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Treatment of industrial wastewater for reuse

Felix Buhrmann[a]*, Mike van der Waldt[b], Dirk Hanekom[b], Fiona Finlayson[c]

[a]Weir Envig (Pty) Ltd., 5 De Vreudge Crescent, Dal Josafat, Paarl, South Africa
Tel. +27 (21) 871-1877; Fax +27 (21) 872-2664; email: felixb@envig.co.za
[b]Technical Department, Tutuka Power Station, Standerton, South Africa
[c]Weir Westgarth Limited, 149 Newlands Road, Cathcart, Glasgow G44 4EX, Scotland

Abstract

Faced with environmental and water shortage problems at their Tutuka Power Station, Eskom, the South African Power Company approached Envig to assist them in finding a solution. This was achieved by the installation of a spiral reverse osmosis (SRO) plant to treat 12 Mld of mine water and spent cooling water. The result is a mine with no effluent problems, a new source of water for the power station and a treatment plant which produces significantly better cooling tower water and zero liquid discharge. Process details and 6 months of operational data are presented which demonstrate that good pretreatment and cleaning system design allow SRO to produce consistent high-quality water from this difficult and varying feed.

Keywords: Spiral reverse osmosis; wastewater; reuse

1. Introduction

The spiral reverse osmosis (SRO) plant constructed last year in South Africa at Tutuka, one of the country's major power stations, desalinates a difficult effluent stream for reuse in the sites cooling towers. The effluent stream fed to the plant is a blend of the sites' cooling tower effluent and the neighbouring coal mine's produced water. The power station is situated on the Highveld, 150 km south of Johannesburg, and is owned by the South African electricity giant, ESKOM.

The SRO plant was required for two reasons: (a) to replace an electrodialysis reversal (EDR) plant which was ageing, costly to operate/ maintain and too small for the site needs; and (b)

*Corresponding author.

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(b) to ensure they had a coal supply since the local mine which supplies the plant was under threat of closure unless it stopped dumping mine water into the local river.

Envig assisted Eskom in assessing the best solution to these two problems, finally settling on the installation of a 12 Ml/d SRO plant to treat the combined cooling water discharge and mine water, for reuse. Envig formed a joint venture with Weir Westgarth Limited to allow the execution of the project in the short time-scale required.

The result is a lower cost, better quality water stream to the site cooling towers and a zero liquid reject from the cooling towers and the mine. The plant was designed and constructed between 15 July 1998 and 15 December 1998. The first phase treating 4 ML/d was commissioned on 31 December 1998. The next two phases treating 8 ML/d were completed and commissioned during the first 4 months of 1999 in parallel with the removal of the existing EDR plant.

Following the successful completion of this joint project, Envig were purchased by Weir Westgarth Limited and now trade as Weir Envig.

2. Water quality

Feed water quality to the desalination plant is extremely variable and contains high organic and biological loads. The feed water is a combination of 50% mine water and 50% cooling water. The combined water is saline with a specified maximum conductivity of 5500 μS/cm. The actual conductivity varies between 2000 μS/cm and 6500 μS/cm. The main contaminants are given in Table 1.

Since the mine water is first stored in an open dam and the cooling cycle provides ideal conditions for organic growth, the organic content of the water is naturally high, with TOC up to 65. During algal blooms, the organic content escalates dramatically. Biological activity in the feed water is high at colony counts of between 10^4 and 10^5/ml.

Table 1
Main contaminants

Ion	Concentration (all as ion)
Calcium, ppm	300
Magnesium, ppm	200
Sodium, ppm	1100
Chloride, ppm	700
Aluminium, ppm	400
Sulphate, ppm	1500
Copper, ppm	500
Iron, ppm	500
Barium, ppb	90

During the option study, several pretreatment schemes were considered, and the traditional clarifier, sand filter system was found to be best for removal of organic contaminants without excessive capital investment.

3. Plant performance

The RO plant was constructed and commissioned in stages, with the first stage achieving operation on 31 December 1998, the second stage on 3 March 1999 and the last stage on 8 April 1999. The performance of the plant from start-up to 30 June shows:

- Stable salt rejection between 96% and 98%
- Smooth operation at variable feed quality
- Chemical cleaning frequency of 5 weeks
- No precipitation on membranes
- Excellent organic and biological fouling resistance

4. Design criteria

Due to the high contamination of the feed water as well as the variation in feed salt concentration, the following criteria were of vital importance during design of the plant:

- Resistance against organic fouling
- Resistance against biological fouling
- Effective membrane cleaning facility
- Plant flexibility on feed salt concentration/composition

5. Plant design

See Fig. 1 for a process flow diagram to aid the understanding of the following process design description.

5.1. Pre-treatment

The existing pretreatment plant for the EDR unit was modified slightly for the intake of minewater (see Fig. 2). The combined mine/cooling water is supplied to a clarifier for softening by the addition of lime, as well as the removal of turbidity with the aid of flocculant and coagulant. A 50% reduction in alkalinity and 93% reduction in turbidity is achieved. The clarifier overflow is subjected to pH control by the addition of HCl, followed by gas chlorination to control biological activity in the downstream sand filters. Suspended solids are removed in a battery of pressure sand filters where turbidity is reduced to below 2NTU. A final set of 5 μm cartridge filters, situated directly before the RO units, serves as a safety barrier in order to prevent solids contamination of the membranes.

5.2. Reverse osmosis section

The RO plant is composed of three identical modular units in order to ensure a minimum of 66% capacity at all times. Each unit is equipped

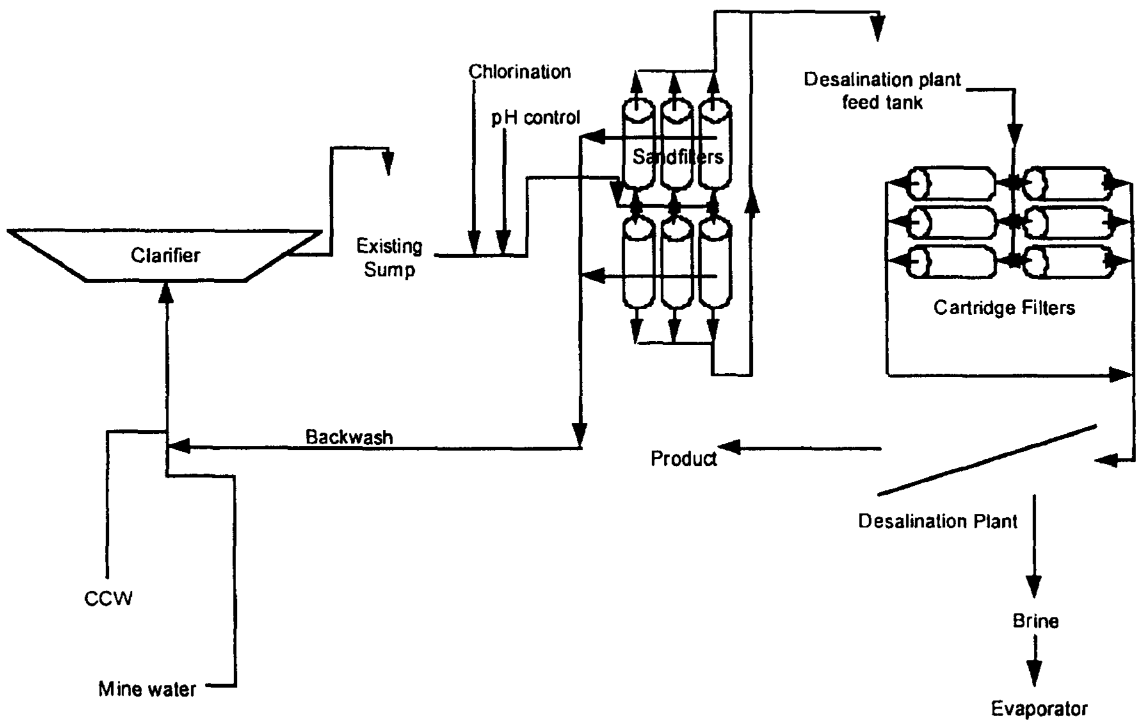

Fig. 1. Tutuka effluent plant process diagram.

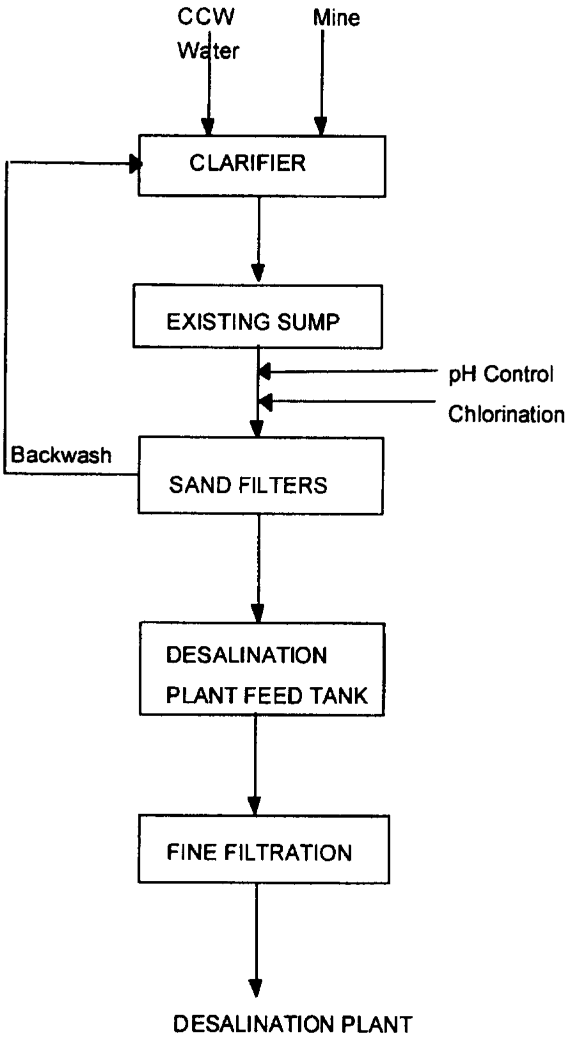

Fig. 2. Pretreatment block diagram.

with a high pressure feed pump and operates independently. Permeate (product) from the three units is combined in a single product tank from where it is returned to the power station cooling circuit. Brine (waste) from the units is concentrated further by means of two vacuum condensers before disposal on the ash heaps. The operating conditions of the SRO plant are summarized in Table 2.

Table 2
SRO operating conditions

Parameter	Value
Feed flow, m^3/h	520
SRO permeate flow, m^3/h	452
SRO brine flow, m^3/h	68
Salt removed, t/d	39
Operating temperature, °C	25 - 35
Operating pH	7
Membrane feed pressure, bar (g)	25
Water recovery, %	87

5.3. RO configuration

Pre-treated water in each SRO train is pumped via a high-pressure pump to 35 permeators, which are arranged in a three stage 20:10:5 tapered array for 87% recovery. A booster pump between the second stage and third stage increases the feed pressure to the third stage in order to compensate for the increase in osmotic back-pressure. The design of the RO unit also allows for the unit to be operated in a two-stage 20:10 array, while the third stage is off-line for chemical cleaning. This arrangement also allows for the reduction in recovery without high flow velocities on the last stage. Each pressure vessel contains seven spiral-wound 8"-diameter membrane elements.

5.4. RO logic

Standard equipment protection is provided for all pumps, filters and dosing systems. A pressure switch is provided on the permeate line to avoid excessive pressurization which could result in membrane damage. The feed flow rate to each SRO train is controlled in a feed forward control loop with a flow transmitter located on the inlet to each high pressure pump, controlling a flow control valve on the pump discharge. Magnetic flow meters are used to measure flow. The pressure in the membrane bank, and hence the water recovery, is controlled by a brine flow control valve on the brine discharge line using ratio control. The ratio of the permeate and feed rate is used to calculate the water recovery. Permeate flows are measured by the magnetic flow meters on each permeate line.

The performance of the membrane streams are is continuously monitored by measuring the common feed and stream permeate conductivity's, permeate flow rates and membrane feed pressures.

By comparing the conductivity of the feed with that from each SRO stream, the rejection of conductivity can be calculated. From the permeate flows, feed pressure and water temperature a standardized/normalized flux is calculated which is used to warn the operator when the membranes require cleaning.

5.5. Ceaning in place (CIP)

Cleaning in place, or CIP, is a manually initiated semi-automatic procedure used to wash the SRO membranes *in situ.* Due to the high fouling characteristics of the water, special provision was made for periodic high-velocity flushing of membranes, periodic biocide dosing and physical turbulence cleaning by means of air/water combination.

5.6. Summary of plant features

Table 3 summarizes the main characteristics of the membrane section of the SRO plant.

6. Operating results

The RO plant was constructed and commissioned in stages with the first stage achieving beneficial operation on 22 December 1998, the second stage on 3 March 1999 and the last stage on 8 April 1999. The performance of the plant from operation to 31 June 1999 is discussed below.

Table 3
Main features of the membrane section

Item	Value
Number of trains	3
Number of pressure vessels	35 per train (105 total)
Vessel array per train	20:10:5
Membrane type	Trisep X-20 (Foulguard™ Technology)
Element configuration	Spiral wound
Element size	8' × 40"
Number of membrane elements	245 per train (735 total)
Membrane area	7350 m^2 per train (22,050 m^2 total)
Average membrane flux	20 LMH

6.1. Product quality

Due to the high variability of the feed water quality, product quality has to be measured against feed quality in order to determine the salt removal efficiency of the plant. The average salt rejections for each train is:

- Train 1: 97.1%
- Train 2: 97.9%
- Train 3: 97.6%

Salt rejection is primarily dependent on temperature with an average rejection of 98% at 20°C and 96% at 35°C (see Fig. 3). Salt rejection is using feed and product conductivity.

6.2. Plant capacity

Plant capacity can be measured by salt removal in t/day, feed flow and recovery. Since

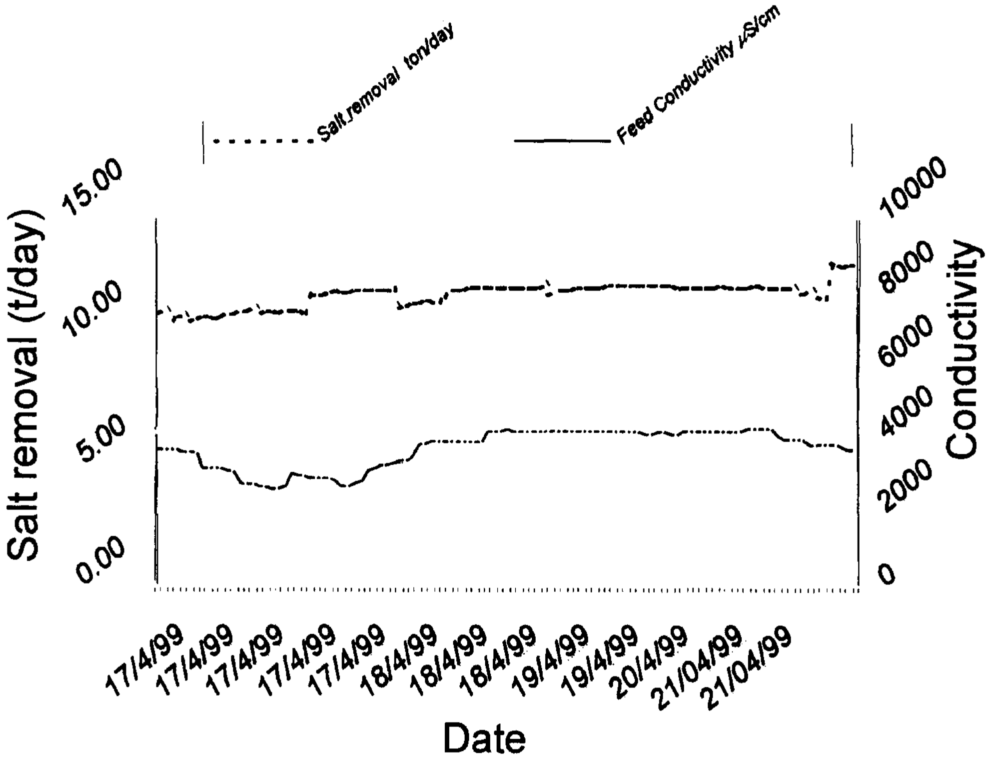

Fig. 3. SRO salt rejection vs. feed temperature.

the plant is designed with an additional 20% hydraulic capacity the feed flow was maintained at the designed flow rate 173 m^3/h. Recovery has been maintained at 87% except when feed concentration is above specification. Salt removal is therefore dependent on rejection and salt concentration in the plant feed. Average salt removal on each train is:

- Train 1: 13.8 t/d
- Train 2: 14.5 t/d
- Train 3: 12.7 t.d

6.3. Membrane fouling

In order to obtain a minimum availability of 90% and maintain contract operating cost, the maximum chemical cleaning frequency is once every 3 days. The average cleaning frequency during the period from 31 December 1998 and 30 June 1999 was 36 days. The membranes were cleaned when either the membrane ratio or flux to membrane pressure drop (water coefficient) increased by 15% or the differential pressure over a stage increased by 15%. No noticeable drop in water coefficient could be detected during the first 6 months, but differential pressure over the first stage increased slowly until chemical cleaning was required. The trends on differential pressure were identical on all three trains.

6.4. Feed water quality

During the first 6 months of operation, the feed water deviations were experienced and are shown in Table 4.

Table 4
Feed water deviations

Description of deviation	Frequency	Effects
Feed conductivity above design	Frequent	None
Oil in feed water	Twice	None
High organic load (high SDI)	7-week period	Increased rate of fouling

6.5. Feed water conductivity above design

Although recovery was reduced during extended periods of high feed water conductivity, the plant was operated for several periods (<3 d) on 87% recovery while feed conductivity was above design. No precipitation could be detected on the third-stage membranes although theoretical values as well as projection programs indicated that precipitation will take place. The two possible explanations are that (a) the organic content of the water interferes with the precipitation process and (b) the high turbulence in the membranes prevents precipitation formation on the membrane surface.

6.6. Oil in feed water

Oil contamination of the feed occurred twice. On both occasions the plant was taken off-line immediately when oil was detected. The period while the plant was operated on contaminated water or the oil concentration is unknown. No change in water factor or differential pressure over the membranes could be detected.

6.7. High organic load

Due to the biocide dosing on the mine feed water being out of operation for 2 weeks, a dramatic increase in organic growth (algae bloom) took place. Although turbidity after the sand filters was maintained below 2NTU, a substantial increase in the silt density index occurred. The water colour changed from slightly brown to green. The cartridge filter differential pressure increase sharply, and the filters had to be changed within 2 weeks after the increase in algae. The differential pressure on the first stage of the RO unit increased sharply, and membranes had to be cleaned within 3 weeks where a cleaning frequency of more than 2 months was achieved before. An increase in chlorine dosing to the sand filters reduced the colour of the feed but did not reduce the SDI or improve organic fouling characteristics.

7. Conclusions

- The dual difficulties of mine water discharge and poor cooling water treatment plant operation were successfully overcome by the installation of a SRO plant.
- The effectiveness of the plant can be attributed to the careful design and operation of the systems pretreatment and cleaning systems which mitigate the effect of the high organic and biological fouling capacity of the feed water.
- Effective use has been made of all liquid streams providing both mine and cooling water with “zero liquid discharge” status.
- The effectiveness of fouling resistant SRO membranes has been demonstrated on a large-scale industrial application. This now allows organic and inorganic effluents to be considered for process water reuse duties using SRO.