ISSN NO. 2320-5407

Journal homepage:http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

ECONOMIC ANALYSIS OF WATER DESALINATION PLANTS USING DEAP PROGRAM.

Dr. Sherine.F.Mansour.
Researcher, Agricultural Economic Department, Desert Research Center.

Manuscript Info

Manuscript History:

Received: 14 January 2016
Final Accepted: 26 February 2016
Published Online: March 2016

Key words:
water desalination; Reverse osmosis; Economic evaluation program, deep.

Corresponding Author

Dr. Sherine.F.Mansour.

Abstract

Reverse Osmosis (RO) is proved to be the most reliable 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 small-capacity RO desalination plant is (4-5 m3/day) in the North West coast of Egypt (as aExample).

This paper presents the thermal and membrane desalination economic analysis and outlines procedure to calculate the product unit cost for various desalination processes.

There are many kinds ofdesalination plants works all over the world and with the continued progress of the technology of desalination makes inter-State competition much more to discover desalination methods less expensive than previously or work to reduce the unit costs of desalinated water in order to alleviate the acute shortage of water all over the world. Even desalination costs to be competitive with the operation and maintenance of water transmission systems for long-distance costs.

This paper aims to be clarified various economic transactions in the analytical program used to calculate the product unit cost of water desalination by different methods used and comparison between them. DEEP program is used to analyze osmosis desalination membranes and thermal data, 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.

Introduction:-

Desalination is the process hope to rid the world of scarcity of water for more than 50 years during this period, the total public and private investment was in the development and improvement of desalination technology more than a billion dollars of water. This continued progress in desalination technology makes it different countries decision-makers to use this technology and make use of them not only to alleviate water shortages all over the world, but in addition to low water desalination costs compared to other ways to transport water over long distances in these countries[1].

It has been observed in recent years, desalination costs decreasing continuously over recent years as a result of progress in the design and operation of the various systems used in water desalination and associated product cost reduction as a result of a decrease in the size of the power unit used in sweetener consumption. There are now more than 12,500 desalination units with an average production of about 22.8 m3 / day and works all over the world. The processes of desalination most widely used and the most prevalent and widespread is the membrane separation by reverse osmosis (Ro) and three other types of thermal separations, a multi-stage - desalination flash (MF) and multi-effect evaporation with thermal pressure (MEE - TVC) and without (MEE) and mechanical vapor compression (MVC)[2].

It was the importance of the study of the current and future economic conditions that are likely to take this technology and developed. So I worked on the paper this research study of the structure of the costs of water desalination and the determinants of those costs, which they can reduce the costs for a desalination units at the lowest possible cost. So we can analyze there plants using the desalination economic evaluation program DEEP-3.2 created by the International Atomic Energy Agency [3].

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 [21].

Reverse Osmosis (RO) system:- Reverse osmosis is a membrane separation process in which pure water passes from the high-pressure water side of a semipermeable membrane to the low-pressure permeate side of the membrane. To overcome the natural osmotic process, the water side of the system has to be pressurized to create a sufficiently high net driving pressure across the membrane. In practice, the water 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 [21]. Furthermore, unlike thermal processes, RO membranes do not provide high-purity water. On average, the permeate salinity varies over a range of 30–150 ppm. The actual value depends on the process recovery, which is defined as the amount of product per unit mass of feed water. Depending on the intended use of the water, a second RO pass may be needed to reduce the salinity to an acceptable level. Energy consumption is reduced through the use of energy recovery systems.

Thermal processes:- All three types of thermal desalination systems are equipped with condenser tube bundles. These are used to preheat the brine recycle stream. The tube bundles in MEE and MVC function as condensers/evaporators, where the heating steam condenses inside the tubes and vapor is formed outside the tubes. The MEE and MVC systems are divided into evaporating effects, while MSF systems are divided into flashing stages. All of the systems employ a number of large pumping units, including pumps for water intake, distillate product, brine blow down and chemical dosing. The MSF and MEE systems have additional pumps for the cooling water. In addition, MSF has pumps for brine recycle. In MSF and MEE, steam extracted from low- and medium-pressure turbine lines provides the heat necessary for flashing or evaporation. In MSF, the heating steam is routed to the brine heater; in MEE, the heating steam is routed to the first evaporating effect. The MSF process operates with a top brine temperature in the range of 90–110°C. The MEE and MVC processes are operated with lower top brine temperatures in the range of 64–70°C. MVC is distinguished from the other processes by the presence of a mechanical vapor compressor, which compresses the vapor formed within the evaporator to the desired pressure and temperature. The system also includes plate heat exchangers for preheating the feed using heat recovered from the brine blow downstream and the distillate product. All thermal processes produce a high-purity distillate product, with a salinity of less than 10 ppm. This is achieved by a wire-mesh mist eliminator, which removes entrained brine droplets formed in the distillate stream.

Factors affecting product cost Unit:-

Product cost is affected by several design and operational variables**:**

- Salinity and quality of feed water. Lower feed salinity allows for higher conversion rates. As a result, the plant can operate with lower specific power consumption and dosing of antiscalant chemicals. Also, downtime related to chemical scaling is considerably reduced.
- Plant capacity. Larger plant capacity reduces cost per unit product, despite a higher initial capital investment (due to economies of scale).
- Site conditions. Installation of new units as an expansion of existing sites eliminates the costs associated with facilities for feed water intake, brine disposal and feed water pretreatment.

- Qualified labor. The availability of qualified operators, engineers and management personnel results in higher plant availability and production capacity, and shorter downtimes.
- Energy cost. The availability of inexpensive sources for low-cost electric power and heating steam have a strong impact on unit product cost.
- Plant life and amortization. Increases in the life of a plant reduce product capital costs.

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 site specific parameters including temperatures and salinity.

Elements of economic calculations:-

Calculations of unit product cost depend on the process capacity, site characteristics and design features. System capacity specifies sizes for various process equipment, pumping units, and required membrane surface area. Site characteristics have a strong influence on the type of pretreatment and post-treatment equipment, and consumption rates of chemicals. Process design features affect consumption of electric power, heating steam and chemicals. A summary of the cost elements for desalination processes Production cost is divided into direct and indirect capital costs and annual operating costs.

Direct capital costs:- Direct capital costs include the purchase cost of major equipment, auxiliary equipment, land and construction.

Land:- The cost of land may vary considerably, from zero to a sum that depends on site characteristics. Government-owned plants normally have zero charges. Plants constructed under build-own-operate-transfer (BOOT) contracts with governments or municipalities can have near zero or greatly reduced charges.

Well construction:- This category includes processing equipment, as well as instrumentation and controls, pipes and valves, electric wiring, pumps, process cleaning systems, and pre- and post-treatment equipment. These are some of the most expensive items, and their cost depends on the type of process and capacity. MSF and MEE equipment is generally more expensive than RO systems.

Auxiliary equipment:- The following are considered auxiliary equipment: open intakes or wells, transmission piping, storage tanks, generators and transformers, pumps, pipes and valves.

Building construction:- Buildings could include a control room, laboratory, offices and workshops.

Membranes:- The cost of membrane modules depends on plant capacity, Equipment costs may be less than 11,000 LE (e.g., a laboratory-scale RO unit used to treat low-salinity water). On the other hand, the equipment cost for a 100,000m3/d RO system could approach 550 LE million. MSF and MEE equipment is generally more expensive than RO systems — current estimates for a plant capacity of 27,000 m3/d are 440LE million.

Auxiliary equipment:- The following are considered auxiliary equipment: open intakes or wells, transmission piping, storage tanks, generators and transformers, pumps, pipes and valves.

Building construction:- Building cost varies from 1100 LE to 11,000LE/m2; this cost is site-specific and depends on the building type. Buildings could include a control room, laboratory, offices and workshops.

Membranes:- The cost of membrane modules depends on plant capacity, and ranges from 5500LE to 11,000LE per 50–100-m3/d module.

Indirect capital costs:- The costs in this category are expressed as percentages of the total direct capital cost.

Freight and insurance:- This cost is typically equal to 5% of the total direct costs.

Construction overhead:-Construction overhead costs include fringe benefits, labor burden, field supervision, temporary facilities, construction equipment, small tools, contractor's profit and miscellaneous expenses. They are about 15% of direct material and labor costs (which depend on the plant's size).
Owner's costs:- These include engineering and legal fees, and are approximately 10% of direct material and labor costs. Contingency costs. These are generally estimated at 10% of the total direct costs.

Annual operating costs:- Annual operating costs are those expenditures incurred after plant commissioning and during actual operation. These include labor, energy, chemicals, spare parts and miscellaneous items.

Electricity:-Electricity costs vary over the range of 0.44–0.99LE/kWh. The upper end of the range is characteristic of European countries, while the lower value can be attained in the Gulf States, Egypt and the U.S.

Labor:- labor costs are site-specific and depend on plant ownership (i.e., public or private). In addition, recent trends in plant operations point to more outsourcing of plant operation and maintenance duties. This often reduces the number of required full-time employees, such as managers, engineers and technicians. It could suffice to have one plant manager and a smallteam of experienced engineers and technicians.

Membrane replacement:-The replacement rate may vary between 5% per year for membranes treating low-salinity brackish water supported by proper operation and pretreatment systems to 20% per year for membranes treating high-salinity water (e.g., Egypt, Arabian Gulf water). The higher costs may also reflect generally inefficient operations and/or inefficient pretreatment systems.

Maintenance and spare parts:-This is typically less than 2% of the total capital cost on an annual basis.

Insurance:- Insurance is 0.5% of the total capital cost.

Amortization or fixed charges:- This item accounts for annual interest payments for direct and indirect costs. It is obtained by multiplying these costs by an amortization factor, which is given by:

$$a = i\,(1+i)^n / (1+i)^n - 1 \qquad (1)$$

Where i is the annual interest rate and n is plant life (in years). Experience in the desalination industry indicates that an amortization life of 30 yr. is adequate. An interest rate in the range of 5–10% is common for economic analyses.

Chemicals:-The chemicals frequently used to clean desalination plants include sulfuric acid, caustic soda, various anticipants and chlorine. The cost of these items may be affected by availability of nearby manufacturing plants and by global market prices. In addition, chemical treatment differs for thermal and membrane processes, with higher specific costs for the latter. Also, treatment depends on the top brine temperature and feed salinity.

Unit product costs for the RO process depend on capacity. Recent field estimates suggest a cost of 6.05LE/m3 for a large RO project, such as one in Florida with a capacity of 113,652 m3/d. Recent data for existing smaller RO units, such as one in Cyprus, reveal unit product costs of 9.13LE/m3 for a capacity of 40,000m3/d and 13.42 LE/m3 for 20,000m3/d and other small size SWRO plants powered by photovoltaic at the North West coast of Egypt the cost of the desalinated water becomes 2.3 – 1.7 LE/m3 for a capacity of 4380-7300 m3/ year. RO costs have decreased over the years [14]. The unit product costs for MSF, MEE and MEETVC are higher than for RO, with an average of 16.5LE/m3. The highest costs are for the MVC process — a field value of 35.42LE/m3 in 1995 can be found in the literature [10]. However, this high value was attributed to high energy costs, which were independent of plant availability. More-recent economic calculations confirm similar, high average unit product costs of 26.73LE/m3 [11]. The capacity of the vertical-stack MEE system is 340,965 m3/d, which is the largest capacity considered here. The MEE-ABS system is a prototype unit with a performance ratio of 21, which is defined as the mass of distillate product per kg of heating steam. This is much higher than the conventional performance ratio of 8–16 for the MEE system with or without thermal vapor compression. The most critical parameters in cost evaluation are the fixed charges (amortization) and energy costs; the costs of chemicals and labor have lesser effects on the unit product cost.

These examples illustrate four cases using the major desalination processes. All calculations are based on recent economic data extracted from actual field data and from design studies in the literature.

The equations used are:-

Annual fixed charges: $A_{fixed} = (a)(DC)$ (2)

Annual steam cost: $A_{steam} = (s)(\lambda)(f)(m)(365)/[(1{,}000)(PR)]$ (3)

Annual electric power cost: $A_{electric} = (c)(w)(f)(m)(365)$ (4)

Annual cost for chemicals: $A_{chemicals} = (k)(f)(m)(365)$ (5)

Annual labor cost: $A_{labor} = (ɣ)(f)(m)(365)$ (6)

Total annual cost:-

$A_{total} = A_{fixed} + A_{steam} + A_{electric} + A_{chemicals} + A_{labor} + A_{membrane}$ (7)

Unit product cost in terms of production: $A_{unit,p} = A_{total} / [(f)(m)(365)]$ (8)

Unit product cost in terms of capacity: $A_{unit,c} = A_{total} / m$ (9)

Nomenclature:-

a = amortization factor, yr–1 c = electric cost, LE/m3

DC = direct capital cost, LE f = plant availability i = interest rate

k = specific chemicals cost, LE/m3

m = plant capacity, m3 /d n = plant life,yr

PR = performance ratio, kg product/kg steam s = heating steam cost, LE/MkJ

w = specific consumption of electric power, kWh/m3

ɣ = specific cost of operating labor,

λ = average latent heat of steam, kJ/kg

Table 1 summarizes the plant and operating cost data used for each process and the results of the example calculations by DEEP. Note that these are four separate applications that illustrate a range of desalination installations. This is not intended as a comparison to identify the most appropriate process for a particular application.

Table1 : Summary of annual cost data

	MSF	**MEE**	**MVC**	**RO**
Direct Capital Cost- million LE	704	220	4.4	1078 + 638*
Plant Capacity	32,732 m3/d	12,000 m3/d	3,000 m3/d	94,625 m3/d
Electric Power Consumption	5 kWh/m3	3 kWh/m3	7 kWh/m3	5 kWh/m3
Fixed Charges LE/yr	45,826,000	14,322,000	275,440	70,180,000
Steam LE/yr	47 ,685,000	17 ,479,000	N/A	N/A
Electric Power LE/yr	29 ,568,000	6,504 ,300	3 ,793,900	68 ,387
Chemicals LE/yr	2 ,956,800	1 ,085,050	271 ,040	8 ,548,100
Labor LE/yr	11 ,825,000	4 ,336,200	1 ,085,000	17 ,094,000
Membrane Replacement LE/yr	N/A	N/A	N/A	64 ,680,000
Total Annual Cost LE/yr	137 ,830,000	43 ,725,000	5 ,435,430	228 ,910,000
UnitCost, Production BasisLE/m3	1,17	11,11	5,511	7,359
Unit Cost, Capacity Basis LE/m3/d	4,213	3,641	1,815	2,420

* 1078,000,000 LE for equipment plus 638,000,000 LE for membranes

Conclusion:-

Based on the analysis of the economics of thermal and membrane desalination processes presented here, several conclusions can be drawn. Increasing plant capacity drastically decreases overall unit product cost, despite an overall increase in the capital cost (i.e., economy of scale). The unit product cost for the RO process consists of approximately equal contributions of the fixed charges, power costs and membrane replacement costs; the costs of chemicals and labor are drastically lower for RO than for the other processes. The fixed charges and energy costs represent 40–50% of the total unit product cost for the MSF and MEE processes. Today, the RO process can be regarded as the optimum choice for desalination of low-salinity water — regardless of plant capacity. The optimum choice for desalination of higher-salinity feed water depends on the required capacity. The MSF process would be the technology of choice for capacities above 25,000 m3/d, while the MEE process should be chosen for capacities on the order of 10,000 m3/d, and the MVC for capacities on the order of 3,000 m3/d. Software packages that employ very simple models and required input can be used to estimate costs for various desalination technologies and energy options. The International Atomic Energy Agency's software package DEEP was used to estimate the general competitiveness of various energy sources and desalination technologies, including nuclear power reactors as energy sources. The results of product water cost calculations (4.4LE– 20.9LE/m3) agreed well with actual operational data. The results also confirm the decrease in unit product cost for larger desalination plants due to the economy-of-scale effect.

Acknowledgment:-

The research presented in this paper has been done within the project "Local Development and Manufacturing of a Small Mobile Solar Reverse Osmosis Water Desalination Plant" which is funded by Misr El-Kheir Foundation.

References:-

1. K.V. Reddy, N. Ghaffour, Overview of the cost of desalinated water and costing methodologies, Desalination 205 (2007) 340–353.
2. E.S. Mohamed, G. Papadakis, Design, simulation and economic analysis of a stand-alone reverse osmosis desalination unit powered by wind turbines and photovoltaics, Desalination 164 (2004) 87–97.
3. Desalination Economic Evaluation Program (DEEP), International Atomic Energy Agency, Vienna, Austria, 2006.
4. DeGunzbourg, J., and D. Larger, "Cogeneration Applied to Very High Efficiency Thermal Seawater Desalination Plants:A Concept," Desalination and Water Reuse, 7, pp. 38–41 (1998).
5. Darwish, M. A., and N. M Al-Najem, "Energy Consumptions and Costs of Different Desalting Systems," Desalination, 64, pp. 83–96 (1987).
6. Darwish, M. A., et al., "Comparison Between Small Capacity Mechanical Vapor Compression (MVC) and Reverse Osmosis (RO) Desalting Plants," Desalination, 78, pp.313–326 (1990).
7. ESCWA Water Development Report 3, Role of Desalination in Addressing Water Scarcity, E/ESCWA/SDPD/2009/4, 10 November 2009.
8. Economics of Nuclear Desalination: New Developments and Site Specific Studies. IAEA- TECDOC-1561, Final Results of a Research Project 2002–2006, July, 2007. 10.
9. M. Dore, Forecasting g the economic costs of desalination technology, Desalination 172 (20 February 2005), pp.207-214.
10. G. Bakshi, "Civilizations, ancient and present depend on water," Green Prophet Weekly Newsletter, April 29, 2010.
11. Hammond, R. P., et al., "Seawater Desalination Plant for Southern California," Desalination, 99, pp. 459–481 (1994).
12. International Atomic Energy Agency, "Examining the Economics of Seawater Desalination Using the DEEP Code," Technical Document 1186, IAEA, Vienna,Austria(2000).
13. J. K¨ampf1 and M. Sadrinasab, The circulation of the Persian Gulf: a numerical study, Ocean Sci. 2, 27–41, 2006.
14. Leitner, G., "Water Desalination: What are Today's Costs," Desalination and Water Reuse, 2, pp. 39–43 (1992).
15. Leitner, G., "Developer Selected for 25 MGD (94,625 m3/d) Florida West Coast Seawater Desalting Plant," Desalination and Water Reuse, 9, pp. 11–16 (1999).
16. Martin, Chulov, Water shortage threaten two million people in southern Iraq. Guardian Co, UK, August, 2009.

17. Matz, R., and U. Fisher, “A Comparison of the Relative Economics of Sea Water Desalination by Vapour Compression and Reverse Osmosis for Small to Medium Capacity Plants,” Desalination, 36, pp. 137–151 (1981).
18. Morin, O. J., “Desalting Plant Cost Update: 2000,” Proceedings of the IDA World Congress on Desalination and Water Reuse,” San Diego, CA, Vol. III, pp. 341–359 (1999).
19. Morin, O. J., “Design and Operating Comparison of MSF and MED Systems,” Desalination, 93, pp. 69–109 (1993).
20. O.K. Buros, 1987 An introduction to desalination. In Non-Conventional Water Resources Use in Developing Countries. New York, United Nations, pp.37-53. (Natural Resources/Water Series No. 22)
21. Pappas, C., “For Cyprus, 10 Year ‘BOOT’ Contract, Desalination and Water Reuse, 7, pp. 28–34 (1997).
22. R.L. Stover, 2008. Energy Recovery Devices in Desalination Applications, Proceedings of the International Water Association’s 2008 North American Membrane Research Conference, University of Massachusetts, Amherst,
23. Massachusetts.
24. Source Book of Alternative Technologies for Fresh Water Augmentation in Latin America and the Caribbean. United Nations Environmental Program, UNEP, International Energy Environmental Technology Center, 1997.
25. Sea water and brackish water deslination in the Middle Esat, North Africa and Central Asia. Final Report.DHV& BRL, 2004.
26. Total dissolved solids (TDS) in drinking water. WHO/SDE/WSH/03.04/16
27. Veza, J. M., “Mechanical Vapour Compression Desalination Plants: A Case Study,” Desalination, 101, pp. 1–10 (1995).
28. Wade, N. M., “Technical and Economic Evaluation of Distillation and Reverse Osmosis Desalination Processes,” Desalination, 93, pp. 343–363 (1993).
29. Zimerman, Z., “Development of Large Capacity High Efficiency Mechanical Vapor Compression (MVC) Units,” Desalination, 96, pp. 51–58 (1994).