The World's Largest Membrane-Based Water Reuse Project

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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.

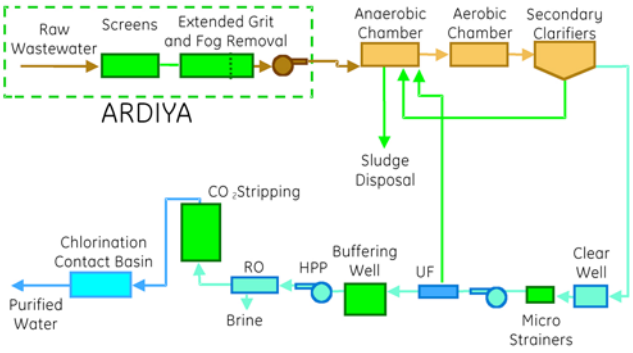

Figure 2: Major Treatment Steps

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 an average monthly value of less than 20 mg/l BOD and 20 mg/l TSS. The water reclamation plant

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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.

Table 1: Water Quality Data

	WWTP Effluent Average monthly value	Water Reclamation Plant Product Average monthly value	WHO Potable Water Guidelines
PH	7	6 – 9	6.5 – 8.5
TSS (mg/l)	12	< 1	
BOD (mg/l)	5	< 1	
Ammonia Nitrogen as N (mg/l)	< 2	< 1	
Nitrate (mg/l as N)	< 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 100 mgd (375,000 m^3/day) of secondary effluent, which is prefiltered with disk filters and then fed to the ultrafiltration system. UF product feeds a reverse osmosis plnt, 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. Hence, the feed to the RO system is also 100 mgd. The RO plant is designed for 85% water recovery, so the expected production rate is 85 mgd.

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. It is expected that 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 membranes is impossible. Thin film composite (TFC) membranes would suffer quick fouling. Also, the combination of UF and RO removes bacteria and pathogens and provides potable quality water suitable for agriculture or groundwater recharge.

Bids for the membrane filtration system were solicited from major suppliers of membrane filtration equipment. After a thorough evaluation, Norit's UF technology was selected. The technology was selected both for favorable life cycle costs and, since this is a UF membrane, for the better quality of water to the RO membranes. The ultrafiltration plant utilizes Norit's 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 35 m^2 (42 $yards^2$)of membrane area per element. Four membrane elements are placed inside a 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 plant is operated continuously and is fully automatic, with very little operator attention required.

The UF units are operated individually. Each unit is backwashed regularly, whereby all suspended matter that is being 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. Occasionally, 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, taking only a minor section of the plant out of filtration mode, 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 than 1 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 3,014 mg/l. RO is used to desalinate the water to 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. Approximately 21,000 membranes, 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.

Plant Operations

Since this is a build, own, operate and maintain contract, the consortium is also responsible for running the plant once construction is complete. 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 includes a number of managers, chemists and engineers, as well as qualified technicians and laborers. Training to the appropriate level is being provided at manufacturers' premises and on-site during commissioning and testing. During start-up and commissioning of the facility, a total of 42,000 person-days of training are expected to occur. 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.

Summary

This project will convert 100 mgd (380,000 m^3/day) of municipal effluent (expandable to 160 mgd or 610,000 m^3/day) to 85 mgd (320,000 m^3/day) of high quality reclaimed water that will be used for agriculture, providing an alternate source to potable water in Kuwait. 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 a high quality water for non-potable water applications. This project is expected to provide the benchmark and catalyst for the successful implementation of similar BOT projects in the Middle East region, which are particularly relevant due to the scarcity of water in the area. As it was recently named by Project Finance magazine, this truly is the "Wastewater Deal of the Year."