Aerial view of the first stage of Tseung Kwan O Desalination Plant, which takes in water from nearby Joss House Bay

Water management

The Hong Kong Water Supplies Department explains how a new desalination plant will provide fresh water as a solution to sustain Hong Kong's development

Fresh water is a precious resource and its supply is not unlimited, with many places in the world facing fresh water shortage problems. As water covers three-quarters of the earth's surface, it appears to be abundant. However, in reality, over 97% of the earth's water is found in the oceans as salt water and around 2% stored as fresh water in glaciers. With over 8 billion of people in the world relying on the remaining 1% of fresh water readily accessible for human consumption, development of new water sources is of paramount importance.

A reliable fresh water supply is vital in sustaining Hong Kong's development and economic growth. As a result, the Water Supplies Department (WSD) of the Hong Kong Special Administrative Region (HKSAR) has implemented strategic infrastructures to overcome this concern. The Total Water Management Strategy was implemented in 2008 to better prepare Hong Kong for water supply challenges. The strategy focuses primarily on water demand management and water supply management. Major initiatives include educating the public on water conservation, promoting water control methodologies, and actively exploring new water resources. A review of the strategy was conducted in 2019, confirming that it has achieved its goals. The review also updated future water demand and supply methodologies up to 2040, with an emphasis on containing fresh water demand growth and building resilience in the fresh water supply to cater to the extreme effects of climate change through the use of diversified water resources. One key initiative is the adoption of seawater desalination, which is not susceptible to climate change.

In December 2019, the WSD commenced the design-build-operate (DBO) project for the first stage of Tseung Kwan O Desalination Plant (TKODP) at a contract sum of HK$9,018 million and it started supplying fresh water on 22 December 2023. TKODP is one of WSD's strategic infrastructures for building resilience in fresh water supply. It provides a reliable supply of potable water without being affected by climate change. The first stage of TKODP has a potable water production capacity of 135 million litres per day (Mld), which is equivalent to about 5% of the daily freshwater consumption in Hong Kong. The plant can be expanded for its second stage which will make it capable of providing an ultimate capacity of 270 Mld (approximately 10% of Hong Kong's daily freshwater consumption). The TKODP is the first of its kind in Hong Kong to adopt reverse osmosis (RO) technology for desalinating seawater to produce potable water for municipal use.

Desalination process in TKODP

WSD adopts an advanced seawater processing system at TKODP, setting the precedence of innovative desalination in Hong Kong. Seawater undergoes a number of steps to become potable water (see figure 1, opposite page).

The first process of seawater desalination is taking in seawater. Seawater passes through a submerged offshore hexagonal water inlet with bar screens to carry out preliminary screening, preventing large objects from entering the TKODP. After seawater intake, the pre-treatment of seawater at TKODP occurs in an integrated structure known as ActiDAFF®, which is a proprietary design developed by one of the joint venture members of the main contractor of the project from Spain.

FIGURE 1

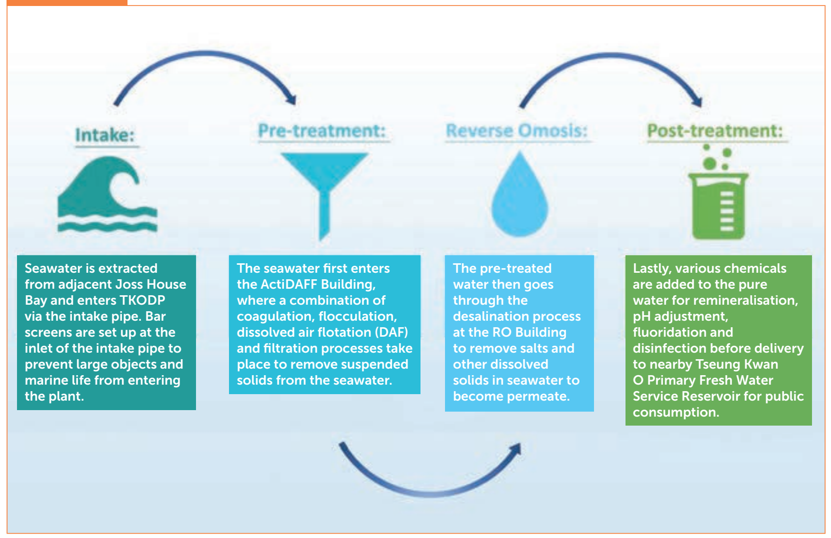


FIGURE 2

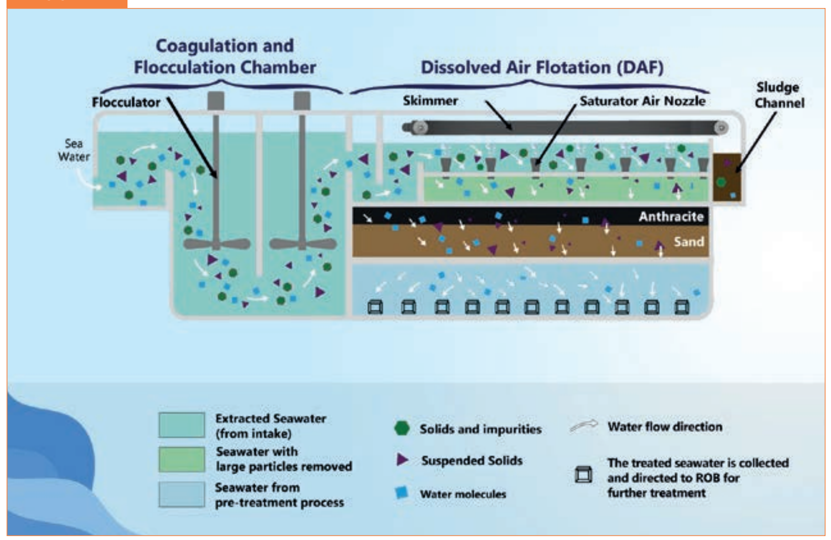
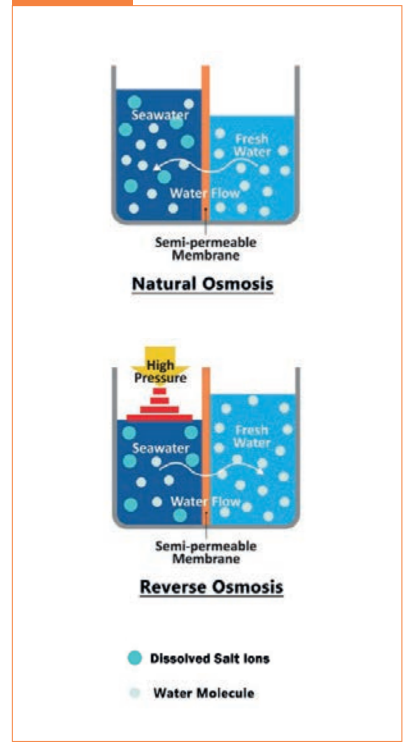


FIGURE 3



Clockwise, from top left: Figure 1: the treatment processes at TKODP; Figure 2: pre-treatment through the ActiDAFF in TKODP; Figure 3: mechanisms of natural osmosis and reverse osmosis (RO)

ActiDAFF is a combination of dissolved air flotation (DAF) technology and media filtration process. The DAF unit is particularly effective in removing low-density particles such as suspended particles, algae, and natural organic matter that cannot be eliminated by the initial screening process at the intake pipe and conventional sedimentation. This step minimises potential foulants, such as particulates and biological materials, which could damage the RO membranes during the desalination process. Ferric chloride is dosed to agglomerate the suspended solids into larger flocs. The flocculated water flows through a distributor, where it comes into contact with injected streams of air bubbles. The flocs are captured by the air bubbles and carried to the water surface, where they are gathered by a skimmer and conveyed to the sludge tank. With the large flocs removed, the seawater descends to the filter media bed, where finer particles are removed.

The ActiDAFF reduces the footprint of the plant and land usage compared to traditional methods, where two separate buildings are required for the DAF and filtration processes respectively. This combined arrangement not only reduces energy consumption during plant operation and hydraulic loss but also saves operational recurring costs and construction costs. Additionally, if the incoming seawater contains below-threshold concentrations of suspended particles, the air flotation process can be skipped, further reducing energy consumption.

After that, the pre-treated seawater flows into the filtered water tank and is ready to undergo the reverse RO process. RO is the process of forcing water from a more concentrated water molecule solution to a less concentrated water molecule solution through a semi-permeable membrane under high pressure, as opposed to natural osmosis where water molecules diffuse from a less concentrated solution to a more concentrated solution. RO technology is capable of removing 99.5% of salt and other impurities with lower energy demand compared to thermal desalination technology. This technology is a well proven and widely used method for efficient desalination worldwide (figure 3, above).

(This picture and right): reverse osmosis racks and pressure vessels at TKODP

In the TKODP, the RO process takes place in a series of white fibreglass pressure vessels. Each vessel contains seven spiral RO membrane elements joined together. Each element consists of a semi-permeable membrane sheet that is approximately 0.001mm thick and 40m long. These sheets are rolled around a desalinated water collection tube at the centre to form a spiral membrane with a diameter of 200mm. The TKODP has over 2,300 pressure vessels, which contain over 16,100 RO membranes.

During the RO process, seawater is pumped through these membranes at a maximum pressure of 66 atmospheric units. This process removes 99.5% of salt, bacteria, viruses, and other impurities. The resulting water, known as 'permeate', enters the water collection tube. Permeate from the pressure vessel is sent for post-treatment. The seawater concentrate, also known as brine, resulted from the RO process is dispersed back into the sea through a submarine outfall diffuser pipeline after its residual energy is recovered.

The residual energy from the seawater concentrate is recycled and reused for the RO process. The submarine outfall diffuser pipeline is strategically located in an area with significant ocean flow to ensure that salts from the brine can quickly diffuse and restore equilibrium upon mixing with seawater, hence protecting the local marine life.

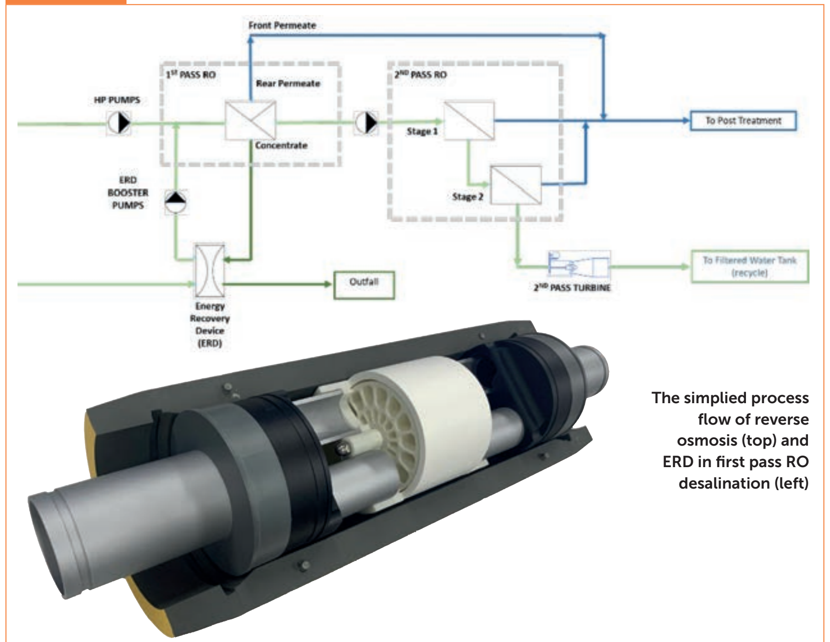
After undergoing the RO process, the permeate is transported to the post-treatment facility. At this facility, chemicals such as chlorine, lime, carbon dioxide, and fluoride are added to disinfect the water, adjust water hardness and pH levels, and promote dental health. The treated potable water is then conveyed to the Tseung Kwan O Fresh Water Primary Service Reservoir for public consumption.

Spatial and energy optimisation

In the TKODP, high-pressure pumps are used to transfer pre-treated seawater from ActiDAFF into the RO system. To optimise land and space usage, a pressure centre design is adopted for the high pressure pump feeding to the RO racks. The pressure centre design consists of two small and two large high-pressure pumps designed to provide the required water pressure for eight sets of RO racks, instead of the conventional layout with a separate individual duty feed pump for each rack (a total of eight pumps) and standby units. This arrangement greatly reduces the footprint while meeting the plant output requirements.

Positive displacement energy recovery devices (ERDs) are also employed to optimise energy usage in the TKODP. Since the RO process is the main energy consumer in the entire membrane desalination process, ERDs are installed to reduce energy consumption for generating high pressure. In the RO process, the brine contains significant residual pressure energy, which can be recovered by the ERDs, reclaiming up to 96% of the initial pressure energy in the concentrate. This results in a reduction of pumping energy of up to 50% required for all RO pump sets (i.e. high-pressure pumps, intermediate pumps and ERD pumps). (See figure 4, opposite page.)

FIGURE 4



The simplied process flow of reverse osmosis (top) and ERD in first pass RO desalination (left)

Sustainable development

The TKODP also prioritises sustainable development. Its design consists of multiple low-rise buildings to integrate well with future adjacent residential developments and the surrounding countryside. Additionally, soft landscaping has been added to mitigate the heat island effect caused by concrete buildings and enhance the appearance of the site.

Over 1,800 solar panels, each with power rating of 450W/540W, are installed on building rooftops to generate renewable energy, reduce energy consumption, and minimise carbon emissions. Furthermore, the WSD is planning a large-scale 10 MW solar photovoltaic (PV) farm in the vicinity of the TKODP. The electricity generated annually (approximately 12GWh) from the PV farm will be exclusively used for the TKODP. This initiative aligns with the HKSAR Government's commitment to spearhead renewable energy development and achieve carbon neutrality before 2050.

Above: photovoltaic (PV) panels will help to power the desalination plant. Left: soft landscaping helps to mitigate the 'heat island' effect of the new buildings as well as providing aesthetic appeal

WSD's Total Water Management Strategy in Hong Kong has yielded significant results

The way forward for desalination in Hong Kong

The implementation of the WSD's Total Water Management Strategy in Hong Kong has yielded significant results in the sustainability and resilience of fresh water supplies.

The establishment of the first stage of the TKODP is one of WSD's water management strategies and plays a crucial role in diversifying water sources to enhance the overall resilience of the water supply systems in Hong Kong. By using reverse osmosis technology, the TKODP efficiently converts seawater into fresh water to provide an additional water source for Hong Kong citizens.

Stage 2 of the TKODP, which has already reserved its location next to Stage 1, is currently under planning. The success of the TKODP will serve as an important milestone for WSD's continuous efforts in diversifying water sources to better prepare for climate change and to contribute for the sustainable development of Hong Kong.