PROCESS OPTIMIZATION - COST CRITERIA

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Contents

1. Introduction

For desalination systems, cost trade-offs can be found between the cost of energy consumed by the process and the capital cost of the plant. For example, in the multistage flash (MSF) process, energy use can be reduced by the addition of more stages and heat transfer surface area. That is, the increase in surface area (increased performance ratio) results in an increase in capital cost, but the increased surface area results in lower energy use (cost). When these costs for capital and operation are added and plotted, an optimum point often results where the total water costs are at a minimum. To determine where this point results is accomplished by performing a cost optimization study.

The methodology used to determine the optimum is different between single- and dual-purpose plant arrangements. This is because, for the single-purpose plant, the energy cost is constant in all studies, whereas, for the dual-purpose plant, the energy cost will vary with each case studied.

2. Process Design and Cost Criteria

2.1. General

The process optimization study begins with defining the process and cost criteria. The process requirements are the flows, pressures, temperatures, etc., that are to be attained during normal plant operation. The flow rates are developed based on the plant capacity, type of process, and design recovery. The pressure requirements are a result of either the process design or equipment requirements. The water quality requirements are those established by the water to be treated and the final product water quality goals set for the project. Each of these items are discussed below. The design criterion then, is the technical data established for determining the process requirements.

The first step is to develop the design criteria. This document is then used for carrying out the preliminary and final designs. The design criteria normally includes the following information.

(a) Plant capacity.
(b) Number of trains or units comprising the total plant.
(c) Feedwater quality.
(d) Pre-treatment requirements.
(e) Post-treatment requirements.
(f) Materials of construction.
(g) Operation and maintenance requirements.
(h) Heat transfer coefficients.
(i) Pump types and sizes.
(j) Cleaning requirements.
(k) Product storage requirements.
(l) Emergency generator requirements.

2.2. Process Design Criteria

2.2.1. Plant Capacity

The plant capacity is of course the amount of water to be produced by the plant. This capacity in consort with the plant recovery will set the major process flow requirements.

2.2.2. Number of Units

The number of units used will be set by the plant operating flexibility desired, the maximum practical unit size, and the plant reliability requirements. The operating flexibility increases with the number of units provided. However, increasing the number of units increases the complexity of the operation and maintenance and can have a detrimental effect on the plant reliability and costs. Thus, the choice of the number of units must keep these parameters in mind. In addition, as the number of units increases, the cost advantage offered by using larger equipment sizes is eroded.

2.2.3. Feedwater Quality

The quality of the feed water to be treated will determine the pre-treatment requirements and materials of construction.

In effect then, the water quality to be treated becomes a critical item in the evaluation of the process.

2.2.4. Pre-treatment Requirements

The pre-treatment requirements for MSF processes are minimal. Typically, the pre-treatment will include one of the following:

(a) Acid Use. Acid can be used to minimize scaling of the tube surfaces. If acid is used for pretreatment, the pre-treatment equipment will be composed of a decarbonator to remove the carbon dioxide gas released from the addition of acid. A deaerator is normally also installed to remove dissolved oxygen. This is done to minimize the corrosive effects of oxygen. A small amount of oxygen scavenger is then added to ensure that all oxygen has been removed before the feed stream enters the unit.
(b) Polymer Use. A polymer chemical, as with acid, can be used to minimize scaling of the tubing surfaces. If a polymer is used, no degassifier is required. However, oxygen must still be removed. Thus, a deaerator will be required. As with the acid treatment system, an oxygen scavenger is also introduced into the feed stream.

2.2.5. Finished Water Quality

The finished water quality required will be determined by the water quality goals set for the project. Normally, these will be set in accordance with the Safe Drinking Water Standards (SDWA) for work in the US or World Health Organization (WHO) standards for work in Europe or the Middle East. Both these standards normally use a total dissolved solids (TDS) content in the finished water of 500 mg l^{-1}. Thus, the finished water quality will be dependent upon the quality set by the design criteria.

2.2.6. Post-treatment Requirements

Post-treatment requirements will be set by the condition of the product water as it exits the process. For all desalting processes the water produced by the process will normally be quite corrosive. If this water is not post-treated to reduce its corrosiveness, severe corrosion will occur in the distribution system.

2.2.7. Materials of Construction

Tables 1 and 2 show the requirements for the materials of construction of the processes and auxiliary equipment. The materials of construction are chosen for their durability and cost. The waters to be treated in desalting systems are normally corrosive. This is particularly true of the product water and brine or concentrate streams. Product water corrosivity results because the product waters are nearly devoid of mineral content. The brine streams, on the other hand, are high in mineral content and are corrosive due in large part to the high chloride concentrations. Thus, the materials chosen for handling these water streams must be of non-metallic materials or of highly alloyed materials such as stainless steel. The final choice of material will normally be dependent upon the operating pressure. The advantage of the non-metallic materials is their resistance to corrosion from seawater, product water, and brine streams. Their disadvantage is their poor strength characteristics. Therefore, these materials are normally relegated to low-pressure applications. In the cases where high pressures are experienced (e.g. 100 psig or more) stainless steel or copper-based alloy materials offer resistance to corrosion while giving higher strength characteristics. The use of these materials has the distinct disadvantage of extremely high cost. The recommended materials of construction are given in Table 1.

Equipment	**Materials**
Pumping equipment	
Supply, recirculation, or brine	Casing - bronze or Ni Resist cast iron Shaft - stainless steel Impeller - stainless steel
Product or condensate	Casing - stainless steel Shaft - stainless steel
Piping and valves	
Seawater and brine	
Low pressure[a]	Polyvinyl chloride or reinforced thermosetting resin
High pressure[b]	Carbon steel lined with copper nickel or stainless steel
Product	
Low pressure[a]	Polyvinyl chloride or reinforced thermosetting resin
High pressure[b]	Stainless steel or steel lined with copper nickel
Evaporators	
Shells	Carbon steel, high temperature stages lined with stainless steel
Tubing	
Temperature above 180°F	Copper nickel, 70/30
Temperature below 180°F	Copper nickel, 90/10

[a] Pressure below 100 psig.
[b] Pressure above 100 psig.

Table 1. MSF Materials of Construction.

2.3. Cost Criteria

2.3.1 Direct Capital Cost Basis

Direct capital costs include the following.

(a) Process equipment.
(b) Piping and valves.
(c) Instrumentation and controls.
(d) Chemical treatment equipment.
(e) Feedwater supply.
(f) Interconnecting piping.
(g) Auxiliary equipment.
(h) Installation labor.

(i) Installation materials.

Direct capital costs normally include installation labor so that the total direct cost is all equipment and materials installed at the site.

2.3.2. Indirect Capital Cost Basis

Once the installed construction costs (direct costs) have been determined, it is necessary to estimate the indirect costs. Indirect costs are calculated as a percentage of the total direct costs and include the following.

(a) Freight, insurance and taxes.
(b) Owner's costs (i.e. engineering and legal).
(c) Contractor's overhead and profit.
(d) Contingency.

The owner's costs depend upon a number of factors and therefore can vary widely. For example, the engineering fees can vary from 4 per cent or less to 12 per cent or more of the direct costs depending on whether detailed engineering is performed or not. The inclusion of other costs such as bond issuance where required, working capital, and interest during construction will also result in presenting very different costs for the indirects. Each of these are discussed in the following paragraphs.

(a) Bond costs. The cost of bond issuance includes the following: (i) bond finance underwriting - this will normally be about 10 per cent of the direct capital costs, (ii) bond legal and issuance printing costs - this is normally about 5 per cent of the direct capital cost, and (iii) bond insurance - this cost is normally 1 per cent of the bond debt. Thus, if bonding is required it can add about 16 per cent to the project costs.
(b) Working capital. Working capital is the term used for the funds required during construction and initial operation of the plant (that is, before income from the project is available). This item is usually taken as 50-60 per cent of the first years operating and maintenance costs. Therefore, the working capital can amount to about 10 per cent of the direct costs.
(c) Interest During Construction. Interest during construction is self-explanatory. These funds will come due during the design and construction period prior to plant operation. It is calculated from the period of design and construction at the loan's interest rate.

Thus, the indirect costs can vary a considerable amount. There are a multitude of methods used to prepare a cost estimate. Over the years, no method has been universally accepted for the desalting industry. The preparation of the direct (construction) costs are much the same but the methods used to calculate indirect costs vary considerably. For this presentation the costs for working capital, interest during construction, and bond costs are not included. However, the following indirect cost method is used.

(a) Freight, insurance and taxes(or import duties) - this cost is taken as 5 per cent for domestic shipping and 10 per cent for international shipping. Import duties can be as high as 10-15 per cent of their value, depending on the material shipped and the port of entry.

(b) Contractors' overheads and profit. This cost relates to direct field costs such as labor, contractors engineering, site supervision, and will vary with the contract value, as shown in Figure 1. The elements in construction overheads and profit are as follows.

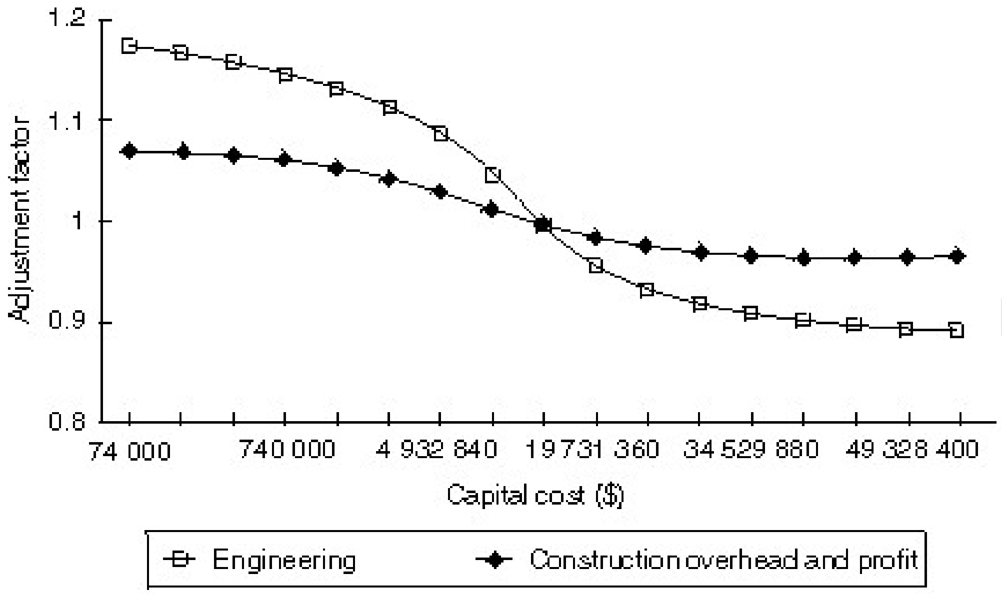

Figure 1. Indirect costs - adjustment factors.

1. Fringe benefits. The fringe benefits are of course, the contractors' contribution to health and welfare, vacations, holidays, sick time, and retirement funds. For some locations funds must also be added for travel and living costs.
2. Labor burden. These funds are the contractors' contributions to the Federal Social Security, unemployment insurance, state unemployment insurance, and workmens' compensation. These will necessarily be different for overseas locations.
3. Field supervision. This cost includes salaries, fringe benefits, and payroll burdens for supervisory and field personnel. For some locations travel and living costs must also be sometimes added.
4. Temporary facilities. These costs include buildings, roads, parking, utilities, work areas, scaffolding, rigging, fencing, and other such miscellaneous costs.
5. Construction equipment. This cost includes equipment rental plus freight to and from the job site.
6. Small tools. These costs are for expendable construction tools usually valued at $1500 or less.
7. Miscellaneous field costs. These costs include job cleaning, costs for security, equipment repairs, medical services, welder qualification and testing, consumable supplies, warehousing, vendor services, and job insurance.
8. Contractors' profit. The contractors' profit will range from 4 to 7 per cent of the direct costs. For this presentation a profit of 4 per cent was used.

A typical percentage used for contractors' overheads and profit as a function of total direct costs is 17.8 per cent. However, this percentage will vary with the dollar magnitude of the direct costs. The variation is shown in Figure 1. The equation used to determine the percentage is

$$C_{oh} = DC \times (0.178) \times F_c \quad (1)$$

where C_{oh} is the construction overheads ($), DC is the direct capital costs ($), and F_c is the factor (dimensionless).

The breakdown of these costs is given in Table 2.

Cost item	**Per cent of direct cost**
Fringe benefits	2.6
Labor burden	4.0
Field supervision	3.2
Temporary facilities	1.6
Construction equipment	2.6
Small tools	0.6
Contractors profit	3.2
Total construction overheads	17.8

Table 2. Construction overheads - cost breakdown.

(c) Engineering costs. Engineering costs will vary widely between projects due to project complexity, unusual design problems, scheduling, type of contract (e.g. performance specification or detailed design), and others. These costs are also normally related to the total direct costs. For a performance-type specification where little or no detailed design work is performed, the engineering cost can be as low as 4 per cent or lower and does not vary with the total direct cost. This is because, for this type of project, the engineering work is not a function of the amount of work to be accomplished. However, this cost must be added to the detailed engineering cost discussed below.

For detailed design-type projects, the engineering costs vary with the amount of work to be accomplished as shown in Figure 1. To obtain a better understanding of how this cost is developed, Table 3 breaks down the make-up of the engineering effort for a complete design type project.

Cost item	**Per cent of direct costs**
Project engineering	1.4
Process engineering	0.4
Design drafting	2.6
Procurement	0.3
Home office during construction	0.1
Engineering total direct labor (total)	4.8
Office indirects and overheads	6.2
Total engineering cost	11.0

Table 3. Engineering cost breakdown - detailed design.

These costs also vary with the dollar magnitude of the project as shown in Figure 1.

The expression used to calculate the actual percentage is as follows:

$$C_{en} = DC \times (0.11) \times F_e \qquad (2)$$

where C_{en} is the engineering cost (%), DC is the direct cost ($), and F_e is the factor from curve (dimensionless).

For the performance-type project, where little or no detailed design work is to be done, the engineering costs as a function of the total direct costs are much less. These costs break down as shown in Table 4.

Cost item	**Per cent of direct cost**
Project engineering	0.5
Process engineering	0.4
Drafting	0.7
Home office during construction	0.1
Engineering total direct labor	1.7
Office indirects and overheads	2.2
Total engineering cost	3.9

Table 4. Engineering cost breakdown - performance specification.

This cost will not change with the magnitude of the contract. However, it can be affected by project scheduling, that is for projects conducted on a fast track, the cost of the engineering services will necessarily increase. The drawback to the performance-type contract is that the detailed design work will still have to be accomplished. Thus, for a project done with a performance-type specification, the detailed engineering costs are added to those for preparation of the performance specification. For the purpose of presenting costs for this discussion, the detailed engineering approach is assumed.

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