Chestnut Avenue Waterworks
Chestnut Avenue, Singapore

1. Background Information

Chestnut Avenue Waterworks (CAWW) is located at the Chestnut Avenue, Singapore and was built in two stages. The first stage of the treatment plant, which treats the water conventionally using coagulation, flocculation, sedimentation and sand filtration unit, was built in 1976. The second stage water treatment was built in 2002 and uses advanced treatment technology like ultrafiltration (UF). This report covers the second stage treatment plant, herein referred to as CAWW-2.

CAWW is run by the Singapore Public Utilities Board (PUB) which is the national water agency of Singapore responsible for managing the collection, production, distribution and reclamation of water in the country. CAWW-2 was constructed by the PUB to double the treatment capacity of the CAWW to 546,000 m^3/day. Thus the CAWW-2 has the treatment capacity of 273,000 m^3/day. CAWW-2 uses the immersed ultrafiltration membrane technology and was the largest operational ultrafiltration (UF) membrane-based drinking water plant in the world when it was constructed.

Table 1 Overall Information of PWTP

Constructed Year	2002
Water Source	Upper Peirce Reservoir
Design capacity (m^3/d)	273,000
Automation	Yes
Date of access of the source information	4 July 2016

2. Water treatment process flow

The water treatment process at CAWW-2 is illustrated in **Figure 1**.

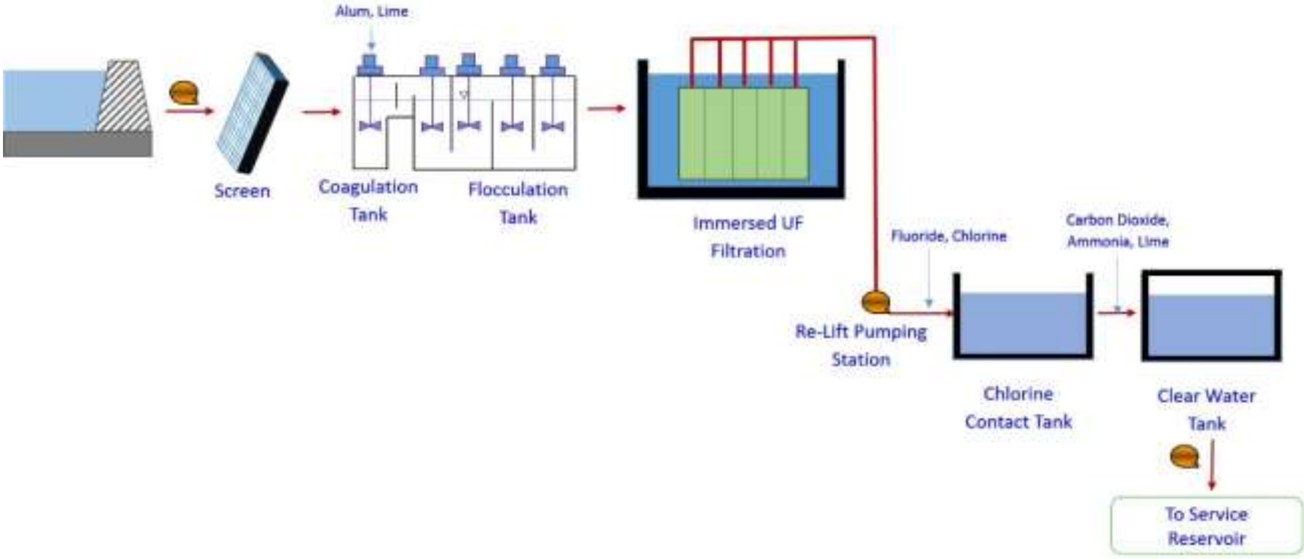


Figure 1 Schematic Diagram of Water Treatment Processes

The treatment process can be summarized as:
Raw water Intake → Screening →Coagulation → Flocculation → Ultrafiltration → Disinfection → Storage → Distribution

The CAWW-2 water treatment plant consists of a screen capable of screening the particles up to 1 mm in size; alum and lime addition unit for the coagulation and pH control respectively; mechanical mixing and flocculation unit; immersed membrane ultrafiltration unit; disinfection unit which uses chlorine for the disinfection; residual disinfection unit using chloramine; fluoridation unit; and lime and CO_2 addition unit to maintain the equilibrium of the water or control Langelier Saturation Index (LSI) for avoiding scaling or corrosion in the distribution pipeline. LSI determines the tendency of calcium carbonate to deposit or dissolve. Positive LSI signifies $CaCO_3$ deposition while the negative $CaCO_3$ signifies dissolution. Zero LSI refers to the equilibrium condition of the water.

Figure 2 CAWW-2 Water Treatment Plant

2.1 Intake

CAWW receives the raw water from the Upper Peirce Reservoir (UPR) (**Figure 3**) which receives the water from its catchment as rainwater drains into it. UPR also receives water from Johor, Malaysia when there is less rainfall, and the water is the UPR is not enough. The quality of raw water in the UPR was reported; the turbidity was around 1-5 NTU and the Total Organic Carbon was around 2.0 – 3.5 mg/L which indicates good quality of water.

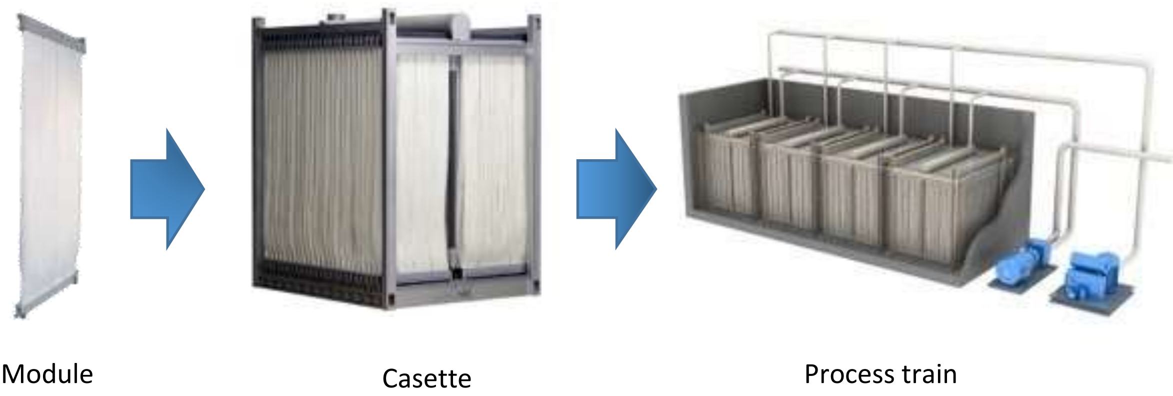
Figure 3 Upper Peirce Reservoir

2.2 Pre-treatment

The pre-treatment of CAWW-2 includes screening, coagulation, and flocculation unit. The fine screen cuts off the size of the particles to 1 mm. As the raw water enters to the flocculation unit through gravity flow, alum is added as the coagulant, and lime is added to adjust the pH for optimum flocculation. The effluent from the flocculation unit is then passed to the immersed ultrafiltration unit for the removal of the suspended particles.

2.3. Immersed Ultra-Filtration Unit

This unit consists of 16 membrane trains installed with Zenon's ZeeWeed500 membrane and capable of treating 273,000 m^3/day of pre-treated water. The membrane is a reinforced hollow fiber membrane and has the membrane area of 2000 m^2 per cassette. With 5 membrane cassettes in the train, the CAWW-2 has a total of 80 membrane cassettes in the system. The total design flux of the membranes are 79 L/m^2/h and have a design recovery of 95%.



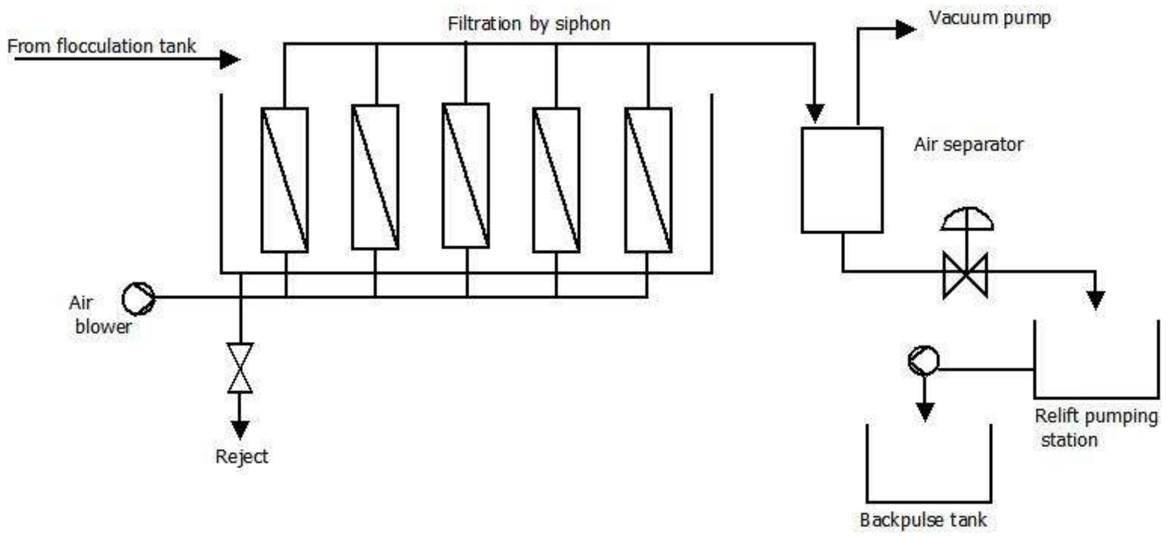


Figure 4 Immersed ZeeWeed Ultrafiltration System (top) and schematic diagram of UF system in Chestnut Avenue (bottom)

The ZeeWeed ultrafiltration system modules (**Figure 4**) has been directly immersed in the concrete tank containing the flocculated water. The membrane works on the "outside-in" flow principle and is a dead end process. Only the water molecules are penetrated through the membrane pores since the membrane has a pore size of 0.04 to 0.10 mm which avoids the penetration of pollutants exceeding 0.1 mm size including microbes like Giardia cysts and Cryptosporidium oocysts.

Normally pumps are required during the usage of UF membrane, either to create pressure on the upstream to force water through the membrane or downstream to create a vacuum. In immersed membrane system, a centrifugal pump is required to create the low-pressure vacuum essential to draw the water from the hollow fiber membrane. However, CAWW-2 creates the necessary vacuum by the siphon-induced through the head difference in immersed membrane and downstream storage tank. The elevation difference between the membrane tank and the storage tank is 8 meter (**Figure 4, bottom**). The use of siphon (**Figure 5**) has proven to use less energy, require lower capital and maintenance cost, and ease the operation of the treatment plant.

Figure 5 Siphoning to operate the UF process

Air separation vessel and air release valves are present to prevent air locking the pipes. As air accumulates in the air separation vessel, it is extracted via the vacuum pumps and vented to the atmosphere. The air-free permeate flows by gravity to the re-lift station wet wall.

UF system uses aeration blower system that consists of 4 blowers (three in operation at a time, one standby) and it is controlled by SCADA system. The membranes are typically operated in cyclic aeration where cyclic valves are operated in a cycle of 10 seconds when the system is in production mode. It is switched to continuous aeration if there are problems such as a valve failure or if the plant is operating with an additional membrane train.

2.4 Post-Treatment

Chlorine, fluoride, carbon dioxide, lime, and ammonia are used for the post-treatment processes.

Carbon dioxide is used to maintain the pH of the water, as well as replenish or recover some minerals and carbon dioxide loss during aeration process. A carbon dioxide plant supplies liquefied CO_2 which is vaporized, metered, and transferred as a gas under pressure. It is then mixed with water using a side stream static mixer and dosed as a solution.

The plant also comprises three 14.5 m^3 fluoride preparation tanks. Each tank is fitted with a vacuum operated automatic bag loader and a manual bag loader filled with dust extraction. Bags of fluoride powder are uploaded either by vacuum into the powder using the automatic unloading system or directly into the preparation using the manual bag unloader (dry feed). Sometimes, dosing pumps dose fluoride solution from the preparation tanks to treatment works (liquid feed).

As a disinfectant, chlorine is dosed at two stages in the plant, pre-chlorination and post chlorination. Chlorine is purchased in a number of cylindrical tanks that are stored in a place called ‘chlorine house’. The chlorine is in liquid form and is vapourized before dosing. Chlorine contact time is provided and the water is stored in the clear water tank before being sent to the service reservoir. The disinfection process is carried out in the form of chloramine because its residual is longer than the equivalent free chlorine residual, and therefore can penetrate stagnant areas of the system. Ammonia is added to the water, following normal chlorination treatment, to produce a chloramine residual.

2.5 Distribution system

The treated water is then distributed through the PUB (Singapore’s National Water Agencies) distribution network. In order to determine the quality of water from source and water the sampling and monitoring program has been planned according to the WHO’s Guidelines for Drinking-water Quality and is being reviewed regularly.

3. Advanced technology used in this water treatment plant or any points to improve the process, water quality and capacity

CAWW-2 uses innovative SCADA system to simplify the complexities of the membrane operation. CAWW-2 uses programmable logic supervisory control and data acquisition (PLC/SCADA) system for regular monitoring and operation. Additionally, the CAWW-2 has integrated large fieldbus network called Profibus to efficiently control the individual membrane trains. Profibus simplifies the complex operation of the system.

P&T-GCMS system with an automated sampler is used in the CAWW-2. This system is fully automated and is also programmed to send a mobile alert in case of emergency. It automatically takes the sample and measures the parameters from the membrane and clear water tank outlet.

4. Aspects of treatment process posing most difficulty for daily operation

Fouling is an inevitable issue in the membrane-based treatment system. The membranes are clogged with the suspended solids which inhibit the filtration process and affect the water quality. Other operational problems encountered by the plant include:

i. Airlock in permeate pipe
ii. Excessive transmembrane pressure

5. Aspects of water services management, in general, posing most difficulty at the moment

No significant problems other than the ones described above were found in the water services management.

6. Measures taken now to cope with 3) and 4)

In CAWW-2, three types of cleaning are done as described below to prevent and mitigate fouling conditions in the membrane:

i. Regular cleaning in 15-30 minutes interval is done with air scouring and backwashing to eliminate clogging in the membrane surface. Water which drains out of the pond is around 5% of influent water.
ii. Maintenance cleaning is done every week. The membrane is washed with the sodium hypochlorite with the concentration of 1,000 ppm. It takes around an hour to clean each pond.
iii. Recovery cleaning is done every 35 days which includes the usage of sodium hypochlorite and citric acid for the removal of organic clogs.

For the airlock problem in the permeate pipe, air separation vessel and air release valves are present to prevent air locking the pipes. As air accumulates in the air separation vessel, it is extracted via the vacuum pumps and vented to the atmosphere.

7. Recent investment made for the plant's improvement

Other than the SCADA system installed in the system for monitoring and operation of the system, no other recent investments have been made.

8. Other Highlights

i. Chestnut Avenue Waterworks has a fish activity monitoring system (FAMS), a device that combines video cameras with image analysis software to automate the fish-monitoring process, as a means of monitoring treated water quality at lower cost compared to other toxicity monitoring systems. The idea behind this technique is that fish change their behaviour at the first sign of chemical or biological contamination in water being passed through their tank so by observing the fish, contaminations can be detected quickly.

ii. The CAWW-2 occupies about 2500 m^2 of the area and is equivalent to about 180 $m^3/day/m^2$ treatment capacity which is very high than the conventional treatment plant.

iii. PUB has only 5% of the Non-Revenue Water (NRW) which is significantly low compared to the typical rate of 10 to 30%.

iv. Singapore does not have any water aquifer or lake. It is still able to meet the daily demand of 1.51 Mm^3/day of water demand, due to its effective water security planning. The per capita water consumption has also lowered from 162 L/d in 2003 to 151 L/d in 2014 and is targeted to reach 143 L/d by 2020. In addition to importing raw water from Malaysia, it also has desalination plant which runs on advanced membrane technology. Furthermore, it also has water reclamation plants and a separate water supply system for reclaimed water which can be used for flushing and gardening purpose.

9. Water quality data

The quality of our drinking water is regulated by the Environmental Public Health (EPH) (Quality of Piped Drinking Water) Regulations 2008. The drinking water standards set out under the EPH Regulations were based on the WHO Guidelines for Drinking-water Quality

Table 4 Raw Water and Treated Water Quality

No.	Parameters	Unit	Raw water	Treated water	EPH 2008 Standard
1	Color	Hazen	22	<5	<15
3	Turbidity	NTU	5.4	<0.3	<5
4	Aluminium	mg/L	0.1	<0.05	-

10. References

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