Economic and Technical Analysis of a Reverse-Osmosis Water Desalination Plant using DEEP-3.2 Software

Ali Al-Karaghouli and Larry Kazmerski National Renewable Energy Laboratory Golden, Colorado 80401

Abstract

Reverse osmosis (RO) is proved to be the most reliable, cost effective, and energy efficient in producing fresh water compared to other desalination technologies. It is the fastest-growing desalination technology with a greater number of installations around the world. The economic and technical performance of a medium-capacity RO desalination plant (2,000 m³/day) proposed to be installed in Umm Qasr city south of Basra, Iraq is analyzed using DEEP-3.2 software created by the International Atomic Energy Agency (IAEA). This port city is located on the Gulf shore and does not have any fresh water resources. The analysis shows that the cost of fresh water produced by this plant is US\$0.986/m³ with a good quality of fresh water (279 ppm), which is a reasonable price for this remote area. The analysis also shows an increase in water production cost of about 12% at increased electricity price from 0.06 to 0.1 US\$/kWh, 5.3% when the seawater salinity increased from 35,000 to 45,000 ppm, 2.5% when the seawater temperature decreased from 33° to 20°C, and 0.71% when the interest rate increased from 0% to 5%. Pumping fresh water from the Basra purification plant (located 175 km north of Umm Qasr) is 22.16 times the cost and 236.7% poorer quality than the fresh water produced by the RO plant.

1. Introduction

Availability of fresh water has been the main factor of growth of all civilizations. In the past, several civilizations, recognizing the importance of water, viewed it as sacred. Water enjoyed a sacred presence in the Indus Valley, Mesopotamian, and Egyptian civilizations, taking a central role in rites and rituals [1]. This precious resource has been a driving factor of progress in the past and will prove to be a determining factor for development in the future, as well. Iraq has abundant water supplies of around of 2,000 cubic meters per capita per year, a comfortable amount by international standards, supplied by Tigris and Euphrates. However, it will suffer from severe water shortage in 2020 due to the effects of water pollution, drought, poor water management, obstruction from upper riparians, and as a long-term consequence of conflict [1]. Therefore, there is a need to use desalination technologies, which can play a large role in supplying fresh water to areas that have access to seawater or brackish water.

Desalination is a separation process used to reduce the dissolved salt content of saline water to a usable level. The earliest form of desalination was accomplished by boiling the salt water, then cooling and condensing as fresh water. The best-known thermal technologies are the following: Multi-Stage Flash (MSF), Multi-Effect Distillation (MED), and Vapor Compression (VC). In colder climates, as in areas along the Arctic Ocean, freezing the water to remove the salt was

more practical. When saltwater is frozen, the salt ions sink to the bottom over time, leaving freshwater at the top that may be melted or shaved off [2].

The newest commercial technology for desalination is based on membrane treatment. Brackish Water Reverse Osmosis (BWRO), or Sea Water Reverse Osmosis (SWRO), is the fastest growing desalination technique with the greatest number of installations around the globe; it is beginning to dominate the current and future desalination markets. Its energy consumption is usually some 70% less than for comparable evaporation technologies [2]. Advancements have been made in membrane technology, resulting in stable, long-lived membrane elements. Component parts have been improved, as well, reducing maintenance and down time. Additional advancements in pretreatment have been made in recent years, further extending membrane life and improving performance. Reverse osmosis delivers product water or permeate having essentially the same temperature as the raw water source (an increase of 1°C or 1.8°F may occur due to pumping and friction in the piping). This is more desirable than the hot water produced by evaporation technologies. RO systems can be designed to deliver virtually any required product water quality. For these and other reasons, RO is usually the preferred method of desalination today [3].

A disadvantage of RO is the need for significant pre-conditioning of the feed water to protect the membranes. The extent of pre-treatment requirements depends on a variety of factors, such as seawater composition and temperature, seawater intake, membrane materials, and recovery ratio.

Typical electricity consumption of SWRO plants is in the range of 4 to 7 kWh/m³, depending on seawater salinity, recovery ratio, required permeate quality, plant configuration, and energy recovery in the brine blowdown [3].

Southern Iraq has been ruined by millennia of poorly engineered irrigation. The ground water in the south of Iraq is almost as saline as sea water, at 30,000 ppm. A water shortage described as the most critical since the earliest days of Iraq's civilization is threatening to leave up to 2 million people in the south of the country without electricity and almost as many without drinking water [4]. Therefore, there is an actual need of water desalination in this part of Iraq.

In this paper, we consider a medium-capacity RO desalination plant with a capacity of 2,000 m^3 /day used to supply water for the people living in Umm Qasr, located at 30°.01' N latitude and 47° 57'E longitude, which is a small port city in southern Iraq, on the western side of the al-Faw peninsula. We analyze this plant using the desalination economic evaluation program DEEP-3.2 created by the International Atomic Energy Agency [5].

2. Reverse Osmosis (RO) system

Reverse osmosis is a membrane separation process in which pure water passes from the highpressure seawater side of a semipermeable membrane to the low-pressure permeate side of the membrane. To overcome the natural osmotic process, the seawater side of the system has to be pressurized to create a sufficiently high net driving pressure across the membrane. In practice, the seawater can be pressurized to pressures as high as 70 to 80 bars. The remaining feed water continues through the pressurized side of the unit as brine. No heating or phase change takes place [2].

2.1 RO system components

The two most basic individual components in a seawater RO system are the high-pressure feed pump and the RO membranes. These components comprise the heart of any RO system and require careful selection and application for successful operation. In addition to these, other components related to the pretreatment of the inlet water and adjustment of the product water are also included. As shown in Figure 1, an RO system consists of four major components/processes [6]:

Pretreatment. The incoming feed water is pretreated to be compatible with the membranes by removing suspended solids, adjusting the pH, and adding a threshold inhibitor to control scaling caused by constituents such as calcium sulfate.

Pressurization. The pump raises the pressure of the pretreated feed water to an operating pressure appropriate for the membrane and the salinity of the feed water.

Separation. The permeable membranes inhibit the passage of dissolved salts while permitting the desalinated product water to pass through. The saline feed is pumped into a closed vessel where it is pressurized against the membrane. As a portion of the water passes through the membrane, the salt content in the remaining brine increases. At the same time, a portion of this brine is discharged without passing through the membrane.

Stabilization. The product water from the membrane assembly usually requires pH adjustment and degasification before being transferred to the distribution system for use as drinking water. The product passes through an aeration column in which the pH is elevated from a value of about 5 to close to 7. In many cases, this water is discharged to a storage cistern for later use.



Figure 1. Schematic diagram of an RO system.

2.2 RO membrane configuration and materials

RO membranes come in a variety of configurations. Two of the commercially successful configurations are the spiral-wound module and hollow-fiber module [7]. In both configurations, module elements are serially connected in pressure vessels (up to seven in spiral-wound modules and up to two in hollow-fiber modules).

Spiral-Wound module

A spiral-wound module element consists of two membrane sheets supported by a grooved or porous support sheet. The support sheet provides the pressure support for the membrane sheets, as well as providing the flow path for the product water. Each sheet is sealed along three of its edges, and the fourth edge is attached to a central product discharge tube. A plastic spacer sheet

is located on each side of the membrane assembly sheets, and the spacer sheets provide the flow channels for the feed flow. The entire assembly is then spirally wrapped around the central discharge tube forming a compact RO module element. The recovery ratio (permeate flow rate divided by the feed flow rate) of spiral-wound module elements is very low, so up to seven elements are arranged in one module to get a higher overall recovery ratio. Spiral-wound membranes have a simple design (reasonable production costs) with a relatively high resistance to fouling. Spiral-wound membranes are currently operated at pressures as high as 69 bars and recovery ratios up to 45%. Figure 2 shows a spiral-wound RO module element.



Figure 2. Spiral-wound RO module element.

Hollow-Fiber module

Hollow-fiber membranes are made of hair-like fibers, which are united in bundles and arranged in pressure vessels. Typical configurations of hollow-fiber modules are Utube bundles, similar to shell and tube heat exchangers. The feed is introduced along a central tube and flows radially outward on the outside of the fibers. The pure water permeates the fiber membranes and flows axially along the inside of the fibers to a "header" at the end of the bundle. Hollow fibers can withstand pressures as high as 82.7 bar and have high recovery ratios up to 55%. Figure 3 shows a hollow-fiber membrane module.



Figure 3. Hollow fiber module

Materials used in SWRO modules

The currently used materials for seawater RO membranes are cellulose acetate membranes, polyamide membranes, and thin-film composite membranes [7]. The choice of a suitable membrane material is particularly influenced by its resistance to free chlorine, free oxygen, temperature, bacteria, and to the index of pH of the saline solution.

Cellulose acetate membranes have been playing an important part in seawater desalination. Although strongly limited in index of pH, the advantages are low material costs and resistance to chlorine, which is used in feed water to inhibit biological fouling. Cellulose acetate membranes have a relatively short operating life and suffer pressure compaction—that is, deterioration of permeate water flow because of creep buckling of the membrane material at high pressure and high temperature. Polyamide and thin-film composite membranes have, in general, higher water fluxes and higher salt rejections than cellulose acetate membranes. However, these types of membranes are subject to chlorine attack. If chlorine is added to feed water to control biological growth, the feed water must be dechlorinated before entering the membrane modules.

Thin-film composite membranes consist of two layers of different polymers: one relatively thick and porous layer (e.g., polysulfone) that provides the membrane support, and one relatively thin (about $0.05-0.1\mu$ m) and dense layer (e.g., polyamine) that provides the semipermeable characteristics. The different materials of the layers make it possible to optimize each layer separately, which results in higher water fluxes and higher salt rejections at high mechanical strength in contrast to membranes consisting of only one material.

The membrane performance of RO modules such as salt rejection, permeate product flow, and membrane compaction resistance were improved tremendously in the last years.

2.3 Energy recovery in RO system

A key criterion for the RO layout is the specific electricity consumption, which should be as low as possible. That means that the recovery ratio must be kept as high as possible and the accompanying feed water pressure as low as possible, fulfilling the drinking water standards as well as the design guidelines of the manufactures. Because the overall recovery ratios of current seawater RO plants are only 30% to 50%, and because the pressure of the discharge brine is only slightly less than the feed stream pressure, all large-scale seawater RO plants, as well as many smaller plants, are equipped with energy-recovery turbines that recover a part of the pumping energy. Recent advances in energy-recovery device technology, together with improved membrane technology and process operations, have reduced the energy required by SWRO to a level comparable to the energy required to pump and treat surface water in many locations [8]. A number of turbine-based centrifugal energy recovery devices such as the Pelton wheel, Francis, and Reversal pump have been employed since the 1980s to recover pressure energy from the membrane reject stream and return it to the feed of the RO process. A typical RO process with a turbine is illustrated in Figure 4.



Figure 4. RO unit with a Pelton turbine energy recovery device.

2.4 Operation and maintenance of RO system

Assuming that a properly designed and constructed RO unit is installed, the major operational elements associated with the use of this technology will be the day-to-day monitoring of the system and a systematic program of preventive maintenance. Operation, maintenance, and monitoring of RO plants require trained engineering staff. Staffing levels are about one person for a 200 m^3/day plant, increasing to three persons for a 4,000 m^3/day plant. Preventive maintenance includes instrument calibration, pump adjustment, chemical-feed inspection and adjustment, leak detection and repair, and structural repair of the system on a planned schedule. The main operational concern related to the use of RO units is fouling, caused when membrane pores are clogged by salts or obstructed by suspended particulates. It limits the amount of water that can be treated before cleaning is required. Membrane fouling can be corrected by backwashing or cleaning (about every 4 months), and by replacement of the cartridge filter elements (about every 8 weeks). The lifetime of a membrane has been reported to be 2 to 3 years, although the literature has reported higher life spans.

3. Desalination economic evaluation program (DEEP)

The Desalination Economic Evaluation Program (DEEP) is a tool made freely available by the International Atomic Energy Agency, which can be used to evaluate performance and cost of various power and water co-generation configurations [9]. The program allows designers and decision makers to compare performance and cost estimates of various desalination and power configurations. Desalination options modeled include MSF, MED, RO, and hybrid systems, and power options include nuclear, fossil, and renewable sources. Co-generation of electricity and water, as well as water-only plants, can be modeled. The program also enables a side-by-side comparison of a number of design alternatives, which helps to identify the lowest-cost options for water and power production at a specific location. Data needed include the desired configuration, power and water capacities, as well as values for the various basic performance and costing data. The DEEP performance models cover both the effect of seawater salinity and temperature on recovery ratio and required feed water pressure.

The DEEP package is implemented as Excel spreadsheet files and serves three important and specific goals:

• Enables side-by-side comparison of a large number of design alternatives on a consistent basis with common assumptions.

- Enables quick identification of the lowest-cost options for providing specified quantities of desalinated water and/or power at a given location.
- Gives an approximate cost of desalted water and power as a function of quantity and sitespecific parameters including temperatures and salinity.

4. RO system performance results and discussion

A medium-size desalination RO plant with a capacity of 2,000 m³/ day is proposed to be installed in Umm Qasr, a small port city in southern Iraq located on the western side of the al-Faw peninsula at 30° 01'N latitude and 47° 57'E longitude. DEEP-3.2 software is used for the performance analysis of the RO system. The most important factors need to be locked at is the fresh water production cost and its quality. At normal condition, where seawater salinity is assumed to be 35,000 ppm, water feed temperature is 30°C, and the interest rate (I.R.) is 5.0%, total water production cost is US\$0.986/ m³, which is the total of the plant construction cost at 5% I.R. (US\$0.278 /m³), electricity cost (US\$0.178 /m³), and O&M cost (US\$0.530 /m³). Due to the location of the plant and the unavailable fresh water in this region, the cost is reasonable and its quality of 279 ppm is excellent, according to the price of fresh water produced by other RO plants in the world [10]. DEEP analysis results are presented in Table 1.

| | | F | | | | | | |
|----------|-------------|-------------|-------------|----------|-----------|------------|------------|----------|
| Salinity | Fresh water | Fresh water | Power | Recovery | Feed flow | Feed water | Brine flow | Brine |
| (ppm) | cost | quality | consumption | ratio | (m³/day) | pressure | (m³/day) | salinity |
| | (\$/m³) | (ppm) | (kWh/m³) | (%) | | (bar) | | (ppm) |
| 35,000 | 0.986 | 279 | 2.97 | 0.42 | 4,800 | 56.1 | 2,800 | 60,000 |

Table 1. RO system performance

Effect of different variables on water production cost

There are many factors which has an effect on the water production cost of a desalination plant. These are: the fixed capital cost at certain interest rate which includes the building construction cost, the equipment cost, the and installation cost; and the variable operation and maintenance cost., which include the fuel (electricity) cost, membrane and other devices replacement cost, and the labor cost. The effects of electricity price, interest rate, feed water salinity, and feed water temperature on the water production cost and quality were estimated using DEEP software and discussed below.

Case 1. Effect of electricity price

Because the high-pressure pump represents the heart of the RO unit, the cost of electricity consumed by the pump and other electricity consuming devices in the RO plant should have a significant effect on the water production cost. We assume in this analysis that the electricity is supplied from the grid or another central source in the region. The analysis shows that increasing the electricity price from US\$0.06 to US\$0.10 per kWh will increase the cost of water by about 12%. This increase seems reasonable since electricity is the only prime mover to the system. This is shown in Table 2 and presented in Figure 5.

| | | Jer i je | | | | | | |
|-------------|-------------|-------------|-------------|----------|-----------|------------|------------|----------|
| Cost of | Fresh water | Fresh water | Power | Recovery | Feed flow | Feed water | Brine flow | Brine |
| electricity | cost | quality | consumption | ratio | (m³/day) | pressure | (m³/day) | salinity |
| (US\$/kWh) | (\$/m³) | (ppm) | (kWh/m³) | (%) | | (bar) | | (ppm) |
| 0.06 | 0.986 | 279 | 2.97 | 0.42 | 4,800 | 56.1 | 2,800 | 60,000 |
| 0.07 | 1.016 | 279 | 2.97 | 0.42 | 4,800 | 56.1 | 2,800 | 60,000 |
| 0.08 | 1.045 | 279 | 2.97 | 0.42 | 4,800 | 56.1 | 2,800 | 60,000 |
| 0.09 | 1.075 | 279 | 2.97 | 0.42 | 4,800 | 56.1 | 2,800 | 60,000 |
| 0.1 | 1.105 | 279 | 2.97 | 0.42 | 4,800 | 56.1 | 2,800 | 60,000 |

Table 2. Effect of electricity price on water production cost



Figure 5. Effect of electricity price on water production cost.

Case 2. Effect of interest rate

Interest rate (I.R.) usually has a large effect when the desalination plant has a high construction cost and high construction period, as in the case of nuclear and fossil fuel desalination. This factor should have a smaller effect in RO water desalination. The results show that increasing the I.R. from 0% to 5% will only increase the water production cost by 0.7 cents/m³ (0.71%), which is a very small amount. This means that there are other important factors that have a greater effect on water production cost. These factors are the electricity, and maintenance and operation costs. The effect of I.R. on water production cost is shown in Table 3 and Figure 6.

| Interest rate (%) | Fresh water cost (\$/m3) | Fresh water quality (ppm) | Power consumption (kWh/m ³) | Recovery ratio (%) | Feed flow (m³/day) | Feed water pressure (bar) | Brine flow (m ³ /day) | Brine salinity (ppm) |
|----------------------|--------------------------------|---------------------------------|---|--------------------------|-----------------------|---------------------------------|-------------------------------------|----------------------------|
| 0 | 0.979 | 279 | 2.97 | 0.42 | 4,800 | 56.1 | 2,800 | 60,000 |
| 1 | 0.981 | 279 | 2.97 | 0.42 | 4,800 | 56.1 | 2,800 | 60,000 |
| 2 | 0.982 | 279 | 2.97 | 0.42 | 4,800 | 56.1 | 2,800 | 60,000 |
| 3 | 0.983 | 279 | 2.97 | 0.42 | 4,800 | 56.1 | 2,800 | 60,000 |
| 4 | 0.985 | 279 | 2.97 | 0.42 | 4,800 | 56.1 | 2,800 | 60,000 |
| 5 | 0.986 | 279 | 2.97 | 0.42 | 4,800 | 56.1 | 2,800 | 60,000 |

Table 3. Effect of interest rate on water production cost



Figure 6. Effect of interest rate on water production cost.

Case 3. Effect of water salinity

Studies show that the main surface salinity gradient was transverse to the Gulf, with salinities of less than 38,000 ppm common on the northeastern side, increasing to more than 41,000 ppm on the southwestern side. The greatest salinities of all—42500 ppm—occurred in Kuwait and Bahrain bays, where water circulation is impeded. In this study, a salinity range from 35,000 to 45,000 ppm was used. Higher water salinity increases the pump water pressure, and then it increases the power consumption. The effect of salinity variations on the water production cost, feed water flow, feed pressure, product quality, brine flow, brine salinity, and specific power consumption are shown in Table 4 and Figure 7.

| Salinity | Fresh water | Fresh water | Power | Recovery | Feed flow | Feed water | Brine flow | Brine |
|----------|-------------|-------------|-------------|----------|-----------|------------|------------|----------|
| (ppm) | cost | quality | consumption | ratio | (m³/day) | pressure | (m³/day) | salinity |
| | (\$/m³) | (ppm) | (kWh/m³) | (%) | | (bar) | | (ppm) |
| 35,000 | 0.986 | 279 | 2.97 | 0.42 | 4,800 | 56.1 | 2,800 | 60,000 |
| 36,000 | 0.990 | 282 | 3.01 | 0.40 | 5,000 | 56.7 | 3,000 | 60,000 |
| 37,000 | 0.994 | 285 | 3.07 | 0.38 | 5,217 | 57.2 | 3,217 | 60,000 |
| 38,000 | 0.998 | 288 | 3.12 | 0.37 | 5,455 | 57.8 | 3,455 | 60,000 |
| 39,000 | 1.002 | 291 | 3.18 | 0.35 | 5,714 | 58.3 | 3,714 | 60,000 |
| 40,000 | 1.007 | 294 | 3.24 | 0.33 | 6,000 | 58.9 | 4,000 | 60,000 |
| 43,000 | 1.024 | 303 | 3.46 | 0.28 | 7,059 | 60.6 | 5,059 | 60,000 |
| 45,000 | 1.038 | 309 | 3.64 | 0.25 | 8,000 | 61.7 | 6000 | 60,000 |

Table4. Effect of sea water salinity on water production cost and quality

As noted in the table, using a salinity of 45,000 ppm instead of 35,000 ppm increases the water production cost, power consumption, and feed pump pressure by 5.3%, 18.4%, and 9.9%, respectively. This slight increase is reasonable and expected. The product water quality was also slightly decreased due to the salinity change by 10.7% ppm. These results imply that the seasonal water salinity has a small effect on the water production cost and higher effect on the water quality.



Figure 7. Effect of seawater salinity on water production cost and quality.

Case 4. Effect of inlet temperature

Literature shows that with higher temperatures, the salt passage increases, flux (permeate flow) increases, and operating pressure required is lower. With lower temperatures, the inverse occurs, in that salt passage decreases (reducing the total dissolved solids (TDS) in the product water), whereas operating pressures increase. When operating pressures do not increase, then the amount of permeate or product water is reduced. In general, RO systems are designed for raw water temperatures of 25°C. Higher temperatures or lower temperatures can be accommodated with appropriate adjustments in the system design. In this study, because the Gulf surface water temperature always remains higher than 20°C and goes up to higher than 30°C [11], a temperature range between 33° and 20°C is used to estimate its effect on RO system performance. The analysis shows that at constant permeate flow (2,000 m³/day), the fresh water cost increased slightly by 2.5%, power consumption increased by 12.6%, feed water pressure increased by 16.9%, while the fresh water quality improved by 31.6%. This is shown in Table 5 and Figure 8.

| | | 1 | | 1 | | 1 2 | | |
|-------------|-------------|-------------|-------------|----------|-----------|------------|------------|----------|
| Temperature | Fresh water | Fresh water | Power | Recovery | Feed flow | Feed water | Brine flow | Brine |
| (°C) | cost | quality | consumption | ratio | (m³/day) | pressure | (m³/day) | salinity |
| | (\$/m³) | (ppm) | (kWh/m³) | (%) | | (bar) | | (ppm) |
| 33 | 0.982 | 301 | 2.90 | 0.42 | 4,800 | 54.3 | 2,800 | 60,000 |
| 32 | 0.983 | 294 | 2.92 | 0.42 | 4,800 | 54.9 | 2,800 | 60,000 |
| 31 | 0.985 | 286 | 2.94 | 0.42 | 4,800 | 55.5 | 2,800 | 60,000 |
| 30 | 0.986 | 279 | 2.97 | 0.42 | 4,800 | 56.1 | 2,800 | 60,000 |
| 29 | 0.988 | 272 | 2.99 | 0.42 | 4,800 | 56.8 | 2,800 | 60,000 |
| 28 | 0.989 | 265 | 3.02 | 0.42 | 4,800 | 57.6 | 2,800 | 60,000 |
| 27 | 0.991 | 257 | 3.05 | 0.42 | 4,800 | 58.4 | 2,800 | 60,000 |
| 26 | 0.993 | 250 | 3.08 | 0.42 | 4,800 | 59.2 | 2,800 | 60,000 |
| 25 | 0.995 | 243 | 3.12 | 0.42 | 4,800 | 60.1 | 2,800 | 60,000 |
| 20 | 1.007 | 206 | 3.32 | 0.42 | 4,800 | 65.4 | 2,800 | 60,000 |

Table 5. Effect of RO inlet temperature on water production cost and quality



Figure 8. Effect of RO inlet temperature on water production cost and quality.

5. Cost and quality comparison between RO water and water transported from Basra

The water transport cost is broken into the following:

- Capital costs, which includes the costs of pumps, building, and pipes
- Energy cost
- Operation and maintenance cost
- Cost of water at the source
- Sales tax and interest rate.

Um Qasr port is located about 75 km south of Basra. Basra is currently receiving its fresh water from a purification station installed on the Tigris River about 100 km north of Basra. The salinity of the fresh water produced from this purification station is about 1000 ppm, which is much higher than the salinity of water produced by the RO system (279 ppm); but it is acceptable by the World Health Organization (WHO) Standard, which states that water containing TDS concentrations below 1000 mg/liter is usually acceptable to consumers [12]. If we assume that the cost of water produced by the purification station located at a distance of 175 km north of Umm Qasr city is low and can be neglected, then the fresh water transportation cost from this station to Umm Qasr will be about 22.845 US\$/m³ according to our DEEP-3.2 analysis. This is more than 20 times higher than the cost of water produced by the RO station installed in Umm Qasr. Table 6 presents the variation of water cost with the distance of transportation.

| Location (km) | Cost of water (US\$/m ³) |
|---------------|--------------------------------------|
| 50 | 6.527 |
| 100 | 13.054 |
| 150 | 19.582 |
| 175 | 22.845 |
| 200 | 26.109 |

Table 6. Variations of water cost with distance of transportation

6. Conclusion

A medium-capacity (200 m^3/day) RO unit proposed to be installed in Umm Qasr port city in southern Iraq is analyzed using IAEA's DEEP-3.2 software. The analysis shows that the total water production cost is US\$0.986/m³. This is a reasonable cost considering the size of the plant, the remoteness, and the unavailability of fresh water in this region. The quality of the produced water (279 ppm) is excellent and well within the WHO requirement [12]. We studied several variables such as electricity price, interest rate, and inlet water salinity and temperature that are believed to have an effect on the water production cost. The results of our analysis show that:

- Increasing the price of purchasing electricity from 0.06US\$/kWh to 0.1US\$/kWh increases the water production cost by 11.9 cents/kWh (12%). This shows that the price of electricity has a significant effect on the water production cost.
- Increasing the interest rate from 0% to 5% will only increase the water production cost by 0.7 cents/kWh. This is because, for an RO system, the cost of pretreatment and operation and maintenance represent the highest fraction of the water production cost due to the cost of chemicals, electricity, and membrane replacement.
- Changing water salinity from 35,000 to 45,000 ppm will increase the price by 5.3%.
- Changing the water temperature from 33° to 20°C increases the water production cost by only 2.5%.

The study also shows that desalinated water produced in Umm Qasr port city is much less expensive and has better quality than pumping water from the north Basra purification station. Pumping water from the purification station increases the water production cost by 22.16 times and decreases the water quality by 236.7%.

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