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Steam driven large multi effect MVC (SD MVC) desalination process for lower energy consumption and desalination costs

A. Ophir*, A. Gendel

IDE Technologies Ltd., POB 5016, Hasharon Industrial Park, Hametechet Street, Kadima 60920, Israel
Tel. +972 (9) 892 9740; Fax +972 (9) 892-9715; email: OphirA@ide.co.il

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Abstract

It has been published and demonstrated in operating plants that the low-temperature multi effect desalination process (LT MED) when operated on turbine backpressure steam requires minimal energy consumption yielding specific desalination energy costs approaching values of optimal RO energy costs. However due to variations in electricity demand, the operation of large steam turbines at base load is in most cases impractical. As a result, in order to allow variations in electricity supply and full capacity of the desalination extraction, steam extracted from the turbines at higher pressures than the back pressure is commonly used. The extraction steam pressure of these turbines is in the range of 1.5–4.5 barg. (Typically as required for process steam at refineries and for MSF desalination plants). The LT MED process when utilizing such extraction steam incorporates thermo compressors (steam ejectors) in order to take advantage of the excessive extraction steam pressure, thereby increasing the economy ratio of the MED (decreasing energy consumption). Thermo compressors (ejectors) as a rule have a relatively low adiabatic efficiency, thus limiting the potential of the MED to increase the economy ratio even more. In this paper an approach of using a novel large centrifugal compressor driven by an auxiliary steam turbine utilizing the extraction steam is incorporated instead of the thermo compressor for large LT MED plants. The centrifugal compressor and auxiliary turbine having a much higher efficiency than the thermo compressor results in significant energy savings, thus lowering the desalination costs. This paper will also describe the thermodynamic advantages, the specific investment and desalination costs comparison, and the resulting desalination cost reduction potential of the steam-driven multi effect MVC process.

Keywords: Desalination; Multiple-effect distillation; Steam turbine; Mechanical vapor compression

*Corresponding author.

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1. Introduction

It has already been published and demonstrated in operating plants that the low-temperature multi effect desalination process (LT MED), when operated on turbine back pressure steam, requires minimal energy consumption yielding specific desalination energy costs approaching values of optimal RO energy costs. However, the constraint of effectively utilizing the LT MED is that it requires operating the back pressure turbine at base load (full capacity).

Due to variations in electricity demand, the operation of large steam turbines at base load is, in most cases, impractical. As a result, in order to allow variations in electricity supply and full capacity of the desalination, extraction steam turbines are commonly selected. The extraction steam pressure of these turbines is in the range of 1.5–4.5 barg (typically as required for process steam at refineries and for MSF desalination plants).

The LT MED process when utilizing such extraction steam incorporates thermo compressors (steam ejectors) in order to take advantage of the excessive extraction steam pressure, thereby increasing the economy ratio of the MED (decreasing energy consumption). Thermo-compressors (ejectors) as a rule have a relatively low adiabatic efficiency, due the irreversible mixing of vapor streams having two different pressures, thus limiting the potential of the MED to increase the economy ratio even more.

Due to the recent increase in energy cost, replacing the conventional inefficient ejector has been considered by using a novel, large centrifugal compressor driven directly by an auxiliary steam turbine utilizing the extraction steam. The centrifugal compressor and auxiliary turbine have a much higher efficiency than the thermo-compressor, resulting in significant energy savings, thus lowering the desalination costs.

2. Brief description of the turbo-compressor MED system

MED plants driven by ejectors utilizing extraction steam (Fig. 1) are a major item in our line of products. Many of these plants have been installed and are operating throughout the world. However, due to the recent increase in the energy cost, it has become apparent that a more efficient tool than the ejector should be employed in order to save energy and reduce the manufacturing cost of the desalinated water. It seems that the best tool to replace the ejector, while utilizing extraction steam, is a turbine coupled to a compressor, each of which can reach efficiencies above 70%. Our company has developed and acquired extensive experience with large volumetric flow compressors, which are of a lightweight, radial blade centrifugal type, in our vapor compression desalination and refrigeration plants. The maximum volumetric flow that can be obtained so far per compressor is 320 m^3/s. After a short investigation it was found that turbines operating between extraction steam pressure and discharging steam to 0.35 ata are readily available in the free market, so the road for implementing the concept is now paved.

Fig. 2 depicts the system of a turbo-compressor incorporated in an MED plant. The turbine and the compressor are mounted on a single shaft. The turbine is fed by the supplied extraction steam at a higher pressure and discharges it at a lower pressure of 0.35 ata, which is directed to the first effect of the MED plant. The rotating turbine drives the compressor which, in turn, sucks water vapor from one of the effects and discharges it also to the first effect. After the compressor suction point the remaining vapor, originating from the turbine discharge, continues to operate the rear effects, now lower in size, and eventually discharges its heat to the condenser. It could be noted that compared to the standard vapor compression units, no titanium made plate heat exchangers are needed, which constitutes a major saving in the capital investment cost.

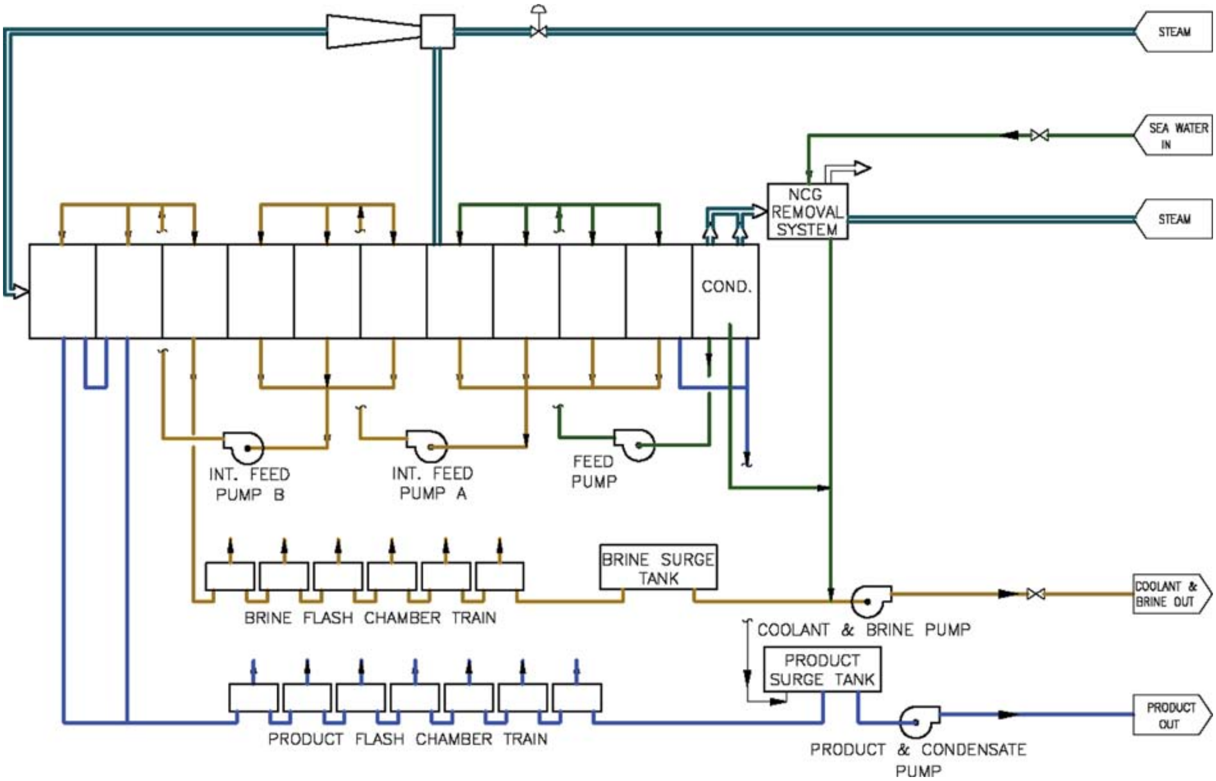

Fig. 1. MED with ejector. Enery input: extraction steam 4.5 ata at 330°C.

In order to make a techno-economic evaluation of the turbo-compressor concept, a preliminary design of an MED plant of 15,000 m^3/d capacity was carried out. For extraction steam of 4.5 ata at 330°C economy ratio (product/steam) of 13 and 20 was obtained for the ejector and turbo compressor systems respectively. The required compressor characteristics would be volumetric flow of 170 m^3/s and a compression ratio of 2, which is within the range of IDE's capability.

3. Experience

A few examples of commercial MED plants utilizing extraction steam by either employing thermal vapor compression (ejector) on one hand, or by using an auxiliary turbine to produce electricity and discharging the back pressure steam to the first effect on the other hand, are presented below. Such units could be easily improved energy-wise by adopting the proposed turbo-compressor systems.

3.1. Combination of extraction steam with an auxiliary turbine

In this scheme the extraction steam (i.e. at 1.5 barg or above) is first used to activate an auxiliary turbine, thus using the energy to produce electricity to the grid and then discharge it at the required pressure of 0.3 bara into the tubes of the first effect of the MED plant.

This principle was adopted in a 10,000 t/d plant for the Kompania di Awa e Electrisidad (KAE) of Curacao, installed in 1988 (Fig. 3). The success of this plant led to the purchase of a second, iden-

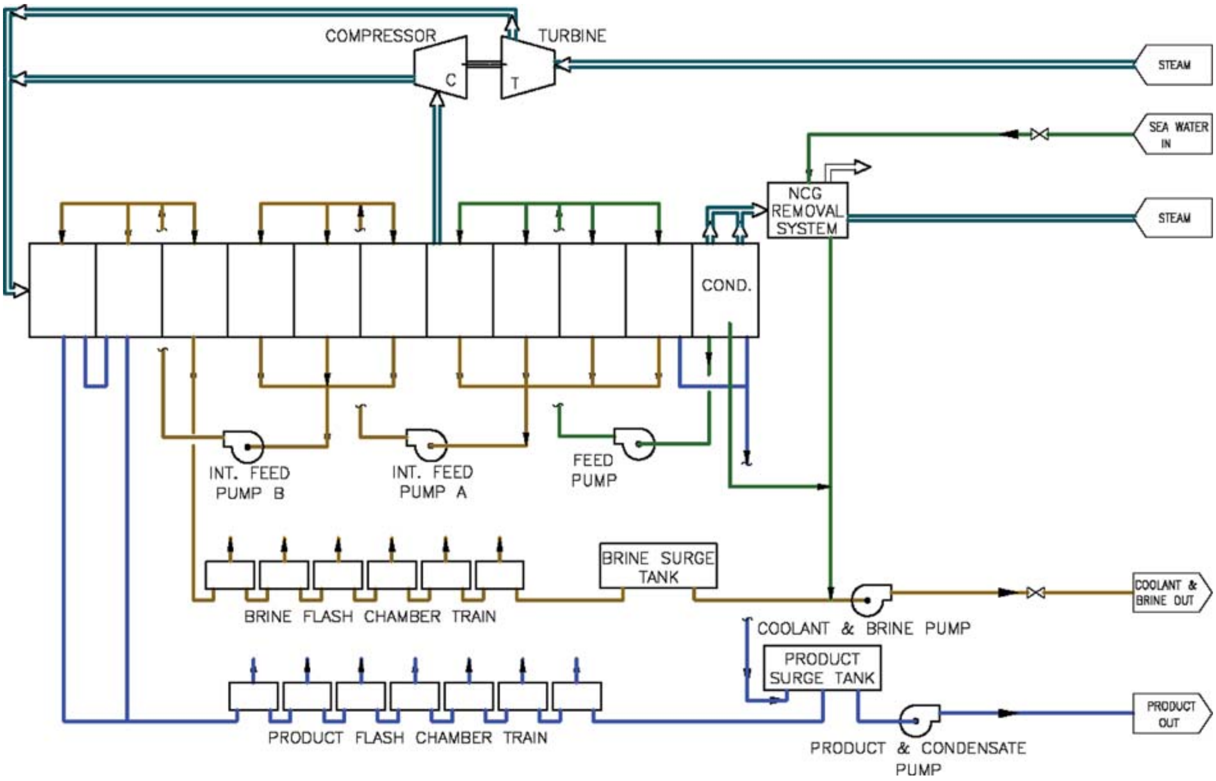

Fig. 2. MED with turbo-compressor. Enery input: extraction steam 4.5 ata at 330°C.

Fig. 3. LT MED 10,000 m^3/d + 3.2 MW.

tical unit, which was commissioned in June 1990. This plant includes an auxiliary low pressure steam turbo generator where 48 t/h of 1.5 barg ex-traction steam (from the main turbine) expands to 0.35 bara, yielding 3.2 MW electricity, and then enters the MED to produce 10,000 t/d of product water. This results in net power consumption for desalination of below 5 kWh/t.

3.2. Thermal vapor compression (ejector) driven MED

In the US Virgin Islands, 15 MED plants with thermocompression have been in operation since the early 1980s. The recent units are of a new, compact design, with up to three effects packed into one evaporator vessel, thus reducing their capital costs and space requirements. These LT MED units have been performing at better than nominal rating ever since their installation.

On the island of Las Palmas 2 MED there are plants operating with ejectors utilizing motive steam pressure as low as 1 bara .The plants consist of 14 effects each, producing 20000 t/d, with a recovery ratio of 11 (Fig. 4).

At the Reliance Refinery (Fig. 5) in India, four MED plants have been in operation since 1998, each with a nominal production of 12,000 m^3/d. The units have proved their reliability and flexibility in operation and they continuously produce 10% above nominal capacity. A fifth MED unit of 14,400 m^3/d capacity was delivered in February 2005.

4. MED desalinated water cost calculation

Table 1 summarizes a desalinated water calculation of a 15,000 m^3/d production plant using an ejector, as compared to one using a turbo-compressor. The generation loss chargeable to the desalination, due to operating at a pressure of 4.5, is determined by the potential capability of a turbine to produce electricity while operating

Fig. 4. Las Palmas MED 20,000 m^3/d.

Fig. 5. Reliance refinery (India) – 4 × MED 12,000 m^3/d.

between this pressure at a temperature of 330°C and a discharge pressure corresponding to 42°C. The enthalpy difference between the two pressure points, obtained at a constant entropy expansion, is multiplied by the total efficiency (including the turbine, the generator and the electric motor), which is assumed to be 70%. The calculation results are 124.3 kcal/kg or 144.54 kWh per ton of steam. This figure is now divided by the economy ratio to obtain the generation loss per one ton of desalinated water. The generation loss is compensated by increasing the boiler size and the amount of fuel to produce more steam. The fuel cost is based on coal prices and was assumed to be 2 cents per kWh electric. The difference in capital investment between the turbo compressor and the ejector is estimated to be one million USD, which constitutes about 7% of the total.

The total cost of the desalinated water is 0.69 USD/m^3 and 0.60 USD/m^3 for the ejector and the turbo-compressor systems respectively, which amounts to a reduction of 13%.

5. Closing remarks

This paper described the main process advantages of using turbo-compressor technology compared to that of an ejector while utilizing extraction steam. The above calculations demonstrate that the manufacturing cost of desalinated water produced in the turbo compressor system is lower by 13% compared to that of the ejector's. It is obvious that the difference would increase further along with the increase in energy cost. The experience accumulated with commercial vapor compression plants either operated by electrically driven compressors or by thermal compressors (steam ejectors) assist us in designing the preferable turbo-compressor systems without great difficulties. In addition, it is recommended that further development activities be considered to improve the efficiencies of the compressors and thereby reduce the desalination energy consumption even further.

Table 1
Desalinated water calculation of a 15,000 m^3/d production plant

	Ejector	Turbo-compressor
Plant configuration, m^3/d	15,000	15,000
Availability, %	95	95
Annual production, m^3/y	5,201,250	5,201,250
Interest rate, %	6	6
Contractual period, y	20	20
Total capital investment, MUSD	15	16
Amortization, USD/m^3	0.251	0.268
Economy ratio	13	20
Operating costs (excluding steam consumption)		
Electricity cost, USD/kWh	0.05	0.05
Electrical consumption, kWh/m^3	1.2	1.2
Electricity cost, USD/m^3	0.060	0.060
Chemicals, USD/m^3	0.050	0.050
Spare parts(1), USD/m^3	0.031	0.031
Labor(2), USD/m^3	0.015	0.015
Operating costs (excluding steam consumption), USD/m^3	0.156	0.156
Desalted water cost (excluding steam consumption), USD/m^3	0.407	0.424
Calculation of the steam cost (at 330°C, 4.5 ata)		
The thermal energy (steam) cost chargeable to the desalination is composed of the additional fuel (coal) cost in an enlarged boiler and the incremental capital cost of enlarging the boiler, required for the compensation for generation loss.		
Electrical generation loss (GL) = 144.54/ER, kWh/t	11.12	7.23
Assuming for fuel cost, USD/kWh	0.02	0.02
Boiler amortization, USD/kWh	0.005	0.005
Total steam cost = GL × (0.02 + 0.005), USD/m^3	0.278	0.181
Total water cost, USD/m^3	0.69	0.60

(1) 1% of capital cost
(2) 13 workers, at $40,000/y each

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