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Experimental assessment of connection of an absorption heat pump to a multi-effect distillation unit

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ABSTRACT

Theoretical analysis of integrating an absorption heat pump cycle in a multi-effect distillation (MED) process has shown better performance than with other types of heat pumps conventionally used as thermo-compressors. However, to date, only two pilot facilities have been implemented worldwide. Both of them have been developed and tested in the framework of two different research and demonstration projects carried out at the Plataforma Solar de Almería (Spain). Two different double-effect absorption (LiBr–H_2O) heat pump (DEAHP) prototypes were coupled to an existing 14-effect MED unit. This paper reports the results of the experimental assessment of integrating the second prototype in the process. Although the initial design of the DEAHP prototype was based on fitting it to the MED unit power demand and their direct connection, the prototype was unable to achieve steady operation in this configuration. However, the indirect connection of both units by means of two auxiliary tanks was successful. An overall performance ratio of 20 was measured; therefore, integration of the DEAHP doubles the performance ratio of the MED unit alone, although the temperature of the external heat input required is increased from 70 °C to 180 °C.

1. Introduction

During the nineties, a unique experiment in solar seawater desalination at the Plataforma Solar de Almería (PSA) connected a parabolic-trough solar field to a conventional multi-effect distillation (MED) unit, optimizing the overall heat consumption of the system by integrating a double-effect absorption (LiBr–H_2O) heat pump (DEAHP) [1,2]. Based on this previous background and experience, in 2001, design of a second, improved DEAHP prototype, also the only one of its kind worldwide, was begun. It was connected to the multi-effect distillation (MED) plant already existing at the PSA. The state-of-the-art connection has been previously reported by the authors [3,4]. This paper describes the experimental assessment of integrating the second DEAHP prototype in a multi-effect distillation process. Two different configurations for DEAHP prototype connection to the MED unit are compared. The experimental system required for this assessment is part of the experimental facility erected under the European AQUASOL Project (Contract no. EVK1-CT2001-00102), which also includes a previously existing MED unit and its auxiliaries.

The AQUASOL Project solar desalination test facility consists of a MED unit with 14 cells (SOL-14 plant), a stationary CPC (compound parabolic concentrator) solar collector field, a water thermal storage system, a double-effect (LiBr–H_2O) absorption heat pump, a smoke-tube gas boiler, and an advanced solar dryer for final treatment of the brine connected as shown in Fig. 1. The heat transfer fluid is water, which is heated as it circulates through the solar collectors, converting the solar energy into thermal energy in the form of the sensible heat of the water, and is then stored in the tanks. Hot water from the storage system provides the MED plant with the required thermal energy. In absence of solar radiation, the gas boiler feeds the absorption heat pump, which is also fed with low-pressure steam from the last effect of the MED unit. As a result, the heat pump heats the water coming from the first effect of the MED unit from 63.5 °C to 66.5 °C.

This paper evaluates connection of the new DEAHP prototype, driven by a smoke-tube gas boiler, to the MED unit. The experiments reported in this paper did not involve any energy contribution from the solar field. Two water tanks were used in one of the configurations tested for the indirect connection of the absorption pump and multi-effect plant.

2. Experimental system

The second DEAHP prototype was originally designed for direct connection to the PSA multi-effect distillation unit, which means that hot water circulates in a closed loop between the first MED effect and the heat pump absorber–condenser tandem. However, the PSA experimental facility allows another connection configuration (indirect) to be tested, in which the thermal power from the DEAHP is delivered

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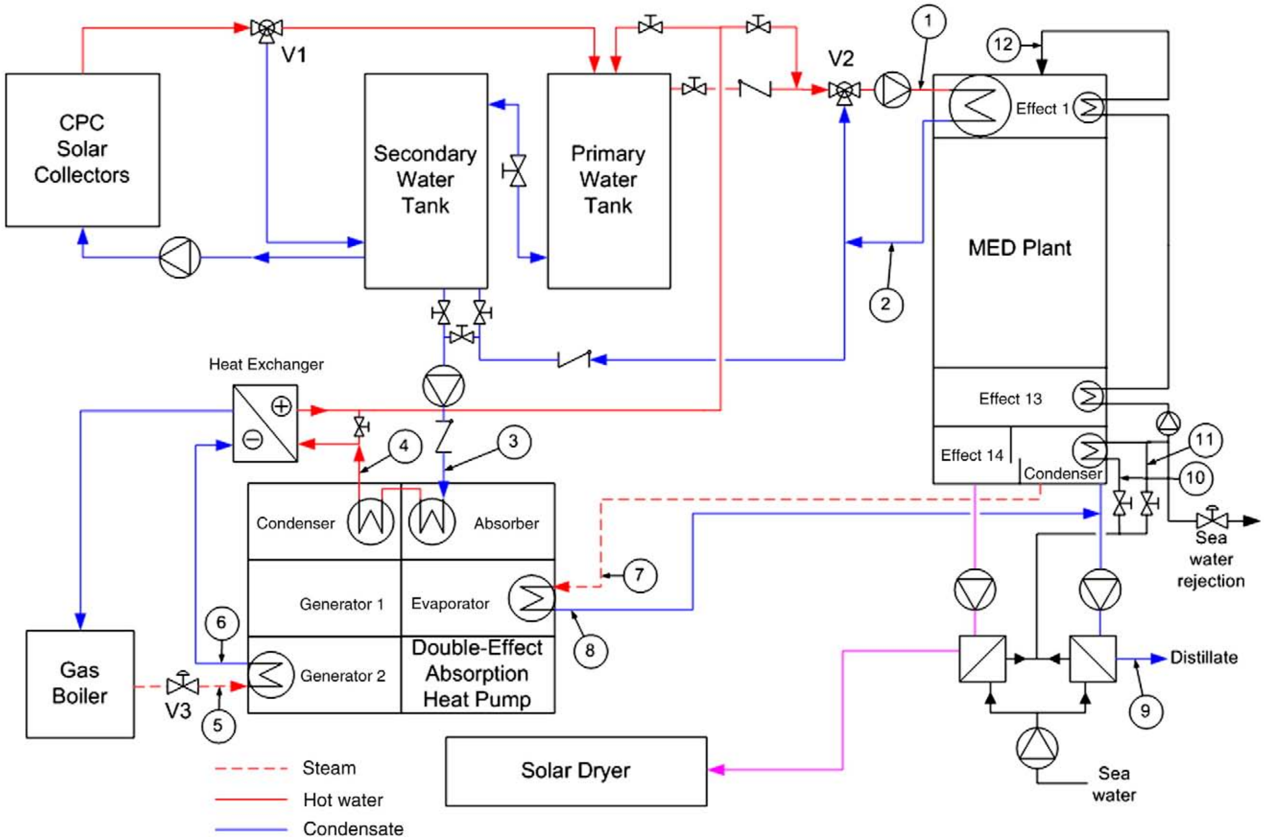

Fig. 1. Final configuration of the AQUASOL seawater desalination system.

to the MED plant by means of two water tanks. Both configurations have been tested and evaluated, and DEAHP performance in nominal and part-load operation was compared to find the best operating layout.

The PSA SOL-14 desalination plant is a forward-feed MED unit manufactured and delivered by ENTROPIE in 1987 (See Table 1 for specifications) in the framework of a previous research project [5]. It has 14 effects, in a vertical arrangement. The original first cell, which worked with low-pressure saturated steam (70 °C, 0.31 bar), was replaced in the AQUASOL Project by a new one, which is able to work with hot water as the heat transfer media (See Table 2).

The double-effect absorption heat pump (DEAHP) was manufactured by ENTROPIE in 2005 and was installed next to the multi-effect distillation unit (See Fig. 2). The working fluid is a water/lithium bromide solution which circulates through two solution circuits connected in series. This series flow configuration has a lower thermodynamic and heat transfer performance than parallel flow but requires less complicated control, especially in transient operation [6].

Table 1
Technical specifications of the SOL-14 desalination plant.

Feedwater 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

3. Experimental results

3.1. Direct connection configuration

The original design of the second AQUASOL DEAHP prototype was designed to be connected directly to the multi-effect distillation unit already existing at the PSA, so that water coming from the first effect of the MED (Fig. 1, Point 2) would circulate directly through the absorption heat pump absorber and condenser without passing through the water storage tanks. In nominal operating conditions, after leaving the DEAHP condenser, the water temperature rises to match the difference between the MED first effect inlet and outlet water temperatures.

First, some tests were conducted with automatic regulation of the high-pressure steam valve (Fig. 1, Valve V3) in order to set nominal steady operation. Fig. 3 shows a typical cold start-up test with the MED-DEAHP direct connection configuration. The following parameters are shown:

i) Inlet and outlet water flow temperatures in the MED first effect (Fig. 1, Points 1–2); water temperature at the inlet of the DEAHP absorber and the outlet of DEAHP condenser (Fig. 1, Points 3–4).

Table 2
Nominal conditions of the new PSA MED plant.

	Desalination driven by solar collectors	Desalination driven by absorption heat pump
Power	200 kW	150 kW
Inlet/outlet hot water temperature	75.0/71.0 °C	66.5/63.5 °C
Brine temperature (on first cell)	68 °C	62.0 °C
Hot water flow rate	12.0 kg/s	12.0 kg/s
Pressure drop	0.4 bar	0.4 bar
Nominal plant production	3.0 m^3/h	2.2 m^3/h