Showcase

Title: **NEWater wastewater reclamation to overcome water shortages**

Sector: drinking water / wastewater; select category (multiple options possible):

☒ drinking water sources
☐ drinking water treatment
☐ drinking water distribution
☐ wastewater collection / influent
☐ wastewater treatment
☐ wastewater effluent / receiving water
☒ other

Utility: **PUB, Singapore**

Date: 2014, updated 2019

Introduction & background information

Singapore has a total population of 5.8 million (2019) with an average daily water demand of 430 MGD (circa 1.5 million cubic metres). Singapore has overcome water shortages despite its lack of natural water resources and pollution in its rivers by investing in research and technology. Today, the nation has built a robust, diversified and sustainable water supply from four different sources known as the Four National Taps (water from local catchment areas, imported water, reclaimed water known as NEWater and desalinated water). By integrating the system and maximising the efficiency of each of the four taps, Singapore has ensured a stable, sustainable water supply that is weather resilient, capable of catering to the country's continued growth.

One of these Taps is the high-grade reclaimed water known as NEWater, made possible by state-of-the-art membrane technologies. For more information, see:
https://www.pub.gov.sg/watersupply/fournationaltaps/newater

There are currently five NEWater factories. Four of these are located at:

i. Ulu Pandan (32 MGD since Mar 2007)
ii. Kranji (17 MGD since Jan 2008)
iii. Bedok (18 MGD since Jan 2009)
iv. Changi (50 MGD since May 2010)

NEWater is primarily for non-potable industrial or indirect potable use. Supplied to wafer fabrication, electronics and power generation industries for process use, it is also piped to commercial and institutional buildings for air conditioning or other cooling purposes. This frees up potable water for domestic consumption. It is delivered via a separate distribution network to industrial and commercial customers. During dry periods, NEWater is added to PUB's reservoirs to blend with raw water for the production of drinking water.

The demand for NEWater grew 15-fold from 4 MGD (18,200 cubic metres per day) in 2003 to approx. 60 MGD (273,000 cubic metres a day) in 2014. Today, NEWater meets 40% of Singapore's total water demand. By 2060, NEWater is projected to meet 55% of Singapore's future water demand.

NEWater Production Process

NEWater is produced by a multiple barrier water reclamation process. Treated effluent from the water reclamation plants (WRPs) is being further treated in NEWater factories using advanced technologies comprising micro/ultra filtration (MF/UF), reverse osmosis (RO) and ultraviolet disinfection (UV) to produce high grade water called NEWater. A typical process scheme is shown in Figure 1.

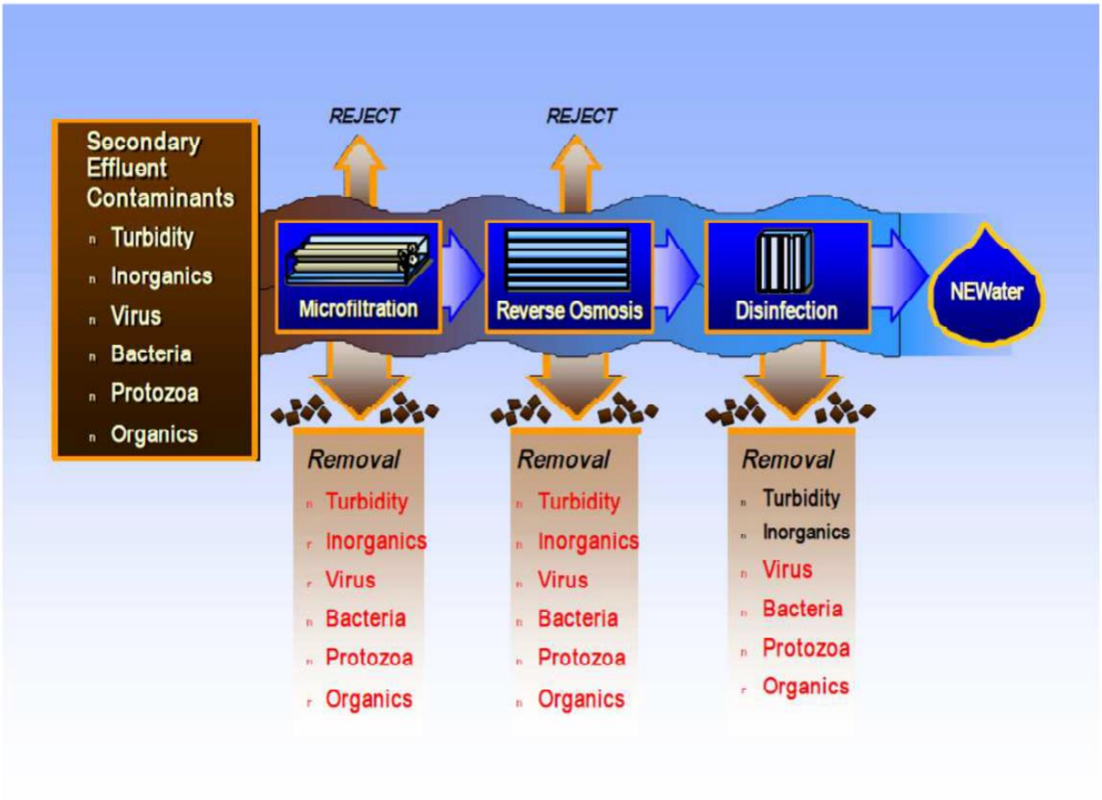

Figure 1: Multiple barrier approach for microbial and chemical contaminant removal

The first stage of the NEWater production process is known as Microfiltration (MF). In this process, the treated water is passed through membranes to filter out and retain suspended solids, colloidal particles, disease-causing bacteria, some viruses and protozoan cysts on the membrane surface. The filtered water that goes through the membrane contains only dissolved salts and organic molecules.

The second stage of the NEWater production process is Reverse Osmosis (RO). In RO, a semi-permeable membrane is used. The semi-permeable membrane has very small pores which only allow very small molecules like water molecules to pass through. Consequently, undesirable contaminants such as bacteria, viruses, metals, nitrate, chloride, sulphate, disinfection by- products, aromatic hydrocarbons, pesticides, etc, cannot pass through the membrane. Hence, NEWater is RO-water and is free from viruses and bacteria, and contains negligible amounts of salts and organic matter. At this stage, the water is already of a high grade water quality.

The third stage of the NEWater production process acts as a further safety back-up to the RO. In this stage, ultraviolet disinfection is used to ensure that all organisms still present are inactivated and the purity of the product water guaranteed. With the addition of some alkaline chemicals to restore the acid-alkali or pH balance, the NEWater is now ready to be piped off to its wide range of applications.

Water quality challenges

PUB is continuously making efforts to maintain NEWater quality at the highest possible level. There is a need to quickly detect any problem in water quality in order to safeguard the high-grade quality of NEWater and to ensure that the water quality is never compromised. Any slightest breach in RO membrane integrity or source water contamination needs to be detected rapidly, which otherwise could affect the quality of the produced water. These challenges are addressed by using surrogate parameters which can be measured online, as the conventional laboratory tests for contaminants are time-consuming. An ideal surrogate parameter is sensitive to changes in water quality and possesses a high correlation to drinking water parameters.

Conventionally, the membrane integrity is monitored by tracking the conductivity of RO permeates. However, this parameter was found not sensitive to change in permeate water quality, e.g. the conductivity of RO permeate remains similar in the event that one out of ten RO vessels failed. In contrast to that, the permeate TOC will show a sudden up-trend into the hundreds of ppbs. At PUB, TOC has been identified to be an effective and reliable surrogate parameter to monitor RO membrane integrity at NEWater factories. The TOC concentrations in RO permeate is monitored online using GE Sievers 900 Online TOC Analyser.

In the NEWater production process, the incoming effluent from the WRPs has a TOC load in the ppm range. This TOC load has to be reduced to a level below 500 ppb upon passing through the multi-barrier treatment process. Typically, the production process could achieve low TOC levels in RO permeate ranged from 50-80 ppb.

Purpose / need for on-line monitoring

The TOC concentration in the RO permeate and product water is a critical plant parameter which is difficult to confirm the accuracy of, as laboratory analysis usually takes more than 24 hours. In addition to that, due to the low TOC level in the RO permeate, off-line measurement is not recommended because the potential for contamination of the sample by organic and inorganic substances in ambient laboratory air, transfer systems, and containers will likely introduce a significant error.

Online TOC analysers are used in our NEWater treatment process as the analysers are capable of automated in-situ TOC measurement in just a few minutes compared to laboratory analysis. Typical analysis time for GE Sievers 900, the model in use now, is 4 – 6 minutes. In the event that the permeate TOC trend deviates from its normal trending, verification and sound operational decisions can be made promptly.

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Approach and implementation

Development of the monitoring programme

Prior to using Sievers Online TOC Analyser, a combustion based analyser (Polymetron) was tested for a couple of months during the commissioning of first NEWater factory. However, it was found that this method is not effective for TOC measurement below 500 ppb due to its unstable TOC background levels, which fluctuate in a range of hundreds ppb. The fluctuation in hundreds ppb hindered its applicability in low ppb measurement, as the permeate TOC is normally < 100 ppb.

Following that, Sievers 820 (this model was discontinued in the market in 2003/4 and was superseded by Sievers 900), an online TOC analyser based on chemical oxidation method, was used for online monitoring of TOC in RO permeate and product water. The analyser is based on the oxidation of TOC to form CO_2 using an oxidiser (ammonium persulphate) and UV radiation. Through our years of experience in such applications, this analyser has proved to be more consistent with good repeatability once it is routinely and properly calibrated. The fluctuation is only about 1 to 2 ppb, and hence able to make sound measurements of TOC < 100 ppb.

Systems, methods, and monitoring instruments

Figure 2 shows the process overview of a NEWater factory. The online TOC analysers are typically installed at:

1. RO permeate to monitor membrane integrity and organic removal; and
2. After the storage tank to monitor water quality of produced water

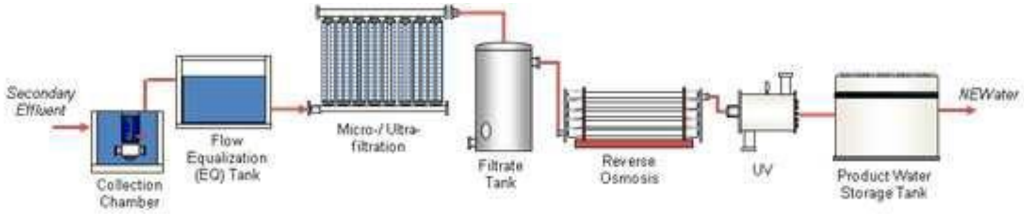

Figure 2: Process overview of a NEWater factory

In addition to the analysers installed in the treatment process, there is a portable TOC analyser that can be installed on-site and run parallel to the in-use analysers as and when needed, to verify the TOC trend of the in-use analysers.

Project Execution and Delivery

The online TOC analysers were deployed at NEWater factories as part of the work during the construction and commissioning of NEWater factories (by consultants and contractors). Except for the Changi and Ulu Pandan NEWater factories, which are owned and operated by Sembcorp and Keppel respectively, the TOC analysers at Bedok and Kranji NEWater factories are subsequently maintained by the qualified OEM representatives. However, minor maintenance of the TOC analysers such as flushing of choked tubing, and changing of in-line filters is carried out by PUB staff.

Costs and maintenance

Each TOC analyser costs about SGD 70,000 (USD 51,000; purchase cost including installation).

The annual maintenance cost per analyser isapprox. SGD 5,000 to 6,000 (USD 3,750 – 4,400) in total, mainly covering the costs for consumables, maintenance items, and calibration. Consumables and maintenance items include those recommended by the manufacturer, such as acid, oxidiser, UV lamp, sampling pump tubing (which usually needs replacement after 1 year), etc.

The analysers are calibrated once a year and the calibration on average costs about SGD 2,500 to 3,000 a year (USD 1,850 – 2,200).

Data handling

Data collection and storage

Data from TOC analysers and other plant operation and water quality parameters are collected, stored and controlled by plant SCADA system. Each NEWater factory has its own SCADA system and they are not linked or centrally controlled. All the data are monitored and accessed via Citect (Schneider Electric). This software displays time series trending of each parameter. Alarms will be generated through the SCADA system if the control parameters are out of the acceptable range. The alarms generated will appear on Citect software and the operators will also be notified via SMS.

Data verification is carried out through the following:

- Data is verified with a comparison between the instrument readouts and the SCADA outputs. The TOC reading on the SCADA system shall be corresponds to that on-site and this verification is carried out at least once a day.
- The instruments data is checked through verification with laboratory tests (at least once a week).
- As and when needed, TOC trend of the in-use analyser will be verified against a portable unit running parallel to the in-use analyser.

Data Handling

False negative TOC measurements rarely occur. False positive signals usually appear as a spike (both spiked up and spiked down). These spikes are considered normal as there's a daily pattern and they were due to the instrument errors or noises resulting from instrument operation, for example, refill of reagent every 8 hours. Incidents such as the breakdown of a fan in the analyser also resulted in significant sudden increase of TOC readings.

Besides the abovementioned regular instrument spikes, other changes in TOC (gradual or sudden uptrend) are usually true positive signals and reflect the permeate water quality that the analyser is measuring.

The TOC concentration in the produced water is a critical plant parameter. Issues associated with the functionality of TOC analyser, RO system and the feed water quality are likely to reflect a deviation of TOC from its original baseline range. Permeate TOC of > 100 ppb often indicates these issues, including

RO membrane integrity issues. In addition to the TOC, online conductivity readings are always used to support the TOC readings in data verification and operational decision-making (Permeate conductivity should not exceed 150 µS/cm).

A change in the permeate TOC could appear as a sharp increase, sudden and gradual uptrend. A sudden up-trend in TOC may have a different cause to a gradual up-trend. In the event that the permeate TOC shows an uptrend or suggests the permeate water is out-of-spec, the operation team will perform prompt investigation and trouble-shooting.

Quality Assurance / Quality Control

Although the SCADA system is very reliable, in general, the accuracy of the readings for all parameters measured online are checked regularly by comparing them with laboratory test results. Water samples are collected and tested every 8-hours (for parameters other than TOC) to ascertain the accuracy of the online readings. A comprehensive calibration schedule for the online meters is in place to ensure that the online readings are accurate and reliable.

Specifically for online TOC readings, data verification is carried out through the following:

- Data is verified by maing a comparison between the instrument readouts and the SCADA outputs. The TOC reading on the SCADA system needs to correspond to that on-site and this verification is carried out at least once a day.
- Online readings are verified by lab analysis through comparison between online results and lab results. This verification is carried out at least once a week or more depending on the TOC trends; however, the best frequency is once daily, as laboratory analysis usually takes more than 24 hours.
- As and when needed, TOC trends of the in-use analyser will be verified against a portable unit running parallel to the in-use analyser.

The maintenance of TOC analysers includes calibration, servicing, and parts replacement. The analysers are maintained by the OEM, i.e. GE for Sievers 820 or 900. The analysers are calibrated at least once a year by qualified OEM representatives. The frequency of parts replacement is based on the schedule recommended by the OEM or on as-needed basis, whichever shorter.

Evaluation of successes and limitations

The use of online TOC analysers is beneficial for water quality; some of the key advantages are:

- Early warning of water quality problems
- Monitoring of RO membrane integrity which will directly affect product water quality
- Early warning of operational problems and equipment failure
- Time-saving on lab analysis and reduced man-hour required for lab analysis

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Problems encountered in operation and maintenance of the TOC analysers included:

- Bubbles – Air trapped in tubing which usually resulted in TOC readings going up and down; corrective action is to dislodge the bubbles by purging the tubing using distilled water; this step needs to be carried out about once every month.
- Sensor drift – Drift happens occasionally (sometimes not even once a year as it will be corrected during the yearly calibration). Should there be any drift, it usually appears as a step-wise change of baseline.
- Clogging of in-line filter – The clogging causes a slower flow at the effluent of the sampling line. Practically, it needs to be flushed once every 3 weeks to avoid clogging.
- Instrument spikes – The interpretation of TOC trends would be less subjective if the instrument spikes (which are attributed to the instrument operational noise) are not present.
- Verification of reading – Complementary to the approach we are practicing now (i.e. to verify the in-use analyser with a portable analyser), it would be good to have a self-diagnosis feature in the analyser which can be triggered by the user as and when needed to verify the functionality of the analyser electronically.