CASE STUDY ON PLANNING A LARGE SCALE MULTISTAGE FLASH DESALINATION PLANT

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Contents

Summary

This chapter presents the design parameters and the construction characteristics that are recommended, for the proposed large scale multistage flash desalination plant.

A comparison between the data that are presented in this chapter and those that are used for Alshuweihat plant shows that how the recommended data for the proposed plant that are concluded based on the knowledge and experience of operation and maintenance of the existing plants are feasible and close to reality.

The case study has performed calculations for plants with 18, 20, and 22 stages, all for plants with single unit output of 75700 m³ per day and weir loads of 1100, 1200, and 1300 ton per meter.hour. The brine velocities 2.0, 2.2, and 2.4 meter pr second were considered in the calculations

1. Introduction

Most of the Arabian Gulf States lie in the water stress zone of the world, depending to a great extent for their fresh water supply on desalination plants installed in this region at a huge cost. The majority of these plants utilize thermal energy from fossil fuels to convert part of the seawater feed supply to the desalination plants into potable water, for household and other applications. The other part with a greater concentration of salt is discharged to the sea. More than 50 per cent of the desalination world capacity has been located and operative in this area for the past few decades; indeed some of the plants are the largest in the world (Figure 1).

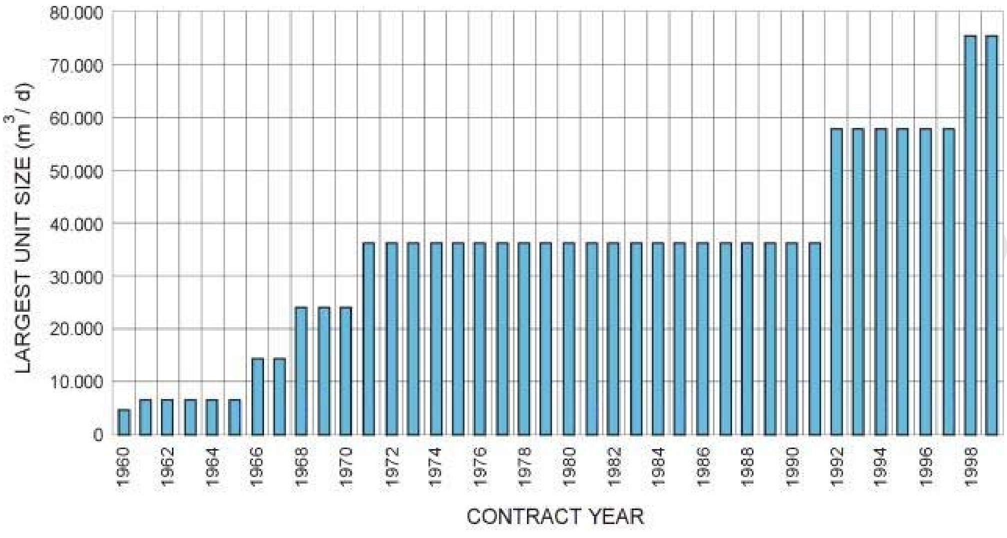

Figure 1. Development of multistage flash train sizes.

With the ever-increasing demand for water, there is a need to exploit the cumulative experience gained over a number of years in the desalination technology to plan and design still larger plants, thus gaining from the economy of scaling.

Such an endeavor should, of course, draw maximum benefit from the knowledge and experience of operation and maintenance of the existing plants.

This article aims to achieve the above goal by presenting a case study in planning such a project in which the experience of several multistage flash (MSF) working plants in the capacity range 3-12.7 MGD (Table 4) is fully utilized. The case study suggests in particular a consideration of the following features:

- Two alternative MSF processes, one with the brine recirculation which is in operation at present, and the other once through with its inherent benefits and likely improvement costwise.
- Elimination of the cooling water recycle system.
- Large capacity pumps, horizontal vs vertical.
- More realistic fouling factors in order to avoid overdesigning the heat transfer surface and thus reducing capital cost.
- Number of flash stages, velocity inside tubes and weir load in reasonable ranges as dictated by experience.
- Proper plant layout with respect to intake, discharges, power and steam supply, elevation etc.

- Employing advanced control strategies and full automation.
- Proper choice of the materials of construction.
- Above all, techno-economically cost optimization.

Lastly, the case study aims to address the problem of environmental impact of desalination in view of its discharges back to the sea and their effect on marine life, as well as air pollution.

1.1. Local Conditions with Basic Data

As the seawater is taken from the intake, which is also used for the existing plants, all the local environmental conditions specified for Plant 7 (Table 4) can also be used for the new facility.

Seawater temperatures at Plants 6 and 7 are shown in Figure 2. Design seawater temperature is taken, as 32°C, but the plant must also be capable of operation at higher seawater temperatures with the same design outputs; in this case higher energy consumption will be accepted.

Total dissolved solids (TDS) of the seawater at Plants 6 and 7 can be obtained from Figure 3.

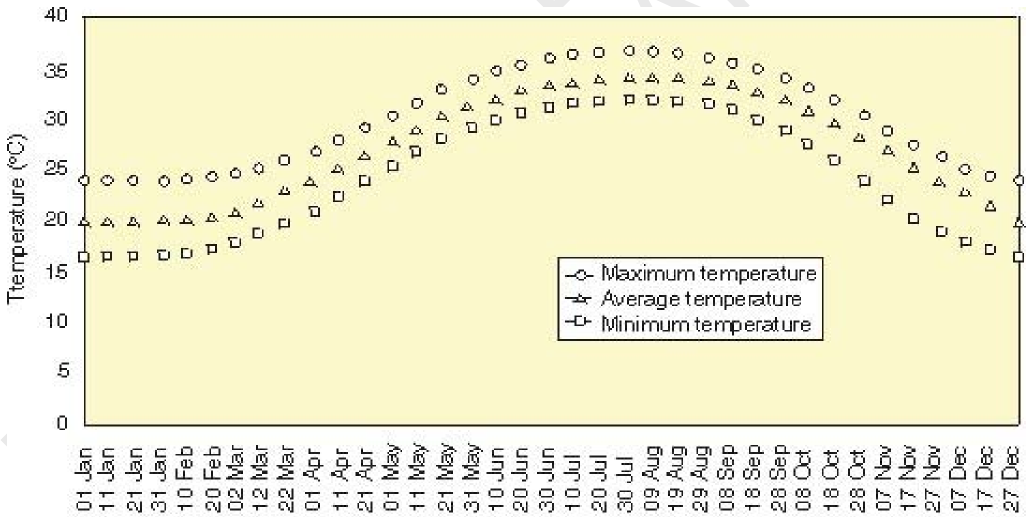

Figure 2. Typical seawater temperatures at Plants 6 and 7 intake.

The design parameter for the case study under consideration should be the seawater concentration 45 000 ppm, although the increased intake capacity led to a decreasing TDS content after the start of operation of Plant 7 (highest TDS measured during operation of Plant 7 is 44 112 ppm).

All other local conditions can be taken from Table 1.

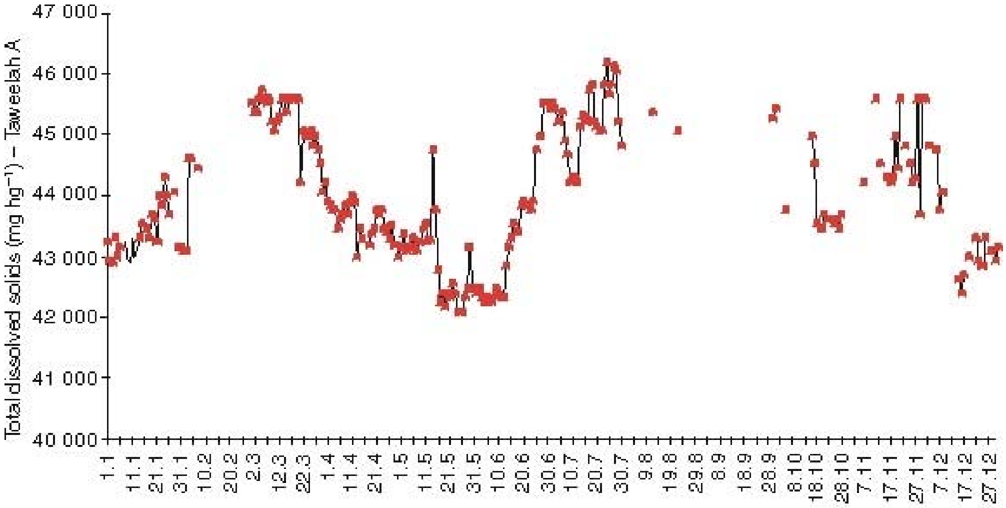

Figure 3. Typical total dissolved solids content of seawater at Plants 6 and 7 intake.

1.2. Partial Load

The study team investigated the operation and maintenance of all the larger desalination units installed in Plant 1, Plants 2, 3, 4 and 5, and Plants 6 and 7. It was found that only in exceptional cases and only if unexpected situations occurred were plants operated in partial load mode.

On the contrary, it can be said that all plants should operate at full load whenever possible and a considerable effort has been made to find solutions for an increase of plant capacity above design capacity, for example, by increasing top brine temperature (TBT), in order to satisfy the ever increasing water demand.

It is, therefore, assumed that the situation will not change in the future.

If the drinking water network is taken as global, and if there is any need to reduce capacity, which can only occur in winter, then individual units can be taken out of operation for maintenance and annual overhaul. This is subject to provision of a good maintenance management.

If it is decided to design the plant for full load operation only, then more flexibility exists regarding the design of interstage orifices, and the plant can be designed for operation without any cooling water system, by slightly increasing the vapor release area in the low-temperature stages.

It is proposed that the new plant be designed for mainly full load operation. For reasons of optimization, it must also be possible to operate the plant at partial load, e.g. 75 per cent, if this is possible without major financial efforts.

The tenderer should therefore be requested to offer the plant for full load operation only and to indicate additional cost for partial load operation.

Elevation	**Sea level**
Distance from the sea	200 m
Maximum ambient temperature (in the shade) and design air inlet temperature for air conditioning and ventilation	52°C
Wet bulb temperature at 52°C	31°C
Minimum ambient temperature	18°C
Design ambient temperature for outdoor installations (in the shade)	52°C
Maximum metal temperature in the sun	85°C
Minimum barometric pressure	970 mbar
Maximum barometric pressure	1030 mbar
Maximum ambient humidity	100%
Maximum design wind velocity	160 km h^{-1}
Average yearly rainfall	50 mm (may reach 200 mm some years)
Maximum seawater temperature	35°C
Minimum seawater temperature	18°C
Dust concentration in the air	1-20 mg m^{-3}
Dust concentration in air under sandstorm conditions	Approx. 100 g m^{-3}

Table 1. Local conditions at Plant 6 extension site.

2. Process Aspects

Thermodynamic calculations were performed in order to obtain design data for the various parameters of investment cost. All calculations were performed stage by stage with a very detailed steady-state computer program, which was developed over the years and reflects the experience obtained with the design and operation of several MSF plants. For the present study, this program was modified so that it is now possible to design almost exactly Plant 7, for comparison reasons. Therefore, the calculation of the heat transfer coefficients has been modified a little by the introduction of a correction factor as well as the calculation of the vapor release and demister areas. The main equations for the calculation such as waterside and vapor-side heat transfer coefficients, non-equilibrium losses, physical properties etc. can be obtained from the Appendices. The basic data used for the calculations are given in Table 2.

The following descriptions and explanations with regard to the process and to the design have been introduced in order to state limits, which should not be exceeded. As too many parameters influence the design of the plant, but only the investment and/or water costs are of interest in the end, a series of cost calculations were performed with the different process and design parameters as the basis, in order to find the optimum plant. As shown later, the cost calculations were performed as realistically as possible, but the main reason for doing so was to find the differences between the various designs, rather than the absolute price. The calculations also show very clearly the possible reductions for plants of larger sizes. Therefore, it should be considered that the stated plant prices do not reflect the expected absolute price.

Distillate flow	t d^{-1}	75 700
Economy	kJ kg^{-1}	290.75
Number of stages (number of heat rejection stages)		18 (3); 20 (3); 22 (3)
TDS of blowdown	ppm	63.800
Flash interval feedwater	°C	0.1
Design temperature seawater	°C	32
Design TDS of seawater	ppm	45.000
HCO_3 content of seawater	ppm	133
Fouling factor: Rejection section Recovery section Brine heater	M^2 K W^{-1}	 0.00018 0.000118 0.000118
Non-condensate gas removal		Yes
Outside diameter of tubes	mm	38-59
Wall thickness of tubes	mm	0.5
Material of tubes		Titanium
Material of tubes (alternatives)		CuNi/Al-brass
Seawater velocity within the tubes	M s^{-1}	2.0; 2.2; 2.4
Weir load	t m^{-1} h^{-1}	1100; 1200; 1300
Brine level	M	0.5

Table 2. Basic data for calculations.

2.1. Once- through Plant

The once-through process offers a number of advantages in comparison to the recirculation process. For this reason, some recommendations are presented below. The potential improvements lead to a preference for once-through plants. In this connection, it must be pointed out that the largest once-through plant to date has a capacity of 10 000 m^3 d^{-1}. However, the arguments in favor of the once-through design are not related to a particular size. A number of small once-through plants that were commissioned in the 1970s are still in operation.

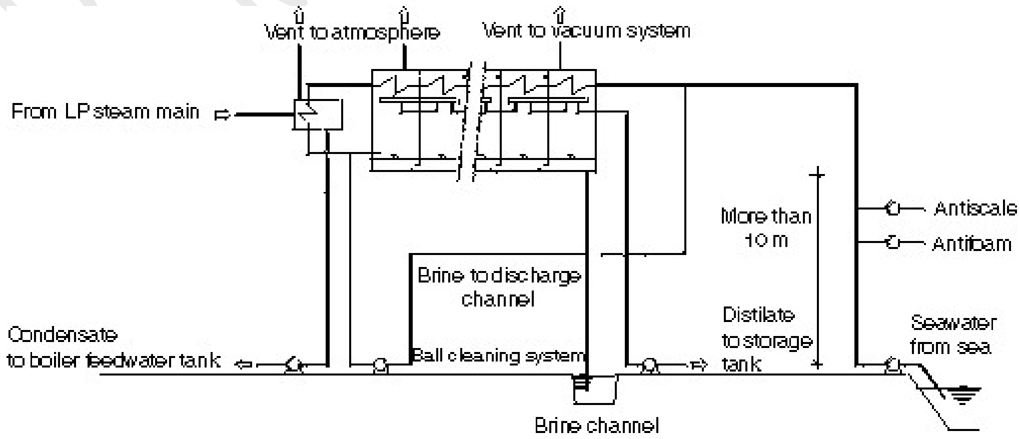

Figure 4. Flow scheme of a once-through multistage flash plant.

The recommendations are to be understood as an interim approach for further consideration; a more detailed investigation of the individual concepts would have to follow. The aim is to identify features for a future plant that will offer considerable advantages over any conventional solution. These advantages are intended to have an effect on both the investment cost and the operating cost as well as on the availability and lifetime of the plant.

2.1.1. Reduced Concentration Factor, Reduced Boiling Point Elevation

The first MSF plants were once-through plants, which were later replaced by the recirculation process for larger capacities. The sole reason for this was the high consumption of chemicals, used for preventing scale formation on heat exchanger tubes in once-through plants, which operated at a maximum top brine temperature of approximately 90°C. The high dosing rates at that time, and the high prices for the antiscale agents, led to high operating costs with a corresponding negative influence on MSF seawater desalination. The high antiscalant consumption resulted from the larger makeup quantity, which in low-temperature, once-through plants with normal seawater could be up to six times as high as in the recirculation plants developed later, although the specific dosing rate was lower for the once-through process.

Today the situation has changed considerably. Firstly, higher temperatures are achieved, reducing the make-up (i.e. seawater) flow in once-through plants. Secondly, the large plants are installed in the Middle East, where the salt content is high, so that the make-up flow is much higher in recirculation plants. Moreover - and this is the most significant aspect in this context - today's antiscale agents are not only cheaper than in previous years, but also much more effective. Consequently, dosing rates of only a few ppm suffice. In conclusion, it can be stated that there is certainly no reason to choose the recirculation process on account of the chemical consumption.

As the concentration factor in once-through plants is much lower than in the recirculation plants, the boiling point elevation is accordingly lower, which is a relevant aspect for the calculation of the heat exchange surface areas. For an average salt content in the evaporator at 75°C and salinities of e.g. 50 000 ppm in a once-through plant and 60 000 ppm in a recirculation plant, the values for the boiling point elevation are 0.68 K and 0.84 K respectively. Since the heat exchanger area is proportional to the log mean temperature difference (being about 3.5 K for plants of the usual configuration and a performance ratio (PR) of 8), the difference in boiling point elevation of 0.16 K permits a reduction in heat transfer area of approx. $0.16/3.5 \times 100 = 4.6$ per cent. For a total installed heat exchanger surface of 125 000 m^2 (for a plant similar to Plant 7) and a specific price of the tubing estimated to be \$350 per m^2, one can obtain cost reductions per plant of $125\,000 \times 0.046 \times 350 =$ \$2 012 000, or for six units of \$12 072 000. This calculation is very simple, but it illustrates inherent potential in the once-through process.

2.1.2. Reduced Number of Plant Components

One of the main advantages of the once-through process is the reduced complexity of the installation. No brine and cooling water recirculation pumps are needed; therefore, the seawater supply pump is designed as the main supply pump of the evaporation plant. The flow is in the order of a "conventional" recirculation pump. The delivery head is one lower than that of a recirculation pump, since the pump need not suck the water from the last vacuum stage. Consequently, the number of other components is also reduced, for example, the piping and the associated equipment, such as control equipment and valves.

2.1.3. Deaeration in Stage One, Main Venting to Environment

If the once-through concept is rigorously applied with the primary goal of simplifying the installation, it is not necessary to deaerate the seawater before entry to the condensers. Consequently, the gases dissolved in the seawater (oxygen, nitrogen) are released in the first evaporator stage. At first glance, this may appear to be a disadvantage, since high oxygen content could lead to increased corrosion. However, as shown in another study, the materials used can tolerate the expected oxygen content (Section 4).

Another advantage, leading to a high reduction in the ejector motive steam demand, results from the higher pressure maintained in the first stage. In that case, practically all the oxygen, and the nitrogen, and the major part of the carbon dioxide can be vented directly to the atmosphere. A compression of probably more than 70 per cent of the non-condensable gases to atmospheric pressure - as is usual in recirculation plants - is not necessary. Since it is also recommended that the top brine temperature is maintained near a constant value of, for example 112°C, and that partial loads be achieved mainly through a reduction of the seawater flow, new operation procedures must be considered for start-up of the distiller.

In addition, it can be shown that the vent of stage 1 can also be employed as motive steam for an ejector system. The other stages of the system can then possibly be equipped with water jet ejectors. As a consequence, a connection of the evaporator system to the medium-pressure steam supply line may even be abandoned.

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