REVERSE OSMOSIS TREATMENT AT DAVIS STATION, ANTARCTICA

Ben Harrison, *Plumbing and mechanical Services Project Officer,* Australian Antarctic Division
Phoebe Nash, *Project Engineer - Water,* Australian Antarctic Division

ABSTRACT

Potable water at Davis Station, Antarctica, is produced by reverse osmosis from a saline tarn source. There are various operational issues associated with this water production method which must be overcome. Challenges include varying tarn salinity levels, low temperatures, a brief two to three month production window and a rotating workforce. This paper discusses solutions which have been developed to address these challenges and improvement plans for the future.

1.0 INTRODUCTION

The Australian Antarctic Division (AAD) is responsible for providing essential services including potable water supplies to communities working and living on Stations on the Antarctic continent and Macquarie Island, a sub-Antarctic island.

Davis Station is the most southerly of Australia's three Antarctic bases and was established in January 1957. Davis is situated on the coastal edge of the Vestfold Hills – a 400km^2 area of ice-free land approximately 20km from the continental ice sheet. Davis is an extremely dry area. The average annual precipitation is 70mm and there is no fresh water readily available for drinking in liquid form.

The production of potable drinking water to sustain the approximately 20 (in winter) to 60 (in summer) expeditioners at Davis has always been a challenge.

Potable water is produced from a saline tarn (see Figure 1) which is only available in liquid state during a short window of in mid-summer. Water is drawn from the tarn and treated to potable water standard via coarse filtration, ultra-filtration (UF) and reverse osmosis (RO) membranes (referred to throughout this paper as the RO plant) The water produced during this summer production period of approximately 60 to 90 days must sustain the station for the remainder of the year.

Management of tarn salinity levels is critical to producing water through the RO plant, which runs at 30-70m^3/day dependant on feed quality and membrane condition. Low ambient temperatures bring operational challenges of pipe freeze-ups, tarn freeze up and low membrane permeability. The annually rotating workforce also presents a challenge as the new plumbers heading south each year may never have operated an RO plant before.

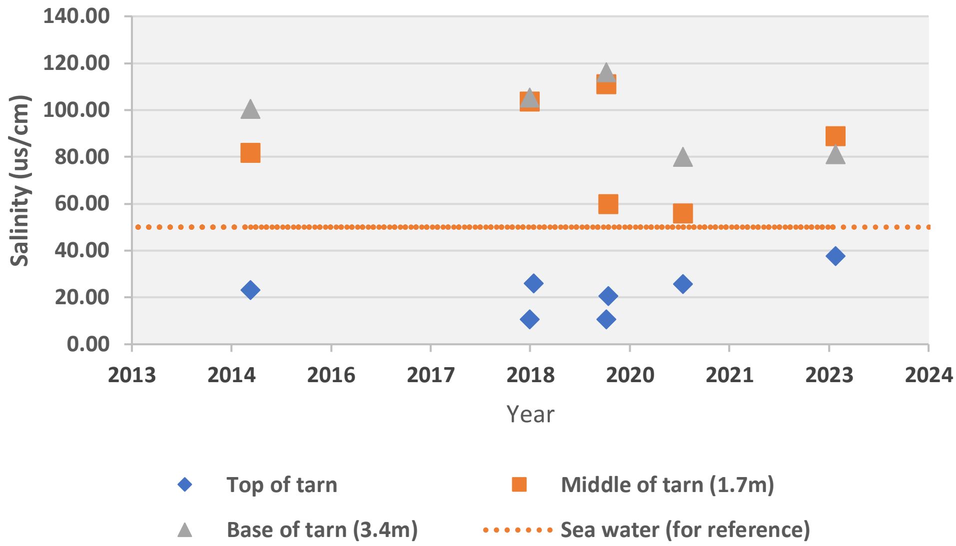
As the RO plant reaches the end of its lifespan, plans are afoot to install a replacement. Increased throughput, a wider temperature operating range and year-round operation are key factors which were considered in the design of the new plant.

Figure 1: – ***Saline tarn at Davis station with Prydz Bay in the background***

2.0 OPERATIONAL CHALLENGE 1 – TARN CONDUCTIVITY LEVELS

The tarn which supplies the feed water to the RO plant was originally a natural depression in the land abutting the station. To increase water storage capacity, in the 1980s the depression was excavated and then filled with pumped seawater and naturally captured snowmelt. The resultant salinity of the tarn is variable. In years of high snow accumulation and melt, the tarn water becomes more brackish and less saline. Conversely, some years there is limited snow melt, and the salinity increases due to both concentrated saline runoff entering the tarn from the surrounding bed rock and the practice of returning the concentrated brine stream of the RO plant to the tarn. The melt/freeze cycle of the sea ice which forms atop the tarn in winter also concentrates salt in the water body: when sea ice freezes during winter it concentrates the salt into the water below, resulting in hyper-saline, very cold and dense water under the ice. Figure 2 shows the variance in conductivity[1] of the tarn over the last decade, which typically ranges from brackish water at the surface of the tarn to just over double the conductivity of seawater at the base.

[1] Salinity and conductivity are used interchangeably throughout this paper as the two are closely related. Salinity is a measure of the amount of dissolved non-carbonate salts in water. Conductivity is a measure of the capacity of water to conduct electrical current, which is facilitated by dissolved salts in water. Conductivity can be measured readily in the field at Davis using a handheld probe.



<u>**Figure 2:**</u> ***Davis Tarn conductivity 2010 - 2023***

This variance in salinity has repercussions for the production rate of the RO plant.

As the feed water salinity increases, the RO membranes produce a lower volume of water. Running at a lower production throughput is undesirable because of the short time frame during summer when the tarn is sufficiently melted to harvest feed water.

To some extent, the variation in conductivity can be overcome by harvesting the RO plant feed water from near the surface of the tarn where the salinity is lower. This is achieved by adjusting the height of the submersible feed pump which is suspended from a pontoon into the tarn.

However, over time the bulk tarn conductivity concentration reaches an unacceptable level due to the return of the RO plant waste to the tarn (marine disposal of the highly saline waste stream is not pursued for environmental reasons). At this point, the tarn must be replenished with sea water. Tarn recharging is a labour-intensive process, requiring the participation of all station expeditioners. The process is only feasible during October and November. During this timeframe the daylight hours are longer and the outside weather more manageable to work in. Most importantly, algae blooms which could clog the UF and RO membranes, have not yet commenced in Prydz Bay (see Figure 1), where replenishment seawater is drawn from.

Emptying the tarn is a relatively straightforward process: a hole is drilled in the ice above the tarn, a submersible pump lowered in and a layflat hose used to convey most of the estimated 13.5 megalitres of tarn water approximately 90 metres away to Heidemann Bay via a sloping rocky route. Refilling the tarn is more complex. 900 metres of layflat hose in 90 metre lengths is laid across the ice over a 20m elevation to transfer water from Prydz Bay to the tarn. The current method involves pumping only during the 6 to 10 hours of daylight. At the end of the day, the hose must be drained and packed up to prevent freezing. During pumping, the line needs to be constantly inspected for flow for flow as even when moving the water can freeze. In theory, this part of the exercise takes approximately ten days however it has taken up to three weeks in the past due to freeze ups of the layflat hose and pumped water (Figures 3 and 4).

Figure 3: ***Pumped water exiting layflat hose as an ice/liquid mixture***

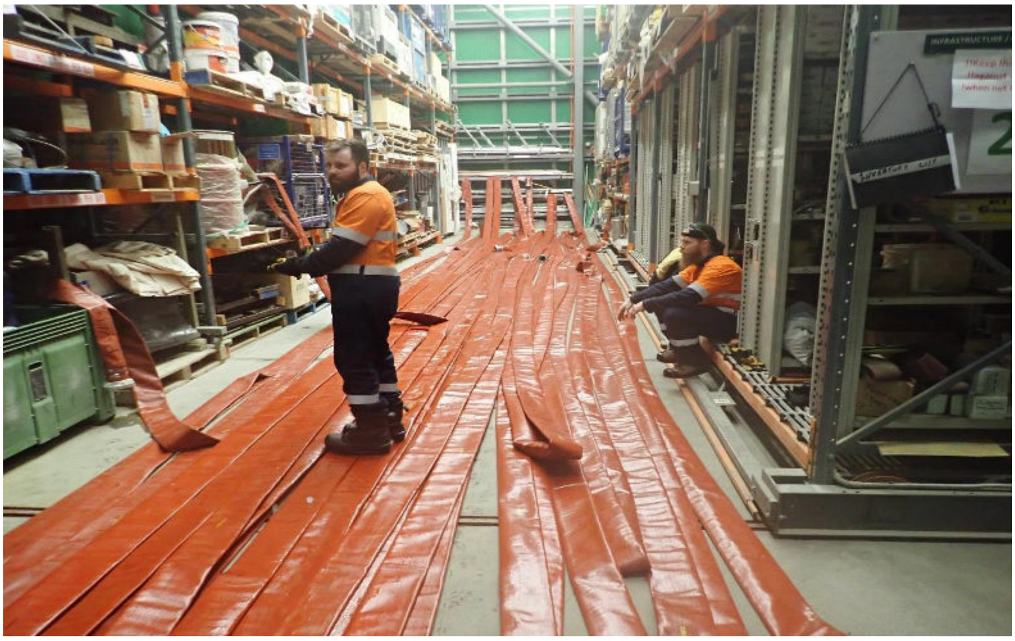


Figure 4: ***Defrosting 900 metres of layflat hose in 2015***

2.1 OPERATIONAL CHALLENGE 2 – EXTREME TEMPERATURES

The ambient temperature at Davis Station ranges from 3 to -20°C. Consequently, even during summer when the tarn is melted, the feed water to the WTP is barely above freezing point. As water gets colder, its density increases resulting in a lower throughput through the RO membranes. This issue is addressed by heating the incoming feed water.
A diesel boiler is used to heat the incoming feed water from approximately 1°C to 17°C. One litre of diesel heats approximately 190 litres of water; in total 9000 litres of fuel is used for feed water heating over the RO plant production period.

There is still a risk of water in the feed pipeline freezing before it reaches the tarn building which houses the boiler. The DN90 feed pipe is therefore well insulated with a 50mm thick layer of polyurethane foam insulation. Heat trace cables are also run along the length of the feed pipe to provide heat input to the fluid inside the pipe. The temperature of the pipe exterior is monitored by temperature transmitters located along the length of the pipe. Exceedances of the temperature setpoint trigger an alarm notification to the on-call tradespeople. Pipe freeze-ups are critical events due to the significant consequences of losing water production capability.

Cold snaps can occur even in summer. This has implications for the RO plant feed pump pontoon, which must be installed and removed in the tarn when the tarn ice is still melted. It cannot be left in the tarn over the winter due to the potential damage caused by the crushing expansion forces of the ice. Figure 5 was taken just after the pontoon was craned out of the tarn towards the end of summer in March 2022. Ice had just started to form around the pontoon floats. The photo demonstrates the delicate balance between eking maximum production time out of the RO plant and removing the pontoon before ice freezes around it and locks it into place.

Figure 5: ***Davis Tarn after removal of pontoon in March 2022***

2.2 OPERATIONAL CHALLENGE 3 – ROTATING WORKFORCE

Two to three maintenance plumbers are sent to Davis each year to maintain all plumbing infrastructure on station. This includes the domestic plumbing fixtures, heat exchangers, hydronic heating, air handling systems, waste incinerator and sewage treatment plant, in addition to the water treatment plant. For most plumbers, this will be their first experience operating a reverse osmosis treatment system.

The reverse osmosis treatment plant is hibernated over winter in a sodium metabisulfite preservative solution. Start-up and water production occurs in late January to early February; just after the ship containing the plumbers and electricians who operated the RO plant during the previous summer has left.

The incoming plumbers are provided with intensive training in a wide range of Antarctic specific plumbing techniques in the lead-up to their departure. Some years this has included a week-long intensive RO training course with an external provider. Some years however, there has been no training at all due to various factors such as course availability, Covid-19 and changes in the shipping departure schedule.

The start-up of the RO plant generally assumes the same format, regardless of training (or lack thereof). In the days leading up, the plumbers are instructed by the support team at the AAD head office in Tasmania to read the Davis RO Manual from cover to cover. The manual has been revised and honed over the years. It succinctly lists the key steps required to start up and operate the plant. When start-up occurs, a support team consisting of plumbers and electricians with multiple past years of experience operating the RO plant, is convened at the AAD head office in Tasmania. The start-up is directed by the support team via a phone hook-up and troubleshooting of any start-up issues (which always seem to occur, a different one every year!) are resolved using their collective operating experience. The use of a concise manual and real-time support is the best current strategy to overcome the inexperience of the new operators and prevent the very real risk of damage to the RO plant which is heightened due to its age and the high operating pressures involved.

2.3 PLANS FOR THE FUTURE

The current RO plant is nearly the end of its service life and plans are underway to install a new system which more effectively addresses some of the operational challenges described above. Two new RO plants have been purchased which have higher throughputs ($100m^3$/day at a feed water temperature of 5°C) to enable harvesting of more water with less fuel during the current summer production window. The plants also include a more robust coarse filtration step using spin disc filters for improved algal removal capacity. This will enable harvesting of feed water from the sea, prolonging the production period.

However until a seawater intake structure – currently at a very early design stage – is built, tarn water harvesting and the arduous task of tarn replenishment will continue. A new containerised hydraulic hose reel for the tarn refilling stage, designed in-house, has been fabricated. It will be sent to Davis on the Summer 2023-24 supply ship and should make the tarn refilling exercise less labour intensive.

Works to increase water storage capacity are also underway. The completion of a 600kL water storage tank will supplement the existing water storage volume (two 600kL outdoor tanks and four indoor tanks totalling 230kL) to provide more capacity to store water, particularly for when the larger RO plants come online.

3.0 CONCLUSION

Water production at Davis station is challenging and unconventional. The AAD has developed the broader system described above to provide the required potable water volume to sustain life at Davis. The success of water production relies on making use of developed knowledge, adapting conventional equipment to suit unconventional operating conditions, adherence to documented procedures and a commitment to making continuous improvements.

4.0 ACKNOWLEDGEMENTS

Thanks to Ducky, Ash, Joe and all expeditioners who have run the plant over the past seasons.

5.0 REFERENCES

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