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Capital cost estimation of RO plants: GCC countries versus southern Europe

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HIGHLIGHTS

- Parameters affecting the direct capital costs of BWRO and SWRO plants were assessed.
- Plants delivered through EPC contracts were considered.
- Assessment was based on cost data from 950 RO plants in the GCC and southern Europe.
- Plant capacity, type, award year, and region were found to affect RO CAPEX cost.
- A model was also developed and verified for RO CAPEX estimation.

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ABSTRACT

The installation of reverse osmosis (RO) desalination plants has been on the rise throughout the world. Thus, the estimation of their capital cost (CAPEX) is of major importance for governments, potential investors and consulting engineers of the industry. In this paper, parameters potentially affecting the direct capital costs of brackish water RO (BWRO) and seawater RO (SWRO) desalination plants, delivered through Engineering, Procurement & Construction (EPC) contracts, were assessed. The assessment was conducted based on cost data from 950 RO desalination plants contracted in the Gulf Cooperation Council (GCC) countries and in five southern European countries. The parameters assessed include plant capacity, location, award year, feed salinity, and the cumulative installed capacity within a region. Our results showed that plant capacity has the strongest correlation with the EPC cost. Plant type (SWRO or BWRO), plant award year and the region of the RO plant were also found to be statistically important. By utilizing multiple linear regression, a model was also developed to estimate the direct CAPEX (EPC cost) of RO desalination plants to be located either in the GCC countries or southern Europe, which was then verified using the *k*-fold test.

1. Introduction

In 2009, over 15,000 desalination plants were in operation worldwide with approximately half of them being reverse osmosis (RO) plants [1]. Although many countries have begun to utilize desalination to produce drinking water, no region of the world has implemented desalination as widely as the Middle East, where 50% of the world's production of desalinated water is installed [1]. Over the past 40 years, use of RO has been gradually gaining momentum in the Gulf Cooperation Council (GCC) countries, due to its lower cost, simplicity, novelties in the membrane fabrication, and the high salt rejection accomplished by RO membranes today [1–4]. It is foreseen that RO will play a key role in increasing fresh water availability globally in the future, but more so in GCC countries [1].

In a simplified manner, the cost of an RO desalination plant consists of two main elements: the capital and the annual operating costs [4–7]. The operating cost, otherwise referred to as OPEX, is not only primarily determined by the cost of energy utilized to power the desalination plant which is subject to fluctuations in energy prices [4,8,9], but also includes other costs such as manpower cost, spare parts, chemicals, membrane replacement, and insurance. The capital cost (CAPEX), on the other hand, includes indirect and direct costs. Direct capital costs comprise of the purchase cost of major equipment (e.g., high pressure pumps) and auxiliary parts, land cost, engineering cost, etc. [10]. The indirect capital costs include elements such as freight and insurance, construction, and overhead [10]. The normalized total water cost (TWC) via desalination in a specific plant is the sum of the plant's CAPEX cost, amortized over the plant's life, and the annual OPEX divided

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by the average annual production of desalinated water in that plant [4,10,11].

A desalination plant can be a large scale project of high complexity. A number of different financing and contracting packages have been successfully implemented in such projects. One family of these financing schemes is the so called 'turnkey projects' [13,14]. Financing options under "turnkey" include BOO(T) (Build–Own–Operate(–Transfer)) and Engineering–Procurement–Construction (EPC) [11,12,14]. An EPC contract is formed by a direct agreement between the client and the EPC contractor [12,14]. The EPC cost consists of all the direct capital costs (apart from land cost) of the plant and the EPC contractor's cost of services. The EPC services include: detailed design, contractor permitting, and project management costs [12]. In return, the EPC contractor must deliver the project (the desalination plant) for a fixed contract cost and by a fixed date in such a way that the plant's final performance will be the same as the one guaranteed by the contractor in terms of output quantity and quality, efficiency and reliability [15,16]. EPC contracts are commonly used for desalination projects in the GCC region.

A limited number of studies can be found in literature which model the capital cost of desalination plants [4,5,9,17,18]. In one study [9], the capital and production costs of medium-sized (100,000 m^3/day) seawater desalination plants using different technologies, including RO, were estimated. The semi-empirical method employed was originally developed in [18] and it estimated the cost of various components of the desalination plant (e.g., pre-treatment system) based on published data for other existing plants.

In another study [5], simple cost-correlations were developed between the capital cost of desalination plants and their respective capacity. The exercise was carried out for multiple stage flash distillation (MSF), multiple effect distillation (MED), SWRO and BWRO plants. The cost database that was collated by the authors contained published cost-data of more than 300 desalination plants. Ninety SWRO and 112 BWRO plants located in various regions worldwide were used in the analysis, respectively. The effect of plant location was not taken into account. Moreover, it was not always specified if the cost of land or civil works was included in the capital cost.

Apart from the mentioned empirical regression models, two packages for desalination cost modeling are also available in open literature: the Desalination Economic Evaluation Program (DEEP) [19] and the Water Treatment Cost Estimation Program (WTCost) [20]. Both are tools developed to evaluate the cost of hypothetical desalination plants. DEEP was created in 1989 by the International Atomic Energy Agency (IAEA). DEEP can perform economic analyses for different desalination technologies using energy produced by various types of fossil fuel or nuclear plants [7,8,11,21]. Water Treatment Cost Estimation Program (WTCost), on the other hand, evaluates and compares various water treatment technologies using reverse osmosis/nano-filtration (RO/NF), vapor compression (VC), ultra-filtration/micro-filtration (UF/MF), electro-dialysis (ED), MSF, MED and ion exchange [8,11].

The mentioned empirical and computerized tools for capital and water production costs have the advantage of being openly available. However, the datasets based on which the models were fitted were not always made available. Additionally, different models are based on different assumptions (e.g., interest rate or ratio of OPEX to CAPEX) and in some cases require a significant knowledge of the plant's technical details (such as the type of pre-treatment applied, intake, etc.) to conduct even a preliminary cost evaluation.

The goal of this research is to develop a model which can give a reasonably accurate estimate of the capital cost of an EPC contracted RO plant in a simple manner. This can potentially offer the desalination engineers a tool to benchmark the capital cost of an RO plant and help decision makers choose among multiple options. EPC-type contracts were specifically selected for our modeling for two reasons: 1) they are very common in the GCC region, as well as in other parts of the world and 2) EPC contracts exclude the land cost, which varies significantly by location. Land cost can later be added by the model users based on their locality, allowing more flexibility and accuracy in CAPEX estimation. The model is based on the cost analysis of a 950 RO-plant dataset, including SWRO and BWRO plants, delivered by EPC contracts between 1985 and 2013. The RO plants in the dataset were selected to be located within the GCC region and southern Europe, which also revealed interesting trends based on location.

2. Methodology

2.1. Model data

Many design parameters can affect the EPC cost of an RO plant. These include, but are not limited to, choices of pre-treatment systems, intake design, brine discharge, location parameters (water depth, geopolitical issues, etc.), product water specifications (e.g., Boron limits), ecological considerations, permitting needs, membranes selected, membrane vessel design, and many more. Cost modeling based on a large number of in-depth design details of the RO plant will lead to more accurate cost estimation. However, if the cost model was to be based on many detailed design parameters, which could be either unknown or not yet determined (as in the case of future plants), this will make the modeling tool ineffective. Therefore, our goal for this work is to provide a tool for the users to easily obtain quick estimate of an EPC cost with an acceptable level of accuracy, based on parameters that can be readily known. To achieve that, we selected easily obtainable key parameters for the model and methodologically attempted to show that these parameters were sufficient to build statistically strong correlations with the EPC cost. The EPC contract cost of a desalination plant (the *regressand* variable in this work), was initially assumed to correlate with six potential variables (the *regressor* variables), two of which were presented as dummy variables. The four numerical variables are: plant capacity (CAP), expressed in cubic meters of water produced per year, EPC contract award year (YEAR), feed water salinity (SAL) in parts per million (ppm), and the cumulative capacity of desalination plants contracted in the respective region up to the date of the award year (CUM_CAP), in cubic meters per year. The two dummy variables are the type of feed water (sea or brackish water) (variable assumes a value of "1" for SWRO, "0" for BWRO) and the region of the plant (variable assumes a value of "1" for desalination plants located in the GCC region, "0" for plants located in southern Europe). The choice of these particular regressor variables came after a comprehensive review of relevant literature on desalination costing, which suggested that the mentioned variables were among the most likely to affect the capital cost of a desalination plant, its operational cost, or both [1,5,6,8,9,11,13,17]. The rationale behind selecting these particular variables as model regressors is as follows: plant capacity reflects directly on the size of equipment, construction size, etc. Hence, it will affect the EPC cost. RO technology maturity (and that of all auxiliary processes in the plant), reflected in the award year and cumulative capacity, is also expected to affect the cost of the EPC contract. Water salinity can affect the choice of equipment or pre-treatment processes, selected membrane type (low, medium or high pressure membranes), type of pumps, pressure vessels, tubing etc. All of these can affect the EPC cost. The same applies for feed water type (SW vs. BW). It is worth mentioning here that feed water type and salinity are known to influence the operational cost of desalination plants, via energy consumption [2,4,11,13]. Finally, the location of the plant (GCC region versus southern Europe in our study) was assumed to affect the EPC cost due to a number of logistical, political and technical reasons.

In order to verify the correlations between the six mentioned variables and the EPC contract cost and to build the quantitative model for this cost, a large desalination plant dataset was used. The dataset includes 950 data points of EPC cost of desalination plants (EPC) awarded during 1985–2013, which was obtained from web-based desalination plant inventory, desaldata.com by Global Water Intelligence (GWI) [22]. The Spatial boundaries of the dataset include the GCC countries