Sulaibiya – World's Largest Membrane Water Reuse Project

Background

In May 2001, a consortium including Mohammed Abdulmohsin Al-Kharafi and Sons (The Kharafi Group) and GE won a 30-year concession involving three years construction and a water sales contract for 27 years from the Kuwaiti government to recover municipal wastewater from Kuwait City and the surrounding area. The consortium was established to design, build, own, operate and maintain a 100 million gallon per day (MGD) (375,000 m^3/day) wastewater treatment facility at Sulaibiya near Kuwait City, Figure 1. The Sulaibiya facility is the world's largest membrane-based water reclamation facility. The reclaimed and desalinated water from the Sulaibiya facility is used for non-potable uses that impact the drinking water supply, by blending with brackish water to better exploit existing brackish water distribution facilities.

Figure 1: Wastewater treatment facility at Sulaibiya near Kuwait City

The team used well-proven processes to design the membrane-based water reuse plant. The major treatment steps for the project are shown in Figure 2. Municipal effluent is given preliminary treatment at Ardiya and then piped 25 km (16 miles) to the Sulaibiya facility. A conventional biological wastewater treatment plant (WWTP) treats the effluent to better than secondary effluent quality. The secondary effluent then flows to the water reclamation plant, which uses ultrafiltration (UF) and reverse osmosis (RO) to further treat the water for reuse. Sludge from the wastewater treatment plant is treated to allow for disposal by landfill, incineration, or by composting.

The water quality used as the basis of design and the projected treated water quality are detailed in Table 1. The plant influent is typical domestic sewage. The WWTP is designed to produce an effluent with a maximum day value of less than 20 mg/l BOD and 20 mg/l TSS. The water reclamation plant is designed to accommodate peaks in water quality due to upsets in performance of the WWTP. The average total dissolved solids (TDS) in the feed is 1,280 mg/l, and the plant product is less than 100 mg/l, significantly better than World Health Organization (WHO) potable water guidelines.

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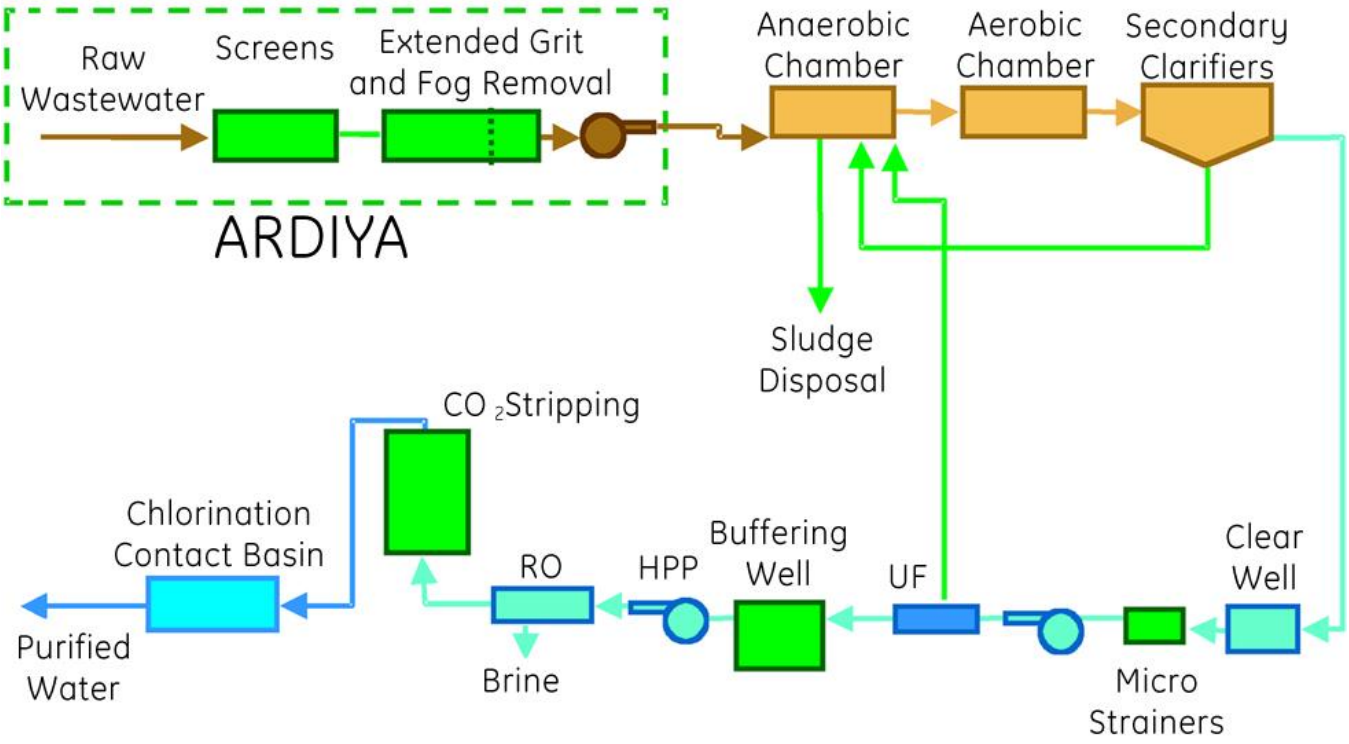

Figure 2: Major Treatment Steps

Table 1: Water Quality Data

Item	WWTP Effluent Avg. Monthly Value	Water Reclamation Plant Product Avg. Monthly Value	WHO Potable Water Guidelines
pH	7	6 to 9	6.5 to 8.5
TSS (mg/l)	12	< 1	
BOD (mg/l)	5	< 1	
Ammonia Nitrogen as N (mg/l)	< 2	< 1	
Nitrate (mg/l)	< 9	< 1	10
Phosphate (mg/l as PO4)	< 15	2	
Fat, Oil & Grease (mg/l)	< 0.5	< 0.5	
Conductivity (µS/cm)	2000		
TDS (mg/l)	< 1280	100	1000

Wastewater Treatment Plant

The Kharafi Group's extensive experience with constructing and operating sewage treatment plants in Kuwait was used as a basis for the wastewater treatment plant design. Preliminary treatment at Ardiya consists of particulate and grit removal, as well as oil and grease removal. The waste is then pumped to Sulaibiya. The WWTP consists of anaerobic, anoxic and aerobic systems for enhanced biological removal of nitrogen and phosphorus, plus secondary clarifiers. To minimize variation in flow, buffer volume was taken into account in the design of the facilities at Ardiya, the aeration basins and the clarifiers. Sludge treatment involves aerobic digesters and drying beds. This process is well-proven in Kuwaiti conditions, and was selected for low odor, low operation and maintenance costs, minimum sludge quantity for disposal, and the environmental benefit of being able to use the sludge as a soil conditioner or organic fertilizer.

Water Reclamation Plant

The water reclamation plant is designed to treat 112 MGD (425,000 m^3/day) of secondary effluent, which is pre filtered with disc filters and then fed to the UF system. UF product feeds a reverse osmosis plant, and UF waste is recycled to the WWTP. The UF system treats 100% of the flow after biological treatment since the UF waste is recycled. Therefore, the feed to the RO system is also 100 MGD (375,000 m^3/day). The RO plant is designed for 85% water recovery, so the expected production rate is 85 MGD (318,750 m^3/day).

Ultrafiltration System

Membrane filtration was selected to provide robust pretreatment of the secondary-treated municipal effluent before being fed to the RO. Membrane filtration was chosen over conventional tertiary clarification and filtration because it reduced the plant chemical consumption and could guarantee that low turbidity water is fed to the RO. Better quality pretreatment to the RO will lead to longer membrane life, lower operating pressure, and reduced cleaning frequency for the RO system. Without the use of pre-RO membrane treatment, using today's more highly efficient RO membrane is impossible. Thin film composite (TFC) membranes would quickly become fouled. Also, the combination of UF and RO removes bacteria and pathogens and provides potable quality water suitable for agriculture or groundwater recharge.

When originally built, bids for the membrane filtration system were solicited from major suppliers of membrane filtration equipment. Norit's UF technology was selected. The UF plant historically utilized X-Flow+ membranes, which are capillary hydrophilic hollow fibers. These membranes are packaged in 8" x 60" (20 cm x 152 cm) membrane elements that provide 42 $yards^2$ (35 m^2) of membrane area per element. Four membrane elements are placed inside the membrane housing, and thirty-two membrane housings are installed in each UF unit. This plant consists of 68 skids, each with 32 membrane housings for a total of 8,704 membrane elements.

The UF units are operated individually. Each unit is backwashed regularly, whereby all suspended matter that is retained by the membranes is removed from the plant. The backwash water is pumped back upstream of the WWTP to achieve the highest possible overall water recovery for the plant. Periodically, a low dose of chemicals is added during a backwash. This Chemically Enhanced Backwash (CEB) removes any matter that may have adhered to the membrane surface and is not removed by a hydraulic backwash alone. Since the backwash and CEB actions are scheduled on an individual unit basis, cleanings take only a minor section of the plant out of filtration mode and the continuous flow of effluent from the biological plant can be accommodated. The effluent fed to the UF first passes through a disk filter, after which a small amount of coagulant is added to coagulate fine particulates and possibly allow some TOC removal to facilitate the operation of the plant. The SDI of the UF product will be below 2, an important criterion for the RO plant performance. Previous experience treating secondary municipal effluent with UF has shown that SDI values of less than1 are possible.

Reverse Osmosis System

The salinity of the municipal effluent has an average monthly value of 1,280 mg/l TDS, with a maximum value of 1,800 mg/l. RO is used to desalinate the water to less than 100 mg/l TDS, as well as provide a second barrier to bacteria and viruses.

RO technology is well proven for desalinating municipal effluent. The system consists of 42 identical skids in a 4:2:1 array. A total of 20,832 membranes, originally provided by Toray of America, were required for this project. The RO system is limited to operating at 85% recovery by calcium phosphate precipitation, which can frequently be the limiting factor for water recovery in membrane systems desalinating municipal effluent. The RO product passes through a stripper to remove carbon dioxide to adjust pH with a minimum amount of caustic before distribution, and the product is then chlorinated before leaving the plant. RO brine is disposed of into the Persian Gulf.

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Continuous Improvement

Upon the successful achievement of the plant's designed production, the possibilities of production improvement projects were identified and executed. These increased the plant daily average production to 92.5 MGD (350,000 m^3/day).

Two additional UF skids were installed in 2009 which increased UF gross production capacity about 3.2 MGD (12,000 m^3/day).

The initial UF membrane elements with 41 $yard^2$ (35 m^2) surface area has been replaced with updated UF X-Flow membranes with 48 $yard^2$ (40 m^2) area. These additions increased flow handling and production capacity by about 10% over the original UF production.

An additional improvement underway is to replace the current UF pretreatment membranes with the ZW700B membranes using SevenBore* fiber technology. The SevenBore fiber is regarded as the most robust polyethersulfone (PES) product on the market. The first of these modules was installed in 2012.

The production capability increment of the UF system, called for an upgrade of the RO plant to increase the final production volume. The upgrade increased the number of RO pressure vessels, adding 20 new pressure vessels in each RO train in different stages with 120 vessels added to the existing RO plant. This was done without replacing major RO equipment such as Feed Pumps, Piping and Valves. The number of vessels in the RO plant increased from 2976 to 3096, which added an additional 840 RO elements to the system. The additional RO elements have increased the RO plant capacity by approximately 2.6 MGD (10,000 m^3/day).

With the additional vessel installation, the RO plant has 21,672 RO membranes. The original installation used Toray Membranes. Since GE produces a wide range of RO membranes, different types of membranes were tested and the appropriate GE membrane model selected for Sulaibiya RO membrane replacement. The first cycle of membrane replacement has been made with GE membranes which presently total 16,772 GE membranes which is about 77% of the total installation.

Sulaibiya Piloting

After the plant commissioning, the Sulaibiya team designed and constructed a pilot plant to optimize the UF/RO plant operation and other testing. The UF pilot plant with single vessel, 4 membrane configuration was installed in 2009. The UF pilot plant is also automated and operates through a SCADA system. Various manufacturers' membranes are trialed for performance and chemical simulation and results are evaluated before any implementation in the main plant.

An independent RO pilot plant with essential monitoring and controlling devices was also designed and installed to test different RO membranes and run other trials. Two vessels in first stage and two vessels in the third stage are installed with monitoring devices, which can be monitored through a SCADA system. Different manufacturers' membranes are tested and compared for R&D purposes and are evaluated for implementation in the main plant.

Sulaibiya ZeeWeed* Demonstration

A pilot study has been carried out at the Sulaibiya WWTP using ZW1000 ultrafiltration membranes to treat the secondary effluent of the conventional system. The pilot plant has been operated for one year to allow all parties involved to evaluate the technology and to understand the seasonal impact on the membrane performance. The ZW1000 showed excellent performance results. Turbidity and SDI values were good; which indicates excellent feed water conditions for RO treatment downstream.

Experienced Plant Operations

Since Sulaibiya is a build, own, operate and maintain contract, the consortium is also responsible for running the plant. The Kharafi Group will operate and maintain the WWTP and GE will operate the water reclamation facility. The Kharafi Group has extensive experience in the Gulf and internationally, and has previously operated other WWTPs in Kuwait. GE owns and operates over 120 membrane installations around the world, and operates 40 additional installations. This vast array of experience will be beneficial for the operation of the Sulaibiya facility.

To ensure ease of operation, operator input was solicited at the design stage. The treatment steps have been selected to minimize the use of power and chemicals, and are simple to operate and maintain. A high degree of standby equipment and redundancy was incorporated into the design to ensure reliable operation.

A key to the successful operation of a world-class facility such as Sulaibiya is to employ highly trained and motivated staff. Operating personnel include a number of managers, chemists and engineers, as well as qualified technicians and laborers. Training to the appropriate level is being provided at the manufacturers' premises and on-site during the commissioning and testing phases. Continuous performance monitoring of the plant is necessary to ensure compliance with the required standards and for process monitoring and control. There is on-line monitoring of flow and water quality parameters. Key process parameters are calculated and trended to ensure that the plant is performing up to expectations. An on-site laboratory is fully equipped to carry out the required water analyses.

Expansion Awarded

GE and Kharafi National have been successful partners in the Sulaibiya project for 15 years, showcasing advanced treatment technologies in one of the world's largest wastewater treatment and reuse plants. GE supplied industry-leading ZeeWeed-1000 UF system along with a state-of-the-art two-stage RO design for the expansion project which will process 60 MGD (225,000 m^3/day). The expansion project works are in progress and will start production at the end of 2016.

Summary

The Sulaibiya project will convert 100 MGD (375,000 m^3/day) of municipal effluent from phase-1 and 60 MGD (225,000 m^3/day) from phase-2, totaling 160 MGD (600,000 m^3/day) of municipal effluent wastewater into high quality reclaimed water that will be used for agriculture. This provides an alternate source of water for agriculture instead of using potable water needed for Kuwaiti residents.

The project uses proven technology both for the wastewater treatment plant and for the water reclamation facility. The combination of UF and RO provides bacteria, virus and TDS removal, producing high quality water for non-potable water applications. This project provides a benchmark and catalyst for the successful implementation of similar water reuse projects in the Middle East, which are particularly relevant due to the scarcity of water in the area.

Contact Us

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