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Experimental analysis of a multi-effect distillation unit operated out of nominal conditions

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ABSTRACT

Solar thermal conversion systems can be used for driving a Multi-Effect Distillation (MED) unit, namely: parabolic trough collectors, compound parabolic concentrators, evacuated tube collectors, flat plate collectors and salinity-gradient solar ponds. This paper deals with an experimental test campaign of a Multi-Effect Distillation (MED) unit installed at the Plataforma Solar Almería (PSA-CIEMAT) operated out of its nominal working conditions in order to provide experimental information required for design criteria and for the analysis of control strategies in solar MED plants. The MED plant (SOL-14) assessed is a conventional forward-feed unit with preheaters, 14 effects and nominal capacity of 3 m^3/h. The experimental test campaign of the SOL14 plant conducted at the PSA proves that the PR exhibits low deviations within the range of working conditions analysed. The SOL-14 unit makes an efficient use of the energy consumption even when it is operated out of the nominal working conditions. The effects of part load operation are higher on distillate production than in PR. On the contrary, at working conditions over nominal, the PR suffers from higher deviation than distillate production, which remains unchanged within the range analysed.

1. Introduction

Multi-effect distillation is the most suitable desalination process to be driven by solar thermal collectors for medium to high-capacity range. The Plataforma Solar de Almería (PSA), the main European solar thermal research centre located in Southern Spain, has significantly contributed to the development of such a technology. Its most important contribution is the reliability demonstration of obtaining an overall Performance Ratio (PR) of 20 by coupling a Double-Effect Absorption Heat Pump (DEAHP) and a multi-effect distillation unit [1–5] within the framework of the European project AQUASOL (March 2002–February 2006). The feasibility of this technology had been previously demonstrated at the PSA [6] with a first prototype of a DEAHP.

There are various solar thermal collectors which have been coupled with Multi-Effect Distillation (MED) unit as a heat source: parabolic trough collectors, compound parabolic concentrators, evacuated tube collectors, flat plate collectors and salinity-gradient solar ponds. Literature reviews show intensive research and demonstration activities in this field [7–9]. Even though the selected solar thermal energy system includes thermal storage, an important issue in the control system of a solar MED plant is the decision of shutting down the MED unit when the thermal storage is not able to provide a given level of thermal power at a given value of temperature. This decision strongly depends on the behaviour of the MED unit operated at part load (or out of Technical specifications of the SOL-14 MED unit, that is, out of its nominal condition), although the selection of aforementioned values of temperature and power input available may depend on:

- the specific solar collector and thermal storage
- the climatic conditions
- availability of conventional energy backup.

Besides that, other design issues also depend on the performance at part load operation as:

– sizing the solar field over its design point, or
– selecting the thermal storage capacity.

Moreover, the sizing of the thermal storage and solar field also depends on the decision about operating the MED unit above its nominal capacity in order to consume the surplus energy provided by the solar field around noon in summer periods. The analysis of this issue requires

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the experimental assessment of the MED unit when it consumes thermal power above nominal temperature and/or nominal power.

In order to provide experimental information required for design criteria and for the analysis of control strategies in solar MED plants, the SOL-14 MED plant was operated out of its nominal working conditions.

2. Experimental system and test campaign

The Multi-Effect Distillation plant (MED) called SOL-14, located in the Plataforma Solar de Almería, is a conventional forward feed unit with preheaters consisting of 14 effects vertically stacked. After being preheated at the end condenser and preheaters, seawater is sprayed on the external surface of the horizontal tube bundle of the first cell evaporator, which receives external thermal power. The remaining brine goes on to the second effect, where it is sprayed on the evaporator. A small part of the steam generated in the first effect preheats the seawater whilst the main part reaches the evaporator of the next stage providing the required thermal power to continue the partial evaporation of the feed water. Similar condensation/evaporation processes are repeated from the second to the 14th effect. The steam generated in the last effect is condensed in the final condenser (cooled by seawater).

SOL-14 plant was manufactured by ENTROPIE in 1987 [10]. Within the framework of AQUASOL project [11], the first cell of the original plant was replaced in order to permit the thermal power consumption by means of liquid water instead of steam — see Fig. 1. The plant is currently connected to a stationary solar field consisting in compound parabolic concentrators manufactured by Ao Sol [12]. Water is used as heat transfer fluid of the solar field, which is heated as it circulates through the solar collectors and is then stored in the hot tank. Hot water from the storage system provides the MED plant with the required thermal power consumption.

Fig. 1. SOL-14 plant. Plataforma Solar de Almería (PSA), CIEMAT, Spain.

Table 1
Technical specifications of the Sol-14 MED unit.

SOL-14 desalination plant (nominal)	
Sea-water flow	8 m^3/h
Brine reject	5 m^3/h
Distillate production	3 m^3/h
Seawater flow at condenser:	
at 10 °C	8 m^3/h
at 25 °C	20 m^3/h
Output salinity	5 ppm TDS
Number of cells	14
Heat source energy consumption	190 kW
Performance ratio	>9
Vacuum system	Hydroejectors (seawater at 3 bar)
Top brine temperature	70 °C
Condenser temperature	35 °C

Table 1 shows main technical specifications of the Sol-14 MED unit. If the plant is operated with seawater at 25 °C, a flow rate of 20 m^3/h is required in order to condensate the 159 kg/h of low pressure steam (35 °C) produced in the last MED effect. That means that 12 m^3/h is rejected to the sea-cooling seawater, because the feedwater flow to the unit is 8 m^3/h. However, the amount of rejected seawater is not always constant. The lower the seawater temperature, the lower the amount rejected to the sea. At 10 °C, 8 m^3/h is enough to condensate all the steam produced in the last MED effect of PSA unit.

In order to assess the behaviour of the SOL-14 plant at partial load operation, the following experimental procedure was carried out:

- Variable temperature and thermal power of the external energy consumption: the range of temperature selected is from 57 °C to 74 °C.
- Seawater flow rate through the end condenser: variable to maintain a temperature difference of 35 °C between the 1st and 14th effects ($\Delta T = T_1 - T_{14} = 35$ °C). This operation condition results in temperature gradient across the heat transfer surfaces similar to nominal working conditions.

Table 2 summarises main parameters of different working conditions in the test campaign conducted. Thermal power input is calculated from:

- The difference between input and output temperature of hot water from the first MED effect.
- Mass flow rate of the hot water and its thermal capacity.

The hot water flow (12 kg/s) and the seawater feed flow (8 m3/hr) being sprayed at the first stage are kept always constant in the test campaign. Therefore, thermal power input depends on the inlet temperature of hot water.

Table 2
Average values of temperature and thermal power input in the test campaign.

Test	Temperature of the thermal input (°C)	Thermal power input (kW)
1	57	137
2	60	153
3	63	166
4	65	191
5	68	182
6	70	195
7	72	203
8	74	207