Australian Water Recycling
Centre of Excellence

Demonstration of robust water recycling:
Energy Use and Comparison

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Peter Scales, Adrian Knight, Stephen Gray, Jianhua Zhang, Michael Packer and Kathy Northcott, October 2015

Demonstration of robust water recycling: Energy Use and Comparison

Project Leader

Prof Stephen Gray
Victoria University
Werribee Campus
PO Box 14428
Melbourne, Victoria, 8001, AUSTRALIA
Telephone: +61 3 9919 8097

Partners

University of Melbourne
Australian Antarctic Division
Veolia
AECOM
TasWater
Coliban Water
Curtin University

Contact: Prof Stephen Gray stephen.gray@vu.edu.au

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The Australian Government has provided $20 million to the Centre through its National Urban Water and Desalination Plan to support applied research and development projects which meet water recycling challenges for Australia's irrigation, urban development, food processing, heavy industry and water utility sectors. This funding has levered an additional $40 million investment from more than 80 private and public organisations, in Australia and overseas.

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Executive Summary

The Advanced Water Treatment Plant (AWTP) for the Australian Antarctic Division's (AAD) Davis Station was operated at Selfs Point Wastewater Treatment Plant (SPWWTP), Hobart, to demonstrate its performance and reliability. This report outlines the energy cost of operating the plant and compares it to larger plants of a similar configuration. The AWTP had seven functional barriers including ozone, ceramic microfiltration (MF), biological activated carbon (BAC), reverse osmosis (RO), ultraviolet radiation (UV), calcite contactor and chlorination (Cl_2), and will be preceded by a membrane bioreactor (MBR) when installed at Davis Station. The conclusions from the work are based on demonstrated results from the trial, data from current operations at Davis Station, comparative data from larger operational plants and technical data from product operational manuals. The latter was necessary as there is no known plant with an identical barrier configuration.

The main outcomes from this report are:

- The potential savings in energy through utilisation of the product water of the AWTP at Davis Station are significant and would amount to a saving of in excess of 33,250 L of diesel per year compared to current operations.
- The energy use of the AWTP based on 15 hrs of operation per day is 1.93 kWh/m^3.
- The energy use of an AWTP operating continuously at larger scale (of order 10 ML/day) is estimated at 1.27 kWh/m^3.
- For the production of drinking quality water, comparison of deciding brackish water desalination to tertiary treatment of a secondary treated waste water with the AWTP configuration shows that the brackish water salt concentration would need to be less than 5 g/L (10000 µS/cm) to be competitive on an energy basis.

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Introduction

In the design of the Advanced Water Treatment Plant (AWTP) plant for installation at Davis Station Antarctica, low energy usage was not a key criterion compared to parameters such as membrane fouling rates, an ability to operate across a range of flow conditions, achieving pathogen and chemicals of concern reductions to meet discharge compliance and producing an effluent that will have minimal effect on the environment. The AWTP had seven functional barriers including ozonation, ceramic microfiltration (MF), biological activated carbon (BAC), reverse osmosis (RO), ultraviolet radiation (UV), calcite contactor and chlorination (Cl_2), and will be preceded by a membrane bioreactor (MBR). The plant operates in batch mode and the standby time is likely to vary from one or two hours per day during the summer to periods of up to forty hours between periods of production during the winter. In addition, to improve reliability and reduce maintenance requirements, the reverse osmosis recovery rate and pressure differential on the MF membranes were kept to a minimum to reduce fouling rates. Despite this, the overall use of energy per m^3 of product water relative to current operations in Antarctica and the likely energy use of the plant if it were scaled up and run as a continuous operation are both of interest. An analysis of actual plant data, data from current operations at Davis Station and data taken from larger, continuous throughput plants with similar barrier components, is considered here. There are no known larger plants operating in the configuration of the AWTP and as a consequence, data was taken from the relevant process sections of three larger plants.

Current operations at Davis Station

As noted, because of the seasonal nature of the Antarctic stations, the AWTP was designed to deal with large variations in flow due to seasonal population variations as detailed in Table 1.

Table 1: Davis Station population profile.

Station Population	Summer	Winter
Maximum	150	30
Average	120	25
Minimum	70	17

Note: Summer is defined as being the six months from November to April inclusive, Winter being the balance. This definition is reflective of the change out of personnel during November and April.

Water use on station is measured and is rising on an annual basis whereby it is estimated that the average daily water use per person is currently around 150 litres. It is likely to be capped at this value. Water use has increased from between 40 to 80 litres/person/day in 2006/07 to 130-140 litres/person/day in 2011. A high of 170 litres/person/day was noted in January 2010. Assuming a usage rate of 150 litres/person/day, the total maximum water use per year based on the average station population may be calculated as 3.276 ML in summer and 0.683 ML in winter, giving a total of 3.958 ML or, in round figures, 4 ML (4000 m^3) per annum.

Current potable water production practice at Davis Station is to source feed water from a hyper-saline tarn, heat it to approximately 20^oC and then pass it through a desalination unit. The practice at other stations (Mawson and Casey) is to melt ice to produce feed water. The yield on the process at Davis Station is around 50% of the total volume of water processed, the residual being a more hyper-saline waste product. The practice of melting ice is very energy intensive with a theoretical energy cost of 91 kWh per m^3. Heating the water from 0 to 20^oC takes another 23 kWh per m^3. This assumes perfect thermal efficiency during the melting and heating process. The water then needs to be desalinated (yield around 50%). Assuming a thermal efficiency of 50% (very conservative), the minimum energy use would be in excess of 230 kWh per m^3 of product water. This is considered conservative. Melting ice is not required at Davis Station, but is clearly a key consideration at the other Antarctic bases.

The energy and financial costs of the current practice at Davis Station have not been formally calculated but a good estimate can be made based on the heat capacity of water and the energy requirements for desalination. To validate the actual costs, both the thermal efficiency of the water heating process and recovery rate or yield from the desalination process need to be known. Data from Davis Station shows that:

- 1 L of diesel is used to heat 194 litres of water to operating temperature (from around 0 to 20°C) for desalination (5.15 L diesel/m^3); and
- 23 kW of energy is used by the desalination facility to run continuously in order to produce 70 m^3 of fresh water per day.

The energy transfer efficiency based on the figures from Davis Station and the known energy density of diesel (35 MJ/L) suggest a thermal heat transfer efficiency of 46 ± 1% for the water heating process. Although waste heat is available for area heating at Davis Station, a separate diesel fuel heater is used for this operation. The yield on the desalination process is 50%, so twice as much water needs to be heated as the volume produced. Table 2 overviews the total energy cost per year to produce 4000 m^3 of water using this practice. Simple division gives an energy cost of 108 kWh per m^3.

Table 2: Energy cost of water production.

Process	Theoretical energy input per m^3 (kWh)	Yield (%)	Thermal efficiency (-)	Energy consumption (kWh/year)
Heating water 0-20 °C	23.32	50	0.46	396,388
Desalination	4	50		31,668
TOTAL				428,046

The total energy cost consists of a combination of electrical and thermal energy inputs, both coming from either diesel as a fuel for burning/heating or diesel as a fuel for electricity generation. Davis Station figures show a utilization of 0.28 L of diesel per kWh of electricity produced. This equates to a conversion efficiency of 36.7%, where 1 kWh is 3.6 MJ of energy. Although presented as a total consumption in kWh in Table 2, the diesel use can be recalculated as 49,647 L per annum, or 12.5 L per m^3 of water produced. At pump prices in Melbourne, this is in excess of \$16 per m^3 of water produced, although the true cost of diesel in Antarctica will likely be far higher. In short, the real cost of water supply under current operations is likely up to two orders of magnitude higher than in an Australian capital city.

Energy use on the AWTP

Calculating the exact energy use of the AWTP is not straightforward due to the fact that it has a number of operational modes ranging from almost continuous (summer mode) to transient (winter mode). The standby and transient ancillary energy requirements are therefore more important to total energy use per m^3 than might be the case in a conventional continuously operated plant. To facilitate the calculations, an energy totalizer was installed on the plant and an assessment made of operations considered to be non-standard (outside of the two standard operational modes). In addition, the energy use of each of the barriers was measured to assess their respective contributions to the total energy use and allow comparison to larger scale operations. The totalizer was operated across a period of use whereby all operations except clean in place (CIP) procedures for the RO membranes were conducted. Given that RO membrane cleaning is anticipated as a twice-yearly event, this was considered to be a trivial extra energy input.

The plant input is 1.2 m^3/h of feed water with a purified water output of 0.84 m^3/h (nominal capacity of 20 m^3/day). The instantaneous energy use on a continuous operational basis can, therefore, be calculated quite easily by averaging energy readouts across a fixed time period within any one batch run, although this is a minimum value since it does not include compressor air and standby energy requirements. Monitoring of energy requirements in this manner shows an average instantaneous value of 1.5 kW. A minimum value for the energy use of water production is therefore 1.8 kWh/m^3. Table 3 shows an approximate breakdown of the energy use per barrier.

Table 3: Instantaneous contributions to AWTP energy use.

Section	**Instantaneous (kW)**	**(kWh/m^3)**
Ancillary including lights, control systems, and instrumentation	0.28	0.33
Feed pump	0.11	0.13
Oxygen generator and ozone circulation pump	0.32	0.38
Ozone generator	0.17	0.20
Total for ozone barrier	0.60	0.71
MF	0	0.00
BAC	0	0.00
RO (pumps)	0.35	0.42
UV	0.19	0.23
Cl_2 (pumps)	0.10	0.12
Total	**1.52**	**1.81**

Other ancillary services include the air compressor and a heater for CIP makeup water heating. The compressor runs intermittently and is used for valve actuation and backwash processes, and draws 1.72kW. Peak electricity use for the AWTP is thus 3.52 kW. The CIP heater use was not included as it is expected to operate every 3 months, and is hence considered trivial. A detailed analysis of energy use across three days of production showed a total use of 75.3 kWh for the production of 38.95 m^3 of water. The operational mode was 6.7 hours of operation and 4 hours standby (15 hrs operation per day). This is considered to be an intermediate production case study. The energy cost per unit of water production was 1.93 kWh/m^3. This is slightly higher than the sum of the individual components during continuous operations and consistent with expectations based on ancillary contributions.

Based on the assessment of the energy use, Table 4 shows the likely energy utilisation at Davis Station after AWTP implementation, assuming the product water is used to augment potable water supplies. The calculation is based on a yield of 70% across the AWTP.

Table 4: Energy use for recycled water implementation.

Process	**Energy input (kWh/m^3)**	**Annual Volume (m^3)**	**Energy consumption (kWh/year)**	**Diesel use (L/year)**
Heat/desalinate	108	1,188	128,417	14,894
Recycle	1.93	2,771	5,348	1,499
TOTAL		**3,959**	**133,765**	**16,393**

The energy savings associated with use of the AWTP to augment the water supply is estimated at approximately 290 MWh or 33, 250 L of diesel per annum.

Comparison to larger continuous AWTP

The expected cost of operations for a larger scale, continuously operated AWTP of order 2-10 ML/day is of interest, especially for use of the current AWTP barrier configuration for indirect or direct potable recycle of water and discharge of an environmentally friendly waste. The waste stream from the configuration was extensively tested and is considered environmentally friendly in terms of both pathogens and chemicals of concern. As noted earlier, there are no known plants that are operating with the current AWTP configuration.

Data from three plants was accessed and although the data are subject to a number of caveats. Table 5 provides an overview of the expected energy use at larger scale.

Table 5: Energy comparison to the AWTP at larger scale.

Section	**Energy use (kWh/m^3)**	**Comments**
Ozone/BAC/UF	0.58	Based on 8 ML/day pressurised membrane plant
Ozone/BAC/UF	0.56	Based on 18 ML/day pressurised membrane plant
UF/ozone/BAC	0.15	Based on 126 ML/day submerged membrane plant
RO	0.56	Based on 1 ML/day plant at 3000 µS/cm
RO	1.3	Small scale brackish water plant at 5000 mg/L (approx. 10,000 µS/cm)
UV	0.004	100 ML/day for Spektron 4000e using 17.2 kW
Cl_2	0.1	Estimate of pumping energy only
Ancillary	0.1	Estimate only

The numbers in Table 5, as compared to Table 3, indicate that a pressurised UF/O_3/BAC plant is substantially more efficient than the AWTP at a scale of between 8 and 18 ML/day. Given that the numbers are for the entire plant, not just the ozone/MF/BAC section, the median value of 0.57 kWh/m^3 should be compared to a value that also includes feed pump and ancillary energy. A substantially lower energy use was found for a submerged membrane plant, with the difference almost certainly being due to reduced pumping energy. A reasonable comparator looks to be of order 0.57 kWh/m^3 compared to 0.90 kWh/m^3 for the AWTP. This difference is indicated as the higher efficiency that can be achieved in ozone generation and lower cost of pumping at scale. There is a higher dose of ozone in the case of wastewater as distinct from drinking water feeds although the dissolution efficiency is substantially higher in large reactors and this is expected to more than compensate.

The energy use of the RO barrier depends on the salinity of the feed. The feed conductivity of the AWTP was typically in the range 600-1000 µS/cm and the energy use was 0.42 kWh/m^3 plus ancillaries. A similar energy use was found at larger scale for a 5000 µS/cm feed plant (0.56 kWh/m^3). The energy use increased to 1.3 kWh/m^3 for a feed of 10,000 µS/cm. This suggests a decrease in energy use of order 10-20% for larger scale operations at the equivalent feed conductivity of the AWTP.

The cost of the UV and Cl_2 dosing was not able to be determined but was considered to be very low. The pumping energy per m^3 is likely of the same order as the UV energy use.

Based on the plant data for the >1 ML/day continuous plants, the energy use of a 10 ML/day AWTP operating in continuous mode on a m^3 basis would likely be of order 0.57 kWh for the O_3/MF/BAC, 0.50 kWh for the RO and 0.2 kWh for UV, Cl_2 and ancillaries. This gives an approximate value of 1.27 kWh/m^3. Therefore, the energy breakeven point for consideration of brackish water desalination versus advanced treatment of secondary treated wastewater (assuming the conductivity of the waste water is <1000 µS/cm) is of order 10,000 µS/cm. That is, the brackish water salt concentration would need to be less than 5 g/L (10,000 µS/cm) to be competitive on an energy basis.

Conclusions

- The potential savings in energy through utilisation of the product water of the AWTP at Davis Station are significant and would amount to a saving of in excess of 33,250 L of diesel per year compared to current operations.
- The energy use of the AWTP based on 15 hrs of operation per day is 1.93 kWh/m^3.
- The energy use of an AWTP operating continuously at larger scale (of order 10 ML/day) is estimated at 1.27 kWh/m^3.
- For the production of drinking quality water, comparison of brackish water desalination to tertiary treatment of a secondary treated wastewater with the AWTP configuration shows that the brackish water salt concentration would need to be less than 5 g/L (10,000 µS/cm) to be competitive on an energy basis. However, the cost of disposal of the RO concentrate from brackish water desalination relative to the far lower salinity waste from the AWTP is not considered here.

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