possible areas where the recycled stream can be suitably reused at.

Based on 2018 reported data, the recycling rates for refineries, petrochemicals and chemical plants range from 0% to 48%, with an industry average of 13%. The large variance in recycling rates seen in the Petrochemicals and Chemicals subsectors is due to the following reasons. First, the sector is heterogeneous and is highly varied in terms of products, processes as well as water usage. As a result, there is no one-size-fit all solution to handle the varying quality of wastewater generated from each plant. Second, a number of plants rely on third-party providers for water utilities (e.g. provision of product water or steam) as well as wastewater handling services. For instance, 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. As such, opportunities for water efficiency improvements are site-specific and can vary significantly.

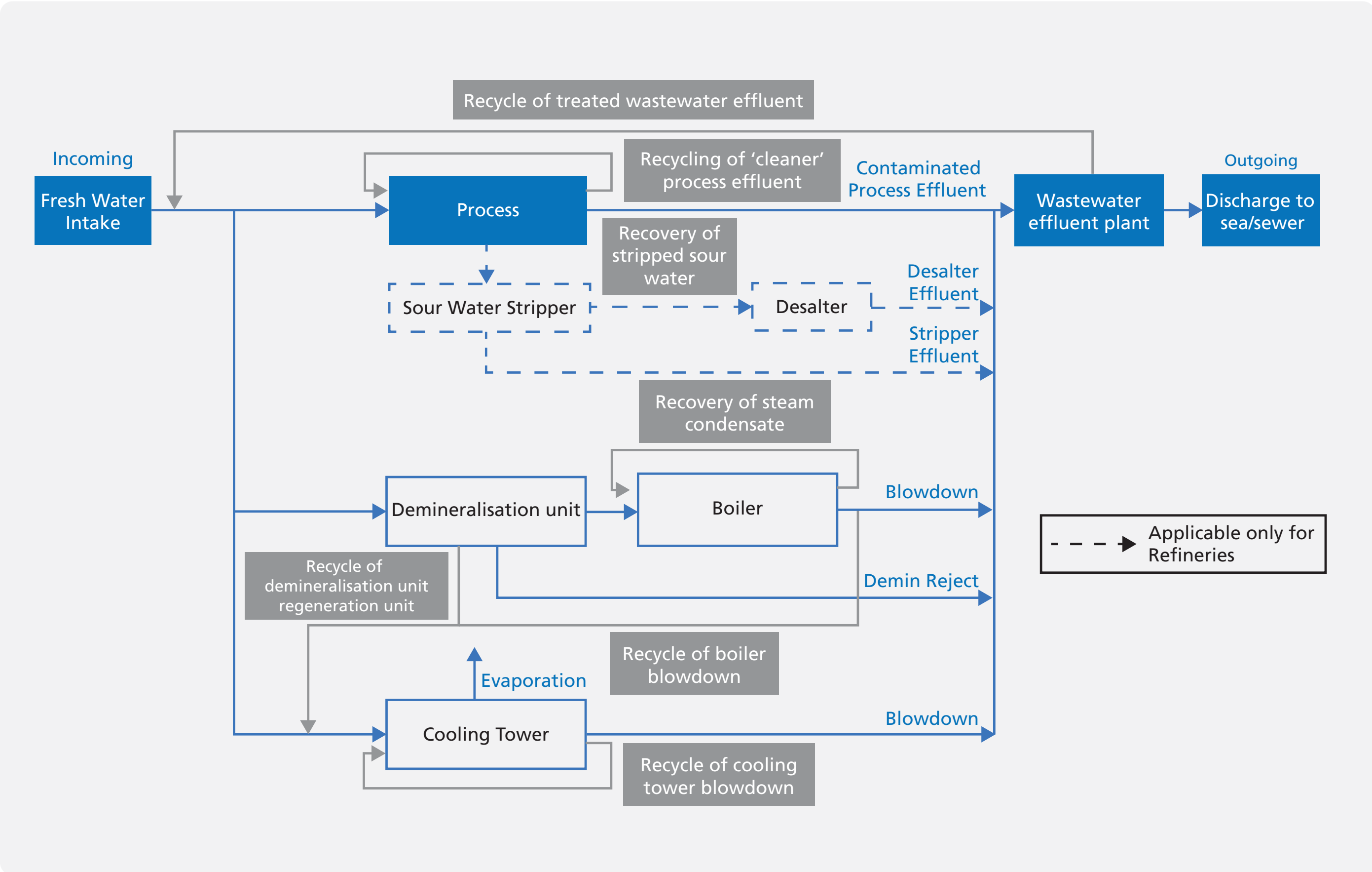
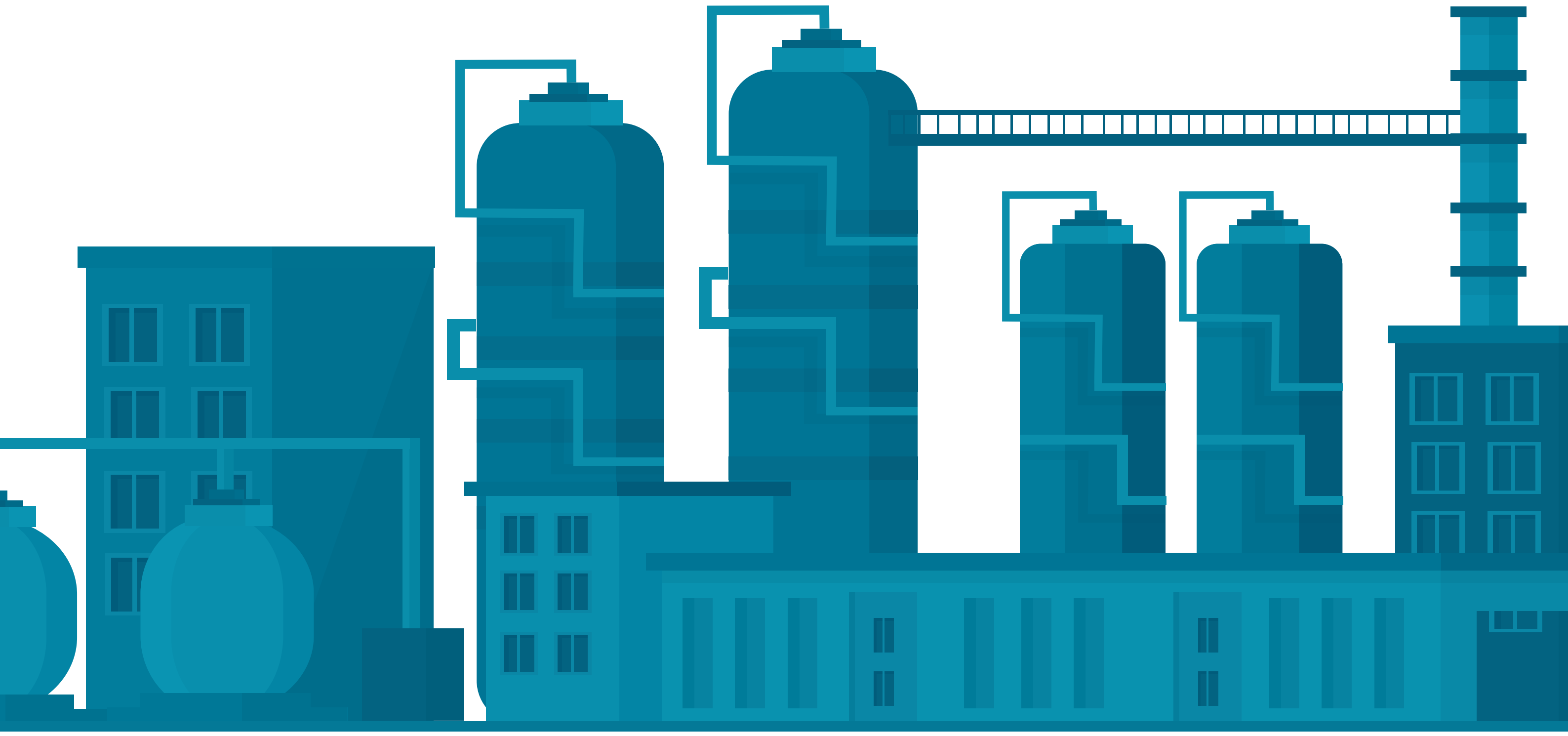


Figure 2: Water Recycling Opportunities in a Typical Refineries/ Petrochemical/ Chemical Facility



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Recommended Water Efficiency Practices

Other than water recycling, opportunities to enhance water efficiency are detailed in the sections below.

COOLING TOWERS

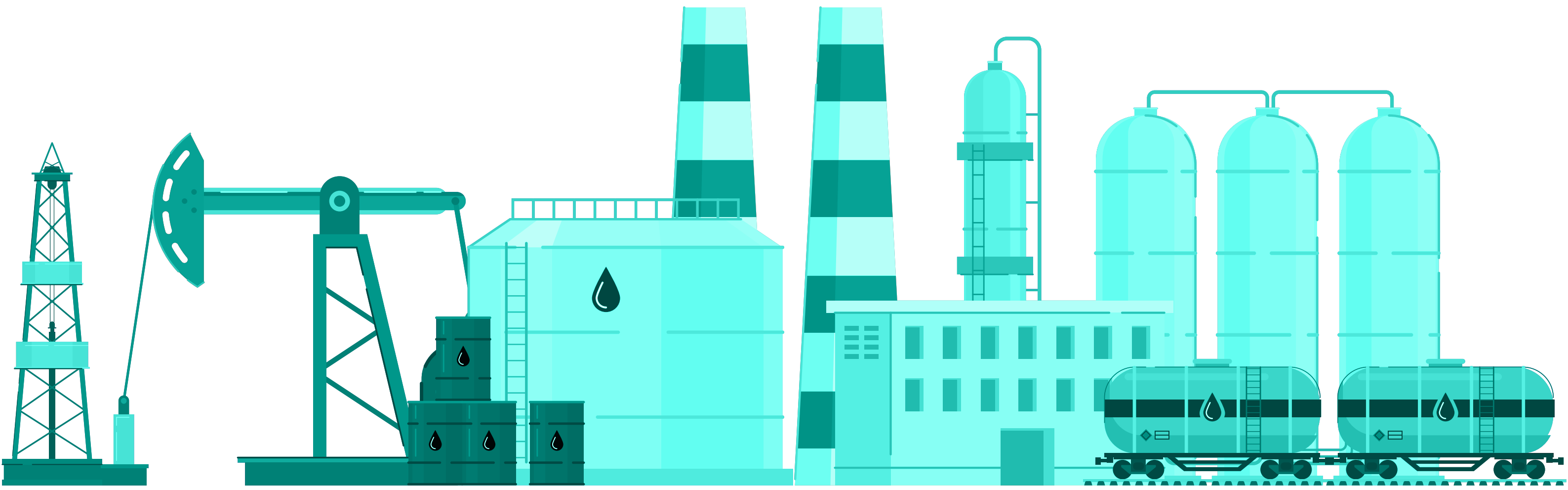
Method	Water Efficiency Opportunities	
	New / Existing Plants	New Plants Only
Reduce	• Improve cycles of concentration (COC) to minimum 7 and 10 for cooling towers using potable water and NEWater respectively • Install a side-stream filter (depending on the quality of incoming water) to reduce likelihood of scale and fouling • Install a makeup water or side-stream softening system when hardness is a limiting factor on COC • Reduce cooling load by minimising waste heat generated and/or using waste heat for other purposes in the facility • Install or retrofit with indirect once-through seawater cooling that utilises a cascade loop to reduce substantially the cooling load of the hot returning cooling water, through retrofitting of the existing freshwater evaporative cooling tower. This will lead to substantial savings of fresh water, especially for industries located at the seafront	• Use of dry cooling instead of cooling towers. • Install and interlock automated chemical feed system with blowdown controls on large cooling tower systems (more than 100 tons).
Replace	• Replace potable water or NEWater with harvested rainwater and air-conditioning condensate as cooling tower make-up	• Use of seawater cooling towers
Reuse/ Recycle	• Recycle cooling tower blowdown back to the cooling tower as make-up, via a combination of Microfiltration (MF)/ Ultrafiltration (UF) and Reverse Osmosis (RO) / Nanofiltration (NF) process • Recycle wastewater effluent (e.g MBR permeate) as makeup for cooling towers.	

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

SEAWATER COOLING

Seawater serves as a viable alternative to fresh water for cooling purposes. Depending on site location and operational process factors such as cooling load, various schemes may be considered. Two types of systems, which can be considered for both new plants or retrofitting existing freshwater evaporative cooling towers, are summarised below.

Method	Water Efficiency Opportunities
	New/Existing Plants
Replace	• Use of indirect once-through seawater cooling - Indirect once-through seawater cooling utilises a heat exchanger to isolate the seawater and cool the hot returning cooling water, saving corrosion-resistant requirements for downstream cooling system components than directly using seawater for cooling. If used to retrofit existing freshwater evaporative cooling towers, this will lead to substantial savings of freshwater, especially for industries located at the seafront • Use of seawater cooling towers - Compared to indirect once-through seawater cooling, seawater cooling towers typically consume a smaller volume of seawater for similar cooling loads as the seawater loss is only due to evaporation, drift and blowdown. This saves a significant amount of seawater pumping capacities and may be more applicable for facilities that are not directly located at the seafront.



BOILERS / STEAM GENERATION

Method	Water Efficiency Opportunities	
	New / Existing Plants	New Plants Only
Reduce	• Minimise 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 • Minimise over steaming of flares by having good controls in place • Implement an effective steam-trap maintenance program with regular steam trap survey	• Optimise steam distribution by ensuring that steam traps and condensate lines are properly sized to avoid unnecessary venting. Condensate return lines are recommended to be designed on the basis of two-phased flow • Minimise boiler blowdown by installing automatic boiler blowdown equipment which maintains a pre-determined level of conductivity in the boiler system
Reuse / Recycle	• Divert contaminated condensate to applications requiring lower quality of water, so that clean condensate can be recovered elsewhere • Recycle boiler blowdown to cooling tower. Typically done by cascading high-pressure blowdown to low-pressure, before being reused at the cooling tower • Recycle hot steam condensate to deaerators. This will also lower regeneration frequency of Steam Condensate Polisher (SCP) thus reducing water, energy and chemicals consumption • Recycle potentially contaminated condensate back to steam generation with clean-up facilities, e.g. activated carbon beds and condensate polisher	• Install a flash steam recovery system so that low-pressure steam and remaining condensate can be recovered instead of being discharged • Setup facilities to recover water from vented stream, e.g. ven t condensers on steam vents and deaerator vents • Aim to recover more than 90% of condensate. In addition to recovery to the boiler, steam condensate can also be reused at processes, cooling tower, scrubber and general washing as long as the quality of condensate is fit-for-purpose

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

Method	Water Efficiency Opportunities – New / Existing Plants
Reduce	• Optimisation of demineralisation unit throughput - Carry out regular performance review to reduce water consumption as actual feed water quality could be better than design quality • Optimisation of regeneration steps - Optimise regeneration flow and duration to reduce water and chemical consumption
Reuse / Recycle	• Reuse of regeneration rinse from demineralisation unit • Segregate wastewater by total 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 for process reuse and recycling is subject to site requirements. Interested companies can approach PUB's in-house Industrial Water Solutions Project Unit team or engage a third-party consultant to review the feasibility of water efficiency improvements at process areas.

Additional Water Efficiency Opportunities

Conduct water audit to prioritise opportunities for water efficiency

Engage a consultant to perform thorough water audit to identify and prioritise 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.

04

Case Studies

Case Study 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 barrels 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 before usage.

Figure 3: From left to right: (i) overview of the effluent treatment recycling plant, (ii) view of the fibre-reinforced polymer tank and the MF filtrate/RO feed tank, and (iii) close-up of the pressure vessels containing the RO membranes.

Detailed Engineering revealed a design capacity of up to 2,500 m^3/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 at a reasonable OPEX of $0.80 - $1.20/m^3 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.

Case Study 2

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 optimise the MBR technology have resulted in about 55% of MBR-treated water being recycled as cooling water.

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.

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.

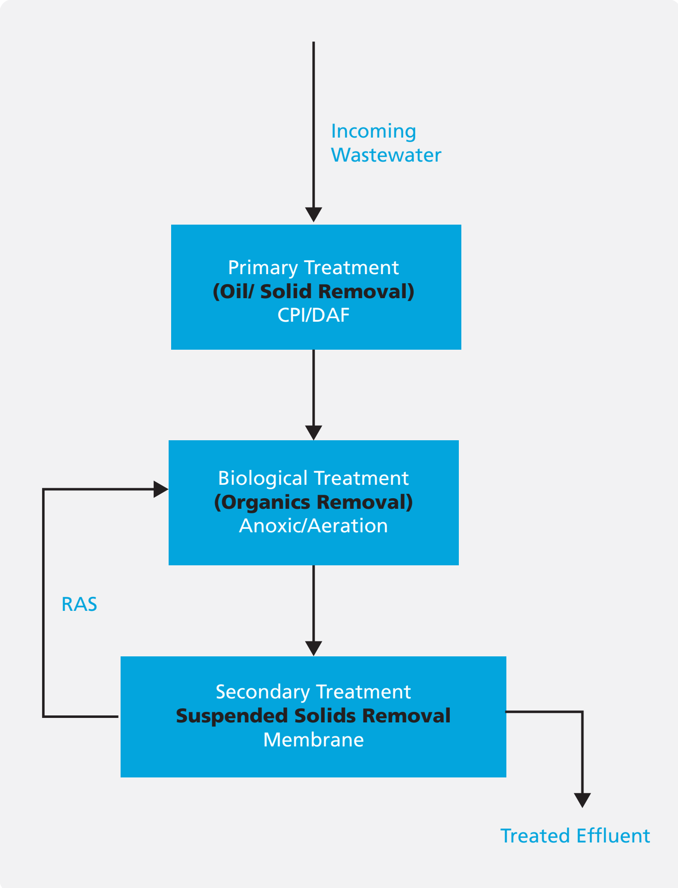
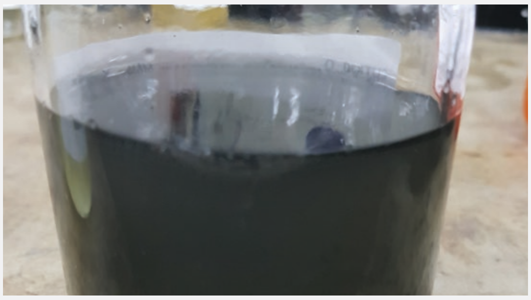


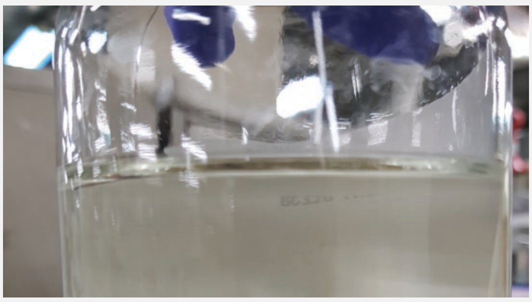
Figure 5: The overall flow in the wastewater unit

(i) Aeration zone



(iii) Sample of Wastewater Inlet

(ii) Membrane rack in MOS basin



(iv) Sample of Treated Wastewater Outlet

Figure 6: Pictures of (i) Aeration Zone (ii) MOS Basin (iii) Wastewater Inlet (iv) Wastewater Outlet

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 m^3/h to 200 m^3/h as depicted in Figure 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.

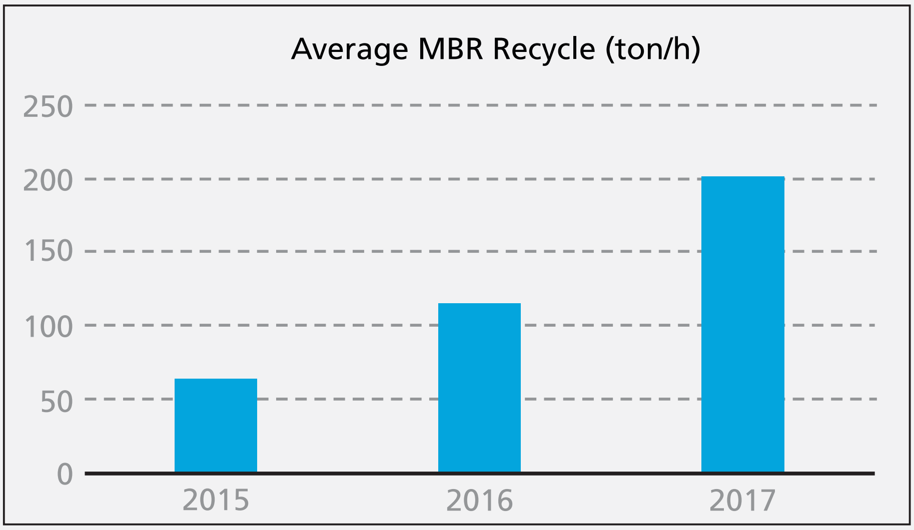


Figure 7: MBR Effluent Recycle from 2015 to 2017

Case Study 3

Implementation of MF-RO-ACF System to Recycle Trade Effluent at a Petrochemical Complex on Jurong Island 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 proactive in its water conservation journey and always look into opportunities to optimise water consumption within its plant. It recently embarked on a wastewater recovery plant using Microfiltration - Reverse Osmosis (RO) - Activated Carbon Filtration System, to recycle treated trade effluent for process use.

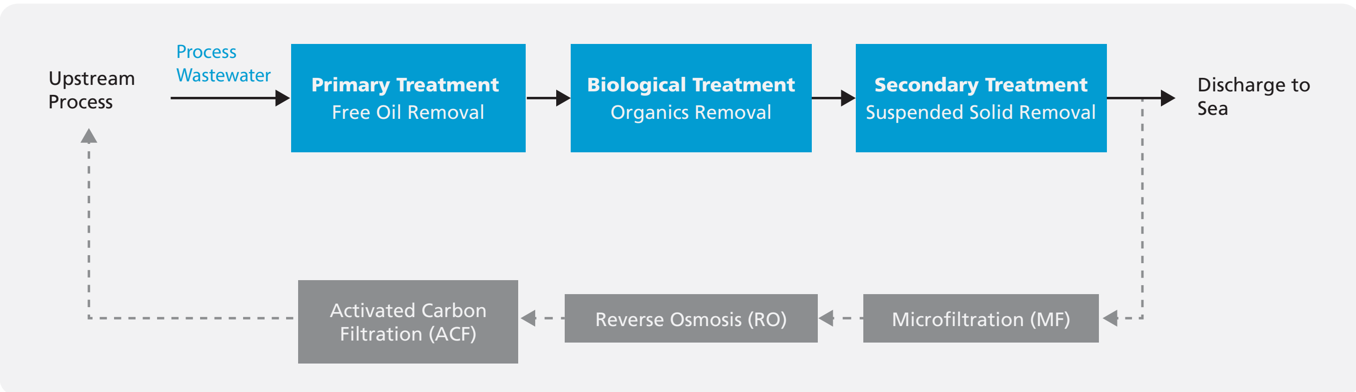


Figure 8: PCS's current Wastewater Treatment System and Demonstration Wastewater Recovery Plant

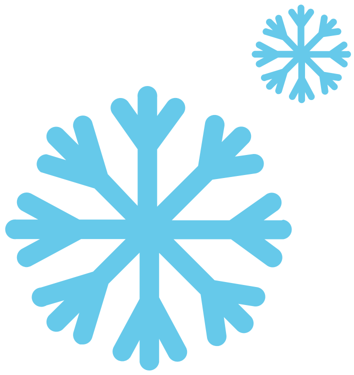
After about one year of pilot testing to assess suitability of membrane technology and also to identify any potential issues, a full scale demonstration wastewater recovery plant with design capacity of up to 1,200 m^3/day was approved for implementation.

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 and oil & grease generated from upstream process units, to a quality suitable for discharge directly to the sea. The demonstration plant, which has been in operation since 2019, 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 filters (ACF). The treated water is 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.

Case Study 4

Implementation of Indirect Seawater Cooling System by Petrochemical Corporation of Singapore (Private) Limited



Following the successful implementation of the wastewater recovery plant, Petrochemical Corporation of Singapore (Private) Limited (PCS) continued to explore further water recycling opportunities and the next project taken up was indirect seawater (SW) cooling system to reduce part of the cooling load from the existing cooling towers.

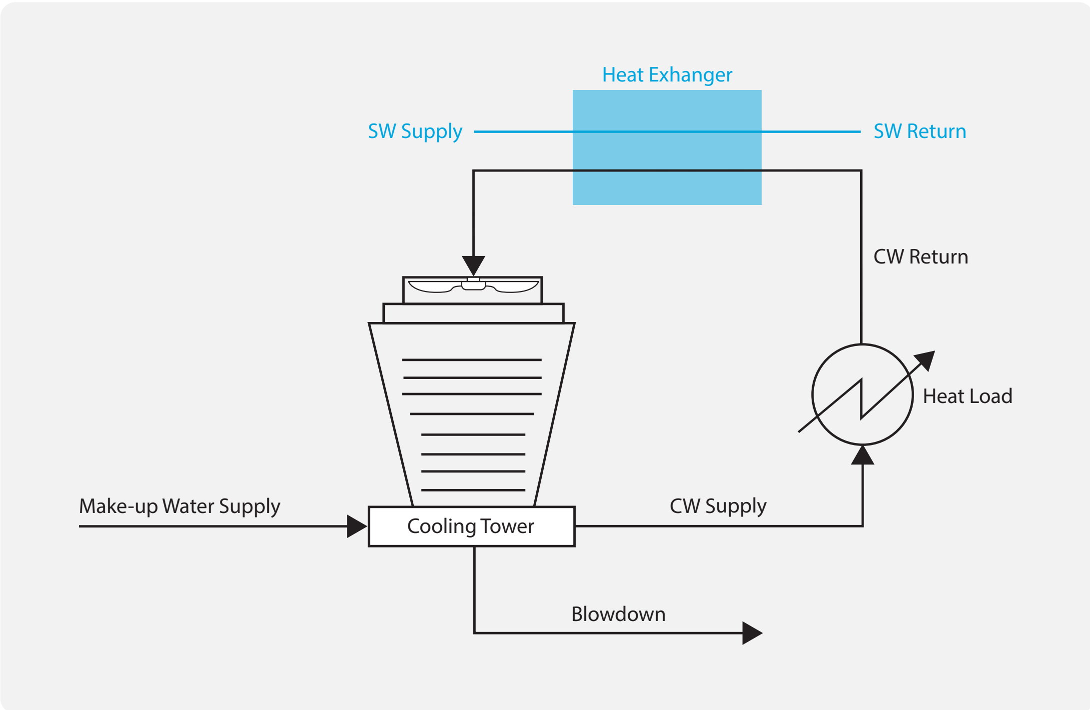


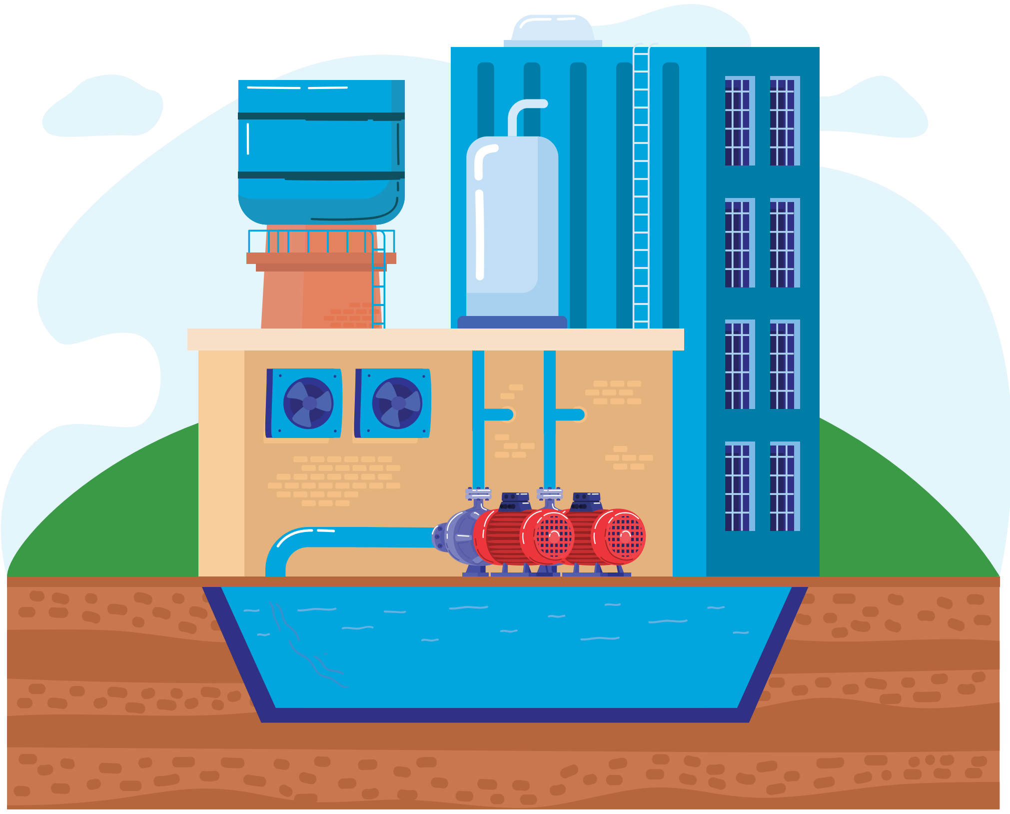
Figure 9: Schematics of Supplemental Indirect Seawater Cooling

The supplemental cooling by the indirect seawater cooling system allowed the existing evaporative cooling towers to save up to 700m^3/day of water which will otherwise to be lost to evaporation.

The hybrid system is retrofitted with mainly the installation of additional seawater heat exchangers, strainers, supply & return lines and pipe-works re-routing and it has been in operation since the third quarter of 2019.

Case Study 5

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 realised 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.

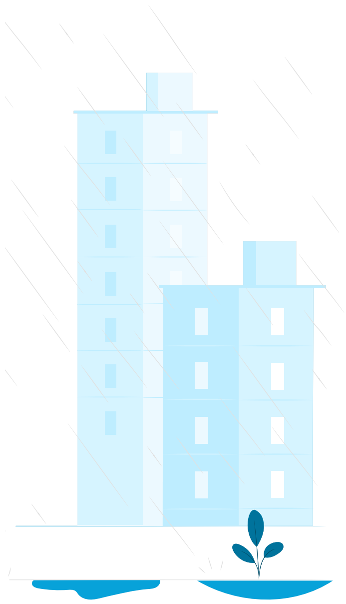
Case Study 6

Implementation of Chlorine Dioxide (ClO2) Based Dosing System by Shell Singapore

Shell Singapore had conducted a water audit in their facility at Shell's Jurong Island chemical complex and had identified an industrial water solution to reduce water consumption in its cooling towers. The cooling tower initially uses bleach/ sodium hypochlorite as a disinfectant. As the cooling tower cycles of concentration (COC) was limited to the chloride levels, the project proposes to replace bleach/ sodium hypochlorite with chlorine dioxide (ClO_2) based dosing system, which contributes less chloride than bleach/ sodium hypochlorite.

With the implementation of ClO_2 based dosing system, the cooling tower COC could potentially improve from 8.5 to 14.5, resulting in cooling tower make-up water savings of 600m^3/day. The project had commissionned in fourth quarter of 2020.

Case Study 7



Implementation of Cooling Water Blowdown Recovery System by Mitsui Phenols Singapore Private Limited

Mitsui Phenols Singapore (MPS) is a subsidiary of Mitsui Chemicals group manufactures mainly Phenol, Acetone and Bisphenol-A in Asia. As the demand for these chemical products rise over the years, the company strives to improve process facility to meet customer's needs without compromising on the environmental sustainability.

Through a pilot trial conducted at the phenol plant cooling water systems, MPS ascertained that 230m³/day of water can be recovered from their cooling water blowdown stream, using microfiltration (MF) and reverse osmosis (RO).

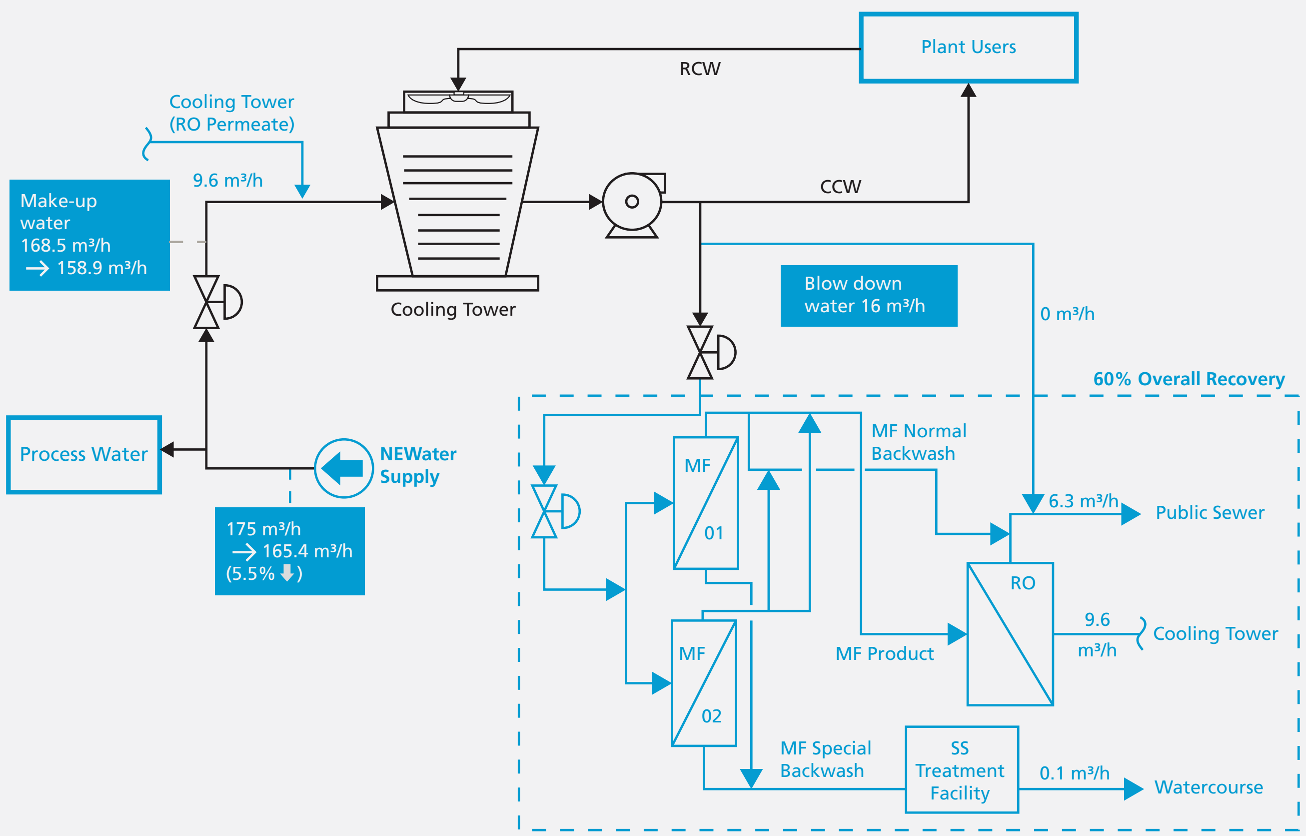


Figure 10: Schematics of Cooling Tower Blowdown Reclaim System

The plant has commissioned in second half of 2020. This recovery system can potentially reduce up to 5% of the facility's NEWater consumption and the OPEX is expected to be within the reasonable range of \$0.80 - \$1.20/m³.

Case Study 8

Implementation of Condensate Recovery Project at ExxonMobil Singapore Refinery (Pulau Ayer Chawan)

The ExxonMobil Singapore Refinery and Singapore Chemical Plant form the largest integrated ExxonMobil manufacturing complex in the world. The Refinery has a combined throughput capacity of about 592,000 barrels a day, and produces fuels and baseoils for lubricants that are marketed globally. It also provides the petrochemical complex with feedstock.

There are two refining sites – Jurong at Pioneer Road on mainland Singapore, and Pulau Ayer Chawan (PAC) on Jurong Island. ExxonMobil has identified a project to recover steam condensate at its PAC facility as part of ongoing efforts to enhance its responsible use of water in its manufacturing operations.

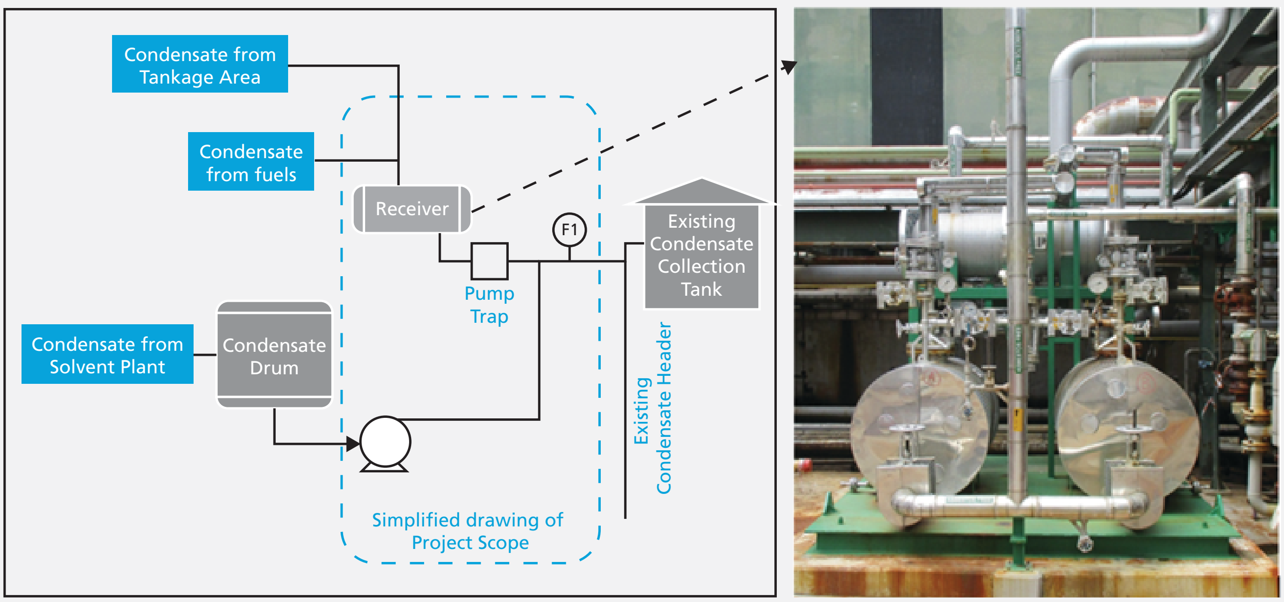


Figure11: Schematic of Condensate Recovery Project

Prior to the implementation of this initiative, steam condensate recovery from recoverable sources in the Fuels area at PAC was relatively low. As the steam traps are scattered across the extensive facility ground, it was challenging to recover all the condensate that is vaporised into the atmosphere. The steam condensate recovery rate in Fuels area was lower compared to Lubes area, which is nearer to the condensate recovery collection tank. The project, which was fully commissioned in early 2021, aimed to centralise condensate return from the Fuels area into a new receiver drum, and subsequently pump the recovered condensate into an existing condensate collection tank for steam generation.

The project is expected to improve condensate recovery rate in the site by approximately 5%, and correspondingly cut back on the unit's freshwater consumption. Also, since the recovered condensate is repurposed as steam, there is the additional benefit of reducing energy that would have been needed to generate the steam.

SUPPORT AND RESOURCE

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_IWSDF@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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MAKE EVERY DROP COUNT