Membrane Bioreactors for Water Re-Use in Southern Africa

S. Kennedy*, T. Young**

* Senior Process Engineer, Eimco Water Technologies, Raydown Offices, Steeple Ashton Road, Edington, Wilts, BA13 4NW, UK
(E-mail: s*tephen.kennedy@glv.com*)
** Director, Aquatorsouthafrica, Stoberry House, Stoberry Park, Wells, Somerset, BA5 3LD, UK
(E-mail: *timyoung@aquatorsouthafrica.com*)

Abstract
In recent years the number of membrane bioreactors (MBR) around the world has increased significantly. This paper focuses on two full-scale MBRs using Kubota flat sheet membranes in Southern Africa; an industrial plant at Illovo Sugar, Sezela, South Africa and a municipal plant at Grand Palm casino and conference centre, Gaborone, Botswana.

The plant at Illovo Sugar was commissioned in April 2005. The MBR has been designed to treat upto 1200m^3/d of the wastewater produced by Illovo Sugars' Downstream Processing Plant. The wastewater has a pH of 2.7 and a chemical oxygen demand (COD) of approximately 17,500mg/l. Re-use of the permeate from the MBR in the mill is planned and a low total dissolved salts (TDS) is essential. The TDS concentration is minimised through a feed forward pH control system. Since commissioning, 95% of the incoming COD has been removed. The degradation of the COD generates heat. The biomass temperature has averaged 47^{o}C and peaked at 56^{o}C. A temperature model has been developed to allow the biomass temperature to be predicted based on incoming COD concentration and flow and local environmental conditions. In the first two seasons of operation, only 1 of the 4800 panels installed has been replaced.

The plant at Grand Palm was commissioned in December 2005. The wastewater produced onsite is collected in a septic tank before being fed into a simplified MBR plant. The permeate is recycled by the complex as irrigation water, freeing 200m^3/d of potable water for use in Gaborone. This volume of water is equivalent to the average water consumption of 8,000 people, based on 25l/capita/d.

Keywords
Africa, Kubota flat sheet membranes, Membrane Bioreactor, Water Re-Use.

INTRODUCTION

The number of membrane bioreactors (MBR) around the world and the volume of wastewater treated by these plants has increased dramatically over the past 15 years. Kubota flat sheet membranes are one of the market leaders in the immersed membrane bioreactor sector and the growth in the wastewater flow treated and the number of Kubota flat sheet membranes in operation in Europe, Middle East and Africa is displayed in Figure 1.

Kubota flat sheet membranes have been applied in MBRs in six continents around the world. This paper focuses on the first two full-scale operational Kubota MBRs in Southern Africa. Both plants were designed, constructed, installed and commissioned by a team which comprised AquatorSouthAfrica, Copa Ltd (now Eimco Water Technologies) and AquaSA and use the Kubota flat sheet membranes.

The first full-scale Kubota MBR treating industrial wastewater in Southern Africa was commissioned at Illovo Sugar, Sezela, Durban, South Africa in April 2005. The MBR was designed to treat upto 1200m^3/d of the wastewater produced by Illovo Sugars' Downstream Processing Plant. The wastewater has a pH of 2.7 and a chemical oxygen demand (COD) of approximately 17,500mg/l. It is intended that the permeate from the MBR will be re-used in the mill and a low total dissolved salts (TDS) is essential.

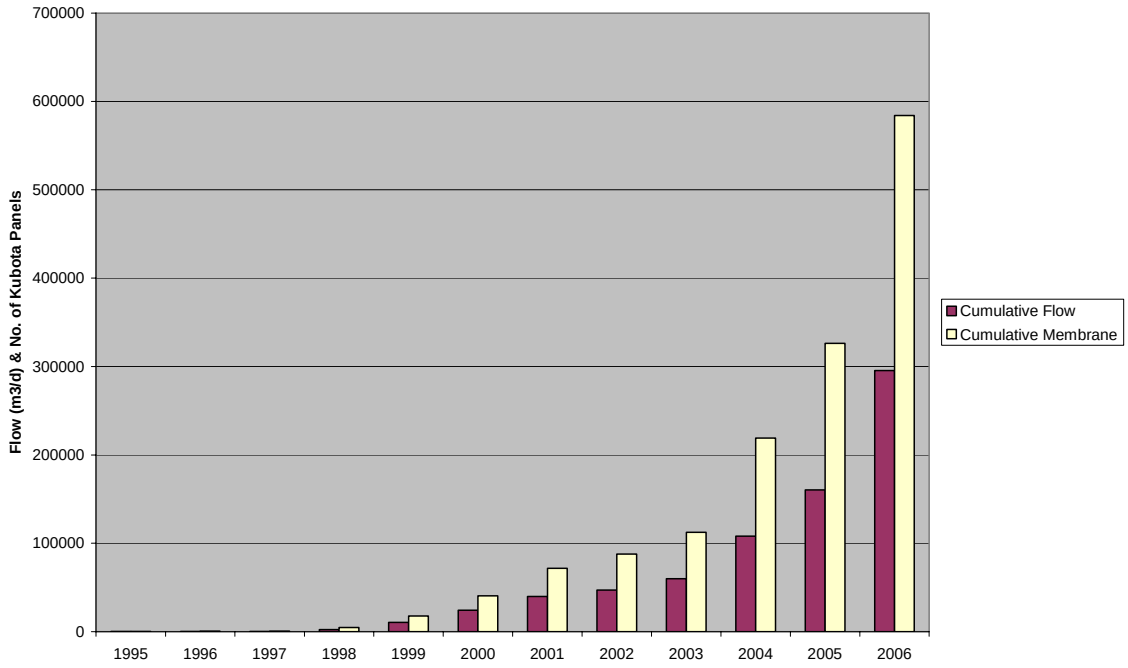

Figure 1: Cumulative flow and cumulative number of Kubota membrane panels in operation in Europe, Middle East and Africa

In December 2005, the first full-scale municipal Kubota MBR in Southern Africa was commissioned at Grand Palm casino and conference centre in Gaborone, Botswana. Following the commissioning of the Kubota MBR plant the permeate has been recycled as irrigation water on the grounds, freeing over 200m^3/d of potable water for other uses in Gaborone.

PLANT DESIGN INFORMATION

Illovo Sugar, Sezela, Durban, South Africa

The influent wastewater treated by the MBR process comes from the downstream by-products area of Illovo Sugars' Sezela sugar mill. Furfural and its derivatives are produced within this area, and the waste stream to be treated originates from the production of these products. The main components within the waste stream are:

- 1% acetic acid;
- 0.1% formic acid; and
- Furfural (intermittent, typically <100 mg/l).

The predominant source of the wastewater is a cooling tower which follows a distillation column and the total suspended solids (TSS) concentration is very low. The industrial stream is fairly consistent on a day-to-day basis, with a COD of approximately 17,500 mg/l and a pH of 2.7. The wastewater is deficient in Nitrogen and Phosphorus. To ensure healthy biological growth, additional nutrients (phosphoric acid and urea) are continually dosed into the flow distribution chamber to mix with the incoming raw effluent. The nutrient dosing rate is manually controlled to ensure a residual of Nitrogen and Phosphorus is maintained in the permeate.

Trace toxins and wax are occasionally present in the wastewater. It is understood the toxin is produced by the sugar cane during periods of stress conditions, either drought or from particular soil types. Previous research by Illovo sugar has shown anaerobic bacteria are inhibited by this toxin, but that it can be degraded in an aerobic environment.

The MBR plant was designed to treat 1200m^3/d of wastewater and achieve more than 95% COD reduction. Due to the harvesting season of the sugar cane, wastewater is only produced during nine months of the year. During the off-season the plant is drained of mixed liquor suspended solids (MLSS). A spray bar system has been installed above the membranes to prevent them from drying out. The off season has been used to inspect the condition of the membranes and the mechanical equipment in the plant.

Prior to the construction of the full scale plant, a three month pilot plant trial was run and the data collected was used in the design of the full scale plant. The key information of the Illovo Sugar MBR plant is detailed in Table 1.

Table 1: Key design information for Illovo Sugar MBR plant

Screen	1.5mm wedgewire rundown screen
Design sludge age	30 days
MBR blower	2880 Nm^3/hr @ 500 mbar (61.5 kW)
FBDA blower	2no. Each 7060 Nm^3/hr @ 740 mbar (224 kW)
Reactor dimensions	28m diameter, 7m deep, Volume 4310 m^3
Membrane Units	12 no. EK400
Total Number of Membrane Panels	4800
Membrane type	Kubota Flat Sheet Membrane Panels

Due to the available budget and the very poor ground conditions in the area allocated for the plant, the fine bubble diffused air (FBDA) zone and the membranes were combined into a single reactor. To minimise the footprint of the reactor the top liquid level was set at 7m, although in normal operation the plant has run at 6.5m water depth. To ensure effective scouring of the membrane surface by the coarse bubbles released by the centipede diffusers, the membrane units were installed on a 2m high plinth. In addition to minimising the plant footprint, money was saved by eliminating all standby equipment. The plant contains only three drives and six automatic valves.

Re-use of the permeate from the MBR in the mill is planned and a low total dissolved salts (TDS) is essential. The TDS concentration is minimised through a feed forward pH control system. The pH in the reactor is used to determine if the plant is able to accept feed wastewater. If the pH is low, the feed is inhibited. The influent wastewater is distributed into the plant via four inlets equally spaced

around the edge of the tank. The pH at each of the inlets is continuously monitored and flow to the works inhibited if the MLSS pH drops below an operator adjustable set-point, typically set at 6.5, at any of the inlets.

SASOL have previously performed trials on the Sezela waste stream to determine the viability of biomass at differing pH levels. They exposed bacteriological cultures from the existing activated sludge plant to different pH conditioned samples, by adding varying concentrations of influent. The prepared samples were aerated for a period of time and the variations in the oxygen uptake rate measured. SASOL's conclusions are given in Table 2.

Table 2: Inhibition rates of biomass cultures using Sezela wastewater at different pHs

Sample pH	**Biomass Culture Viability[1]**
7.0	80%
6.0	80%
5.5	75%
5.0	5%
<5.0	Biomass dead

Nb. [1] Previously summarised verbally by Bryan Robson of Illovo Sugar, Sezela

Grand Palm Casino and Conference Centre, Gaborone, Botswana.

The wastewater from the complex flowed, by gravity, offsite through an existing sewer and was treated in the main Gaborone wastewater treatment works (WwTW). The wastewater fed to the plant is typical of that from a hotel complex with a laundry. Within the complex, there are grease traps on all sewers from locations where fats, oils and greases (FOGs) may be released.

The plant at Grand Palm is designed to treat a future flow of 260 m^3/d, which includes future development of the complex. The current design flow is 210 m^3/d. The plant was designed for a future population equivalent of 1733, with an initial design figure of 1400.

The key information of the Grand Palm MBR plant is detailed in Table 3.

Table 3: Key design information for the Grand Palm MBR plant

Screen	Septic Tank with 3mm 2d perforated plate
Design sludge age	25 days
MBR blower	540 Nm^3/hr @ 350 mbar 15kW
FBDA blower	360 Nm^3/hr @ 380 mbar 11kW
Reactor dimensions	8.4m x 4.2m x 3.5m deep, Volume 123m^3
Membrane Units	3no. ES200
Total Number of Membrane Panels	600
Membrane type	Kubota Flat Sheet Membrane Panels

The FBDA blower is run intermittently using timers in the programmable logic controller (PLC) to allow both nitrification and denitrification. The plant was designed as a sewer mining application and includes a balancing tank to allow short term peaks in flow from the complex to be collected into the plant and treated during periods of low flow. To eliminate a screenings handling plant, and the odour and health issues that can be present in this area of plant, a septic tank with a 3mm static

perforated plate was installed prior to the MBR plant. This septic tank is emptied by tanker every 3 months.

Surplus sludge from the system can either be removed by tanker or discharged to the existing sewer. Permeate is pumped to holding tanks, where it is dosed with Chlorine, before being used to irrigate the complex grounds.

The plant is operated by the hotel maintenance staff and its design has been simplified to make it easy for them to operate. Flows between tanks are pumped and the plant only contains four automatic valves.

RESULTS AND DISCUSSION

Illovo Sugar, Sezela, Durban, South Africa.

Since commissioning, the plant has removed 95% of the incoming COD without the need for pH correction, Figures 2 and 3. The feed forward pH control system has resulted in the permeate TDS averaging approximately 350 mg/l, Figures 2 and 3. During the pilot trials, the influent pH was corrected prior to biological treatment. The permeate TDS concentration during this stage of the trial was approximately 7,500 mg/l, making the water unsuitable for re-use.

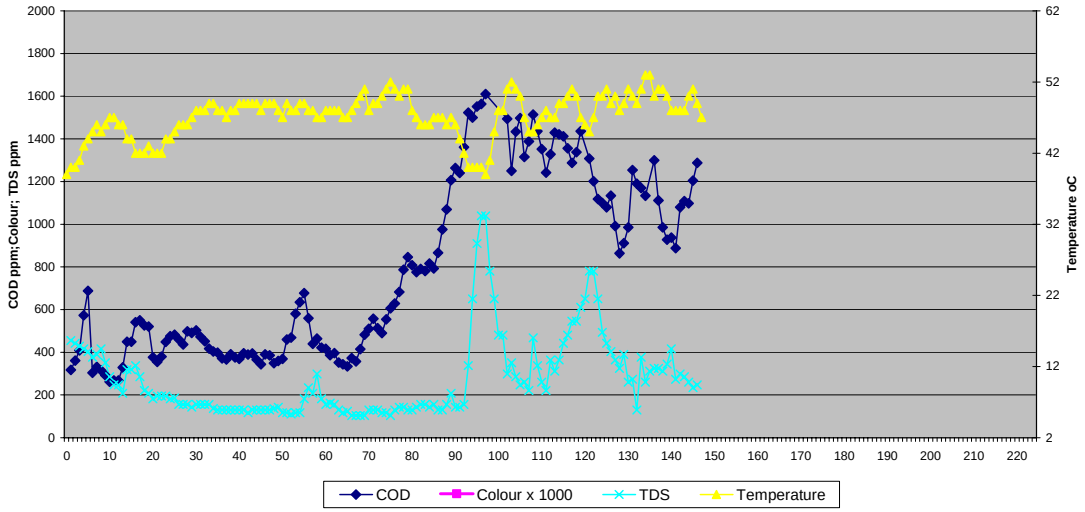

Figure 2: Permeate COD, Colour, TDS and Temperature in 2005

During the operation of the full scale plant, the sludge production has been very low. To try and maintain a fresh sludge in the system approximately 100m^3/d of sludge is wasted, giving a sludge age of approximately 43 days. From 1st September 2006 to 30th November 2006, the sludge yield was approximately 0.062 kgSS/kgCOD, lower than the expected figure of 0.09 kgSS/kgCOD for acetic acid. The lower than expected sludge yield is considered to be due to the high operational temperatures, 47^{o}C.

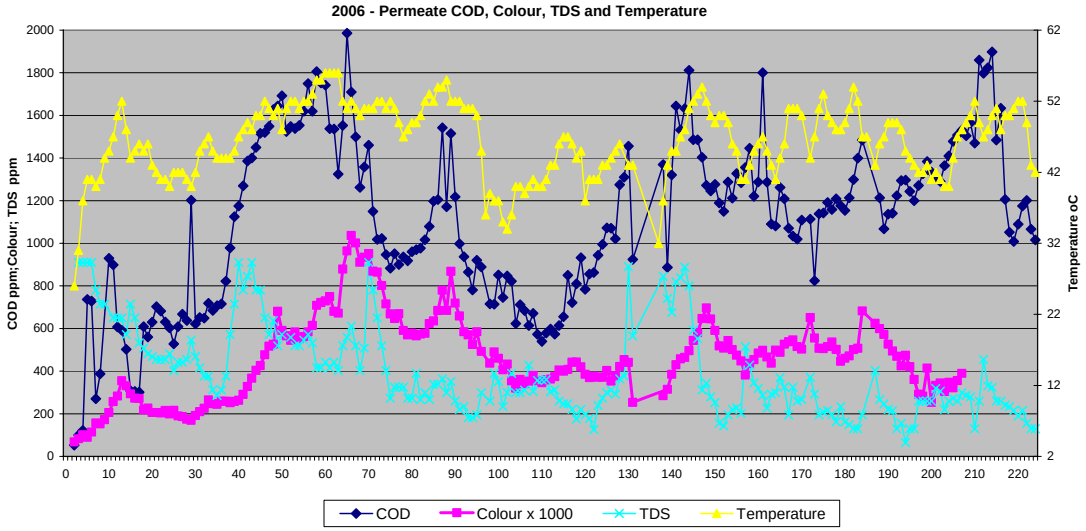

Figure 3: Permeate COD, Colour, TDS and Temperature in 2006

The data from 2006 shows a positive correlation between COD in the permeate and its colour. There is also a positive correlation between colour and reactor temperature. There is a negative correlation between the MLSS concentration and the temperature, Figure 4. It is proposed that the high COD concentrations in the permeate are humic acid type compounds which are produced during the thermal degradation of the biomass at high temperatures. Further investigation of the plant is required to determine if these initial correlations are valid.

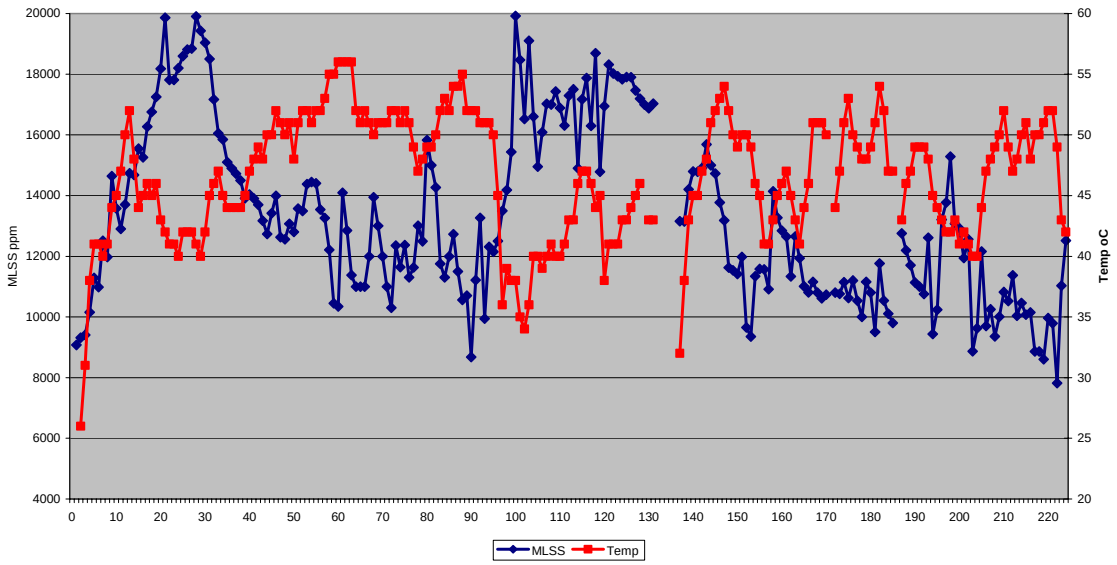

Figure 4: MLSS concentration and Permeate temperature in 2006

The degradation of the COD by the biomass generates heat. The biomass temperature in the reactor has averaged 47^{o}C and at times has exceeded 56^{o}C. The influent wastewater temperature is between 36-38^{o}C. The increase in temperature in the reactor is predominantly due to the aerobic thermal energy release by microbial action. The variation of temperature in the reactor has posed operational

problems because the reactor fluctuates between mesophilic and thermophilic environments. It has been observed the plant goes through a period of instability as the temperature changes between 48^{o}C and 50^{o}C. The aim has been to run the reactor at greater than 52^{o}C, and during periods of stability good performance, both biological and through the membranes, has been achieved. However, due to external factors such as weather and sugar cane availability, there have been frequent changes in acid water availability, which in turn results in temperature variations. These temperature variations have resulted in rapid changes in the biomass viability as the environment changes between mesophilic and thermophilic conditions. Large scale balancing storage could offer continuation of feedstock to ensure thermophilic conditions. Due to the heat generated during the degradation of the COD it is not possible to run the reactor in the mesophilic range without expensive and complicated MLSS cooling. To allow Illovo sugar to predict the reactor temperature an iterative mathematic model has been developed and calibrated against site conditions.

The model includes the heat generated through the energy introduced into the plant by the blowers, and the aerobic thermal energy released by microbial action. The energy lost through the system by evaporation, conduction and radiation are also calculated. An iterative calculation is run to determine the steady state reactor temperature based on factors including the ambient air temperature, the wastewater flow, the wastewater COD concentration, the air velocity parallel to the tank, the tank volume, the tank wall surface area, the liquid surface area, the volume of air supplied to the plant and the humidity.

The model has been calibrated against the full-scale operating data and can accurately predict the reactor temperature on a day to day basis.

Grand Palm, Gaborone, Botswana

Prior to the construction of the MBR plant the complex irrigated the grounds with more than 200m^{3}/d of potable water. The water consumption in the complex was investigated and the typical water consumption of the guests, restaurants, laundry and other uses was also approximately 200m^{3}/d, equivalent to the water consumption of 8,000 people, assuming a water consumption of 25litres/captia/day.

Fresh activated sludge was imported from the main activated sludge plant in Gaborone. To prevent particles greater than 3mm in 2d entering the plant, the seed sludge was discharged into the septic tank.

The diurnal profile of the flow received by the plant is displayed in Figure 5. The flow to the plant is fairly constant with above average flows received during daylight hours and lower flow received at night. During the middle of the day the incoming wastewater had a greyish tinge and predominantly originates from the laundry. Initially the laundry wastewater caused the MLSS to foam. The foam was contained by reducing the run time of the FBDA blower. Within a period of three weeks the biomass culture adapted to the incoming wastewater supply and the foaming reduced significantly.

Initial bacteriological testing of the irrigation water potentially showed the presence of low concentrations of bacteria and viruses, E. Coli 3 MPN/100ml and Faecal Streptococci 6 MPN/100ml. To provide a disinfection residual in the irrigation system, HTH, granular chlorine, is added to the storage tanks each day.

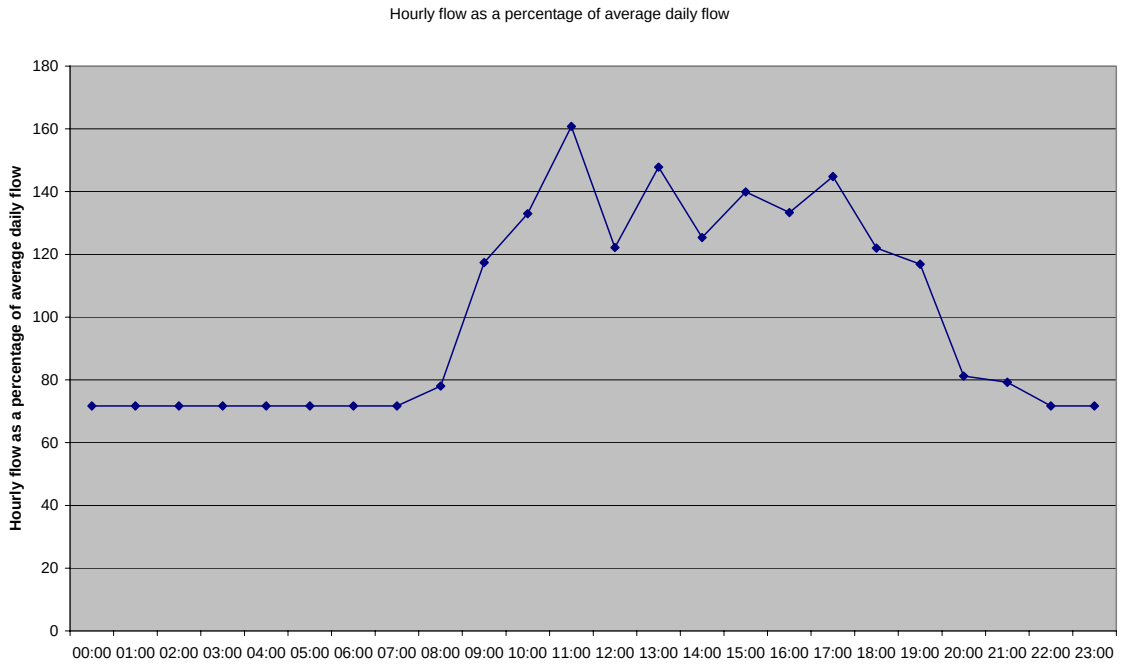

Figure 5: Diurnal flow profile at Grand Palm

CONCLUSIONS

MBRs are a proven technology for producing high quality effluents. The results from the two full scale MBR plants in Southern Africa demonstrate that the simple yet robust Kubota flat sheet membranes can be applied to solve the water shortage issues in Southern Africa.

The temperature model developed for Illovo sugar can predict the temperature of the biomass. The Kubota flat sheet membranes are able to withstand extreme temperatures (> 55oC) without affecting membrane life or permeate quality. The feed forward pH control system applied at Illovo sugar allows biodegradable low pH wastewaters to be treated without pH correction, minimising any increase in TDS.

The Grand Palm MBR proves the Kubota flat sheet membranes can be operated by low skilled staff and produce a high quality water for re-use. This sewer mining application can be used to liberate potable water from irrigation uses for drinking water for 8,000 people, based on 25l/capita/d.