Investment and production costs of desalination plants by semi-empirical method

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Abstract - **Energy consumptions and costs of desalting systems are among the main parameters affecting the choice of certain desalting system and desalted water final cost. The paper describes a semi-empirical method for determining production and investment costs taking into account plant capacity, availability, energy price and consumption, plant capital cost, membrane service life and other process variables. This study concerns the different desalting processes of seawater, namely distillation multi-stage multi-flash, distillation multi-effect, vapour compression and the reverse osmosis. Results show that this method can give a good estimation of the investment and production costs for the concerned processes. Surely, this method can be useful especially in the maturation and the feasibility of any project in the field of desalination. So that most decisions of realization of any project can be taken in a relatively short time and therefore, costs of engineering can be reduced considerably.**

Keywords **-** Desalination, Process, Economical, Plant

1. Introduction

The need of pure water throughout the world is in constant increase, as well as its insufficiency due to limited stocks and pollution. With more than 70% of the earth's surface covered with water, our planet is a "Water Planet". It is the most common substance in our life and is fundamental to all things living. About 97.4% (1350 × 106 km^3) of the water on the earth's surface is salty water leaving less than 3% of water as freshwater. Two per cent of the freshwater is stored as snow, polar ice caps and glacier (27.5 × 106 km^3) while 0.6% is stored below ground, soil moisture and swamp water (8.3 × 106 km^3) [1].

The world has been a six fold increase in water usage since 1950 and the demand for freshwater is increasing twice as fast as population growth. The world population will increase from 6 billion in year 2000 to 8 billion in 25years [1]. The only conclusion that can be drawn from the above facts is that life to continue on earth will need to use the abundant salty water to produce freshwater supplies capable of meeting the increasing demand. Desalination in the last few decades has proven to be the method to

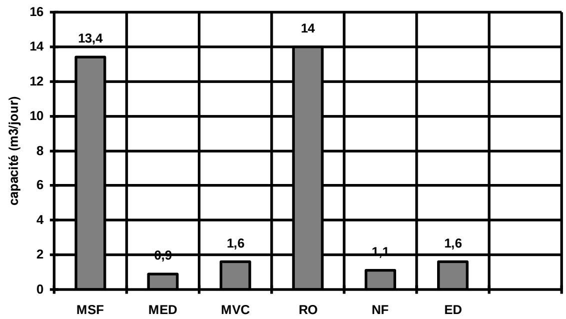

Figure 1. Plants of desalting brackish and seawater throughout the world, according process type [2].

Produce freshwater out of salty water with competitive cost compared to the cost of alternative sources. Because of that, different water desalting plants are used to generate large volumes of acceptable purity water, by processing brackish water, seawater and even waste water. The currently processes employed throughout the world are shown in figure 1.

The major task of desalination engineers is to choose the appropriate process with reduced energy consumption and specific investment cost, long service time and high availability with low amount of maintenance. The cost of producing a unit volume of product water has shown a continuous change over the last two decades. The method of estimation is applied to the plants of multi-stage flash (MSF-Once Through & Brine Recirculation), multi-effect distillation (MED-Horizontal Tubes & Vertical Tubes), vapor compression (VC-Mechanical & Thermal) and the reverse osmosis (RO).

2. Economical evaluation and study

This section develops and discusses a method that estimates investment and production costs for different type of processes. The cost of the produced water for each process is estimated including capital cost, energy cost, operation and maintenance cost, membrane replacement cost and filters replacement cost when used [3].

The data and the assumptions used in this section for the estimation of the capital investment and the production costs for each type of plant, are based on cost studies for specific site items for an approximate comparison plants concerning the costs *Cn* of item *n* and the units of the flow rates and energy rates, *Wn* and capital and erection costs for the main comparison of the year 1986 [4].

These assumptions can be resumed as follows:

• The major design parameters for various types of 1000 m^3/day desalting;

• For thermal desalting process plants, steam requirements are handled as a utility part of operating cost;

• Estimated cost of desalting seawater is based on plant life (about 30 years), production rates approximately 100%, capacity produced 2 × 1000 m^3/day, and stream factor (time that the plant is considered to be in service) nearly equals 85%.

2.1. Investment cost estimation

Total investment cost is defined as the sum of fixed capital cost and working capital cost; this includes the items listed below:

- Direct costs
- Indirect costs
- Contingencies
- Contractor's fee
- Start-up costs (a)

} Total Depreciable Capital Cost

- Land costs
- Site development

} Total Depreciable Capital Cost + Land costs + Site development } Fixed Capital Cost

- Start-up costs (b)
- Working capital

} Fixed Capital Cost + Start-up costs (b) + Working capital } Total Capital Cost

(a) Depreciable portion of start-up costs.
(b) Non-depreciable portion of start-up costs.

Figure 2. Different items of investment cost.

Greig and Wearmouth [4] consider that the total capitalized cost of the plant is to be the sum of capital cost, erection cost and the capitalized operational running costs (steam, electrical power, seawater, compressed air, chemicals and replacements materials). Therefore, the capitalized operational running cost for each type of plant is estimated with the method used for the approximate comparison for other sites according to the following equation:

$$C_t = C_c + C_e + C_r \quad (1)$$

$$C_{rn} = C_{an} \times I \quad (2)$$

$$C_{an} = 8760 \times W_n \times C_n \times A \quad (3)$$

$$I = 1 - \left(1 + \frac{i}{100}\right)^{-T} \Big/ \frac{i}{100} \quad (4)$$

$$C_{an} = 8760 \times W_n \times C_n \times A \times I \quad (5)$$

Ct: plant total capitalized cost; *Cc*: plant capital cost; *Ce*: plant erection cost; *Cr*: plant capitalized operational running cost; *Crn:* plant capitalized operational running cost of item *n* (steam or electrical power or seawater or compressed air or an individual chemical); *Can*: annual operating cost of the item *n*; *I*: represents worth factor; *i*: percentage interest rate; *T:* plant life time; *Wn*: the flow rate of energy rate of the item *n*; *Cn*: unit price of the item *n* for no specific site; *A*: stream factor of the plant.

2.2. Production cost estimation

An important task is to estimate the costs for operating the plant and/or facility, and for selling the products. Total production costs consist of manufacturing and general expenses. The manufacturing are also termed operating costs and is generally divided into direct and indirect portions. The time period that is defined for the basis of production costs is usually a year, although it can also be based on unit-of-product and 24 hours operating or daily basis and can be represented as the sum of the items shown in figure 3.

2.3. Investment cost calculation

Capital running costs for each type of plant is estimated according to Greig and Wearmouth [4]. Building and transport costs are not taken into account due to differences of desalting process types. Results are summarized in table 1.

2.4. Production cost calculation

The total production cost is the sum of direct and indirect costs. A semi-empirical method is used to estimate the production cost. It is based on observed results in different industries such as chemistry and petrochemical where data base has been built over a long period of time (15 to 20 years). Details of different calculation equations, according to Reidy [3] are listed in figure 4.

Results for each plant expressed as capital cost, energy cost, chemical cost and different other costs in \$/m^3/year are listed in table 2.

2.5. Discussion

The economic results are mainly based on the investment and production costs for each type of plant calculated using the results obtained by the method proposed by Greig and Wearmouth [4]. As it is known, we have used the results (data in our case) obtained from the approximate comparison for calculation the running costs, however, the values of the capital and erection costs proposed in the main comparison are taken as data for our case. Justifying this choice by the importance given in our opinion to the running costs which may vary considerably from one country to another, like for example the energy and labour costs, which could represent a major and

- *Prod. Cost*
  - *Direct Cost*
    - Raw materials
    - Catalysts and solvents
    - Utilities
    - Maintenance supplies
    - Maintenance labor & supervision
    - Operating supplies
    - Operating labor
    - Quality control
    - Royalties
  - *Indirect Cost*
    - *Fixed Cost*
      - Depreciation
      - Property taxes
      - Insurance
      - Rent
    - *Plant Overhead Cost*
      - Indirect labour, supervision
      - Fringe benefits
      - Medical facilities
      - Fire, safety, security
      - Waste treatment facilities
      - Recreation facilities
      - Salvage services, control laboratories
      - Shipping & receiving facilities
      - Storage & maintenances facilities
  - *General Cost*
    - *Administration Cost*
      - Executive
      - Clerical
      - Engineering
      - Legal
      - Communications
    - *Marketing cost*
      - Sales expenses
      - Advertising
      - Product distribution
      - Sales service
    - Financing interest
    - Research and developments

Figure 3. Different items of total production cost.

important part of the plant's capital cost during its whole life. The cost structure keeps, in the case of production cost, almost the same pattern and the same share of capital, energy, chemicals and furniture and others costs, which are in the range of those found in literatures and publications having potentially an expected errors. This can be in part explained, in the case of the investment cost, that its composition in figure 2 is reduced to the method [4] where assumptions are made to neglect some extra expense involved in constructing service facilities, storage facilities, loading terminals (this is very true for desalting plant), transporting facilities, and an other necessary utilities at a completely undeveloped site. The fixed capital investment for a new plant located at an undeveloped site may be much greater than that for an equivalent plant constructed as an addition or expansion to an existing plant. On the

Table 1. Investment costs of different desalting seawater plants.

Plant	MSF-OT	MSF-BR	MED-VT	MED-HT	MVC	TVC	RO
$/m^3/year	0.71	0.75	0.91	0.85	0.39	0.65	0.93

Table 2. Production costs of different desalting seawater plants.

Plant	Production cost (%)				Prod. Cost ($/m^3/)
	Capital	Energy	Chem. Fournît.	Other	
MSF (OT)	15	37	3	45	1.20
MSF (BR)	21	30	2	47	1.34
MED (HT)	18	29	13	40	1.38
MED (VT)	28	22	16	34	1.45
MVC	21	7	4	68	1.02
TVC	17	34	2	47	1.15
RO	12	3	34	51	1.81

other hand, and in the case of the production cost, the multiplying factor for each item in the composition of production cost (figure 4) are not determined in the field of the desalination that is why errors in the estimation can be expected to be important in some cases.

It is to be noted that we can apply the same data, as in the production cost, for estimating the investment cost using the composition of the different items shown in figure 2. But the problem is that for the periods start up costs (1 and 2) and the working capital cost in the field of desalination are unknown period for us. So for the rest, we can consider that this can be in a great similitude to any other plant in the field of chemistry.

Direct cost
Raw material=Σ(vol. incoming streams)×unit Price Catalyst-solvents=Σ(vol.income.streams)×unit Price Utilities: Electricity= Power consumed × Rate Fuel= Fuel consumed × Rate Stream = Stream consumed × Rate Operating lab= Operat.labor [(a)] (hr/kg) × (rate, $/hr) Operating supervision = 0.20 × Operating labor cost Quality control = 0.20 × Operating labor cost Maintenance labor = 0.027 × fixed capital Cost Maintenance labor = 0.018 × fixed capital Cost
Indirect costs *Fixed Cost* Depreciation=(1-fs)(c) × deprec.capit.cost /plant life Property taxes = 0.02 × fixed capital cost Insurance = 0.01 × fixed capital cost *Plant overhead costs* Fringe Benefits=0.22×(direct labor & supervis.)(e) Overhead = 0.5 × (direct labor & supervision)(e) *General costs* Administrative = 0.045 × production cost Commercial = 0.135 × production cost Financing= i × (fixed capital cost + working capital) Research = 0.0575× production cost
Production cost = ∑ items above

(a) expressed by modified Wessel equation;
(b) fixed capital cost = depreciable capital cost + land development cost;
(c) salvage fraction of original cost (fs = 0.1);
(d) working capital cost = 0.20 × (fixed capital cost);
(e) direct labor includes both operating and maintenance labor.

Figure 4. Direct and indirect calculation costs.

3. Conclusion and recommendations

We can say that the results found are interesting and encouraging mainly when some data of the plant are not available before the detailed engineering design stage. Such methods provide good order of magnitude estimates for early budgetary purposes. They can be taken as an introduction for the development of new techniques where the number of the many factors influencing the estimation of different costs may be reduced to a minimum number of variables. Consequently and in the case of the production cost, the different items are expressed in relationship with basically fixed capital cost, labour cost and production cost. For future purpose, it is suggested that a semi-empirical method for the estimation of the investment cost will be developed with an adequate number of items which will depend only for example on capital erection, and investment costs just like in the case of the production cost.

And why not creating a data bank concerning the different items of the costs and through a sufficient and necessary period of time adjust the factors used in the production cost estimation to the field of desalination, and proposing an interesting model in the same way for the investment cost estimation.

At the end we hope that the developed methods will completely be empirical so when applying such methods in other countries will not require local rates and neither specific site parameters. Such model will meet at least the needs in the stage of the maturation and the feasibility of any project not more?

4. References

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