A SMALL SOLAR DISTILLATION PLANT FOR THE PRODUCTION OF LABORATORY PURE WATER IN NORTH JORDAN

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Abstract

This paper deals with the applicability of solar thermal energy to produce distilled water for laboratory use under Jordan climate conditions. This solar distillation system is installed on the rooftop of a public building with the aim to generate a balanced answer to the energy demanded by the buildings: electricity, heat and cold, as well as other energy driven services like the supply of distilled water. Within the framework of the STS-Med Project, funded by European Commission under the ENPI CBCMED program, four solar poly-generative plants have been designed to be connected with public buildings. The Jordan plant is installed on the rooftop of Al-Khawarizmi building at Al-Husson University College. The plant introduced a steam circuit that feed a steam turbine manufactured at a very small scale. Raw water is driven to the soft water tank. The water hardness is reduced to 50 ppm. The steam generator produces saturated steam of 18kg/h at 6 bar. In order to recover the steam energy before condensation, steam is superheated to a temperature of 200 °C and fed to the steam turbine. Project outcomes are drawn and documented about the potential impact of solar distillation in the Mediterranean solar belt and the future development of the involved technologies.

1 Introduction

The use of solar energy in thermal distillation processes is one of the most promising applications of renewable energy to water desalination technology. There are two methods used to facilitate solar energy for pure water production: one is the direct use of solar irradiation in solar still, and the other method is converting the solar irradiation into thermal energy, mechanical energy or electrical energy using solar collectors [1-3].

There are several methods for classifying the well-known desalination processes. They can be classified according to the phenomena involved, e.g. those involving phase change in water, as in distillation, freeze separation, and hydrate separation; those utilizing surface properties of membranes, as in electro-dialysis and reverse osmosis; and those utilizing ion-selective properties of solids and liquids, as in ion exchange and solvent extraction. Distillation is the most developed method and can be applied for the production of large quantities of water. The phase change of water from liquid to vapor is the basis of all forms of distillations. The methods commonly used are the multi-effect (ME) and multi-stage flash (MSF) processes [4]. Solar distillation can be used to produce distilled water for industrial and laboratory applications and also for small communities at an average water consumption of 0.4 m^3 /day per person [5].

In Jordan, two main sources are available to be desalinated: the Red Sea and the brackish groundwater in some basins, where preliminary studies show that by the year 2010 more than 20 MCM/yr could be developed in the Central Jordan Valley. This figure may reach 70 MCM/yr by the year 2040 [4, 6]. According to water quality analyses conducted by JICA on brackish water in the Jordan Valley, the TDS concentrations were in the range of 5,000—10,000 mg/L [7].

Solar desalination

In order to deliver high temperatures with good efficiency, a high performance solar collector is required. A solar collector field is connected to a conventional steam generator in indirect solar systems. The solar field could drive the generator by heating the water and generating steam. This steam might be generated (1) at the solar collector (direct steam generation, DSG), in which a two-phase flow is allowed in the collector receiver (2) at an unfired boiler, driven by an intermediate heat transfer fluid, which is heated in solar collectors or (3) at a flash vessel, where pressurized water flashes after it is heated in the solar collectors [8].

Parabolic trough collectors (PTCs)

PTCs are the most mature solar technology to generate heat at temperatures up to 400 °C for solar thermal electricity generation or process heat applications. PTCs can effectively produce heat at temperatures between 50 and 400 °C. PTCs are made by bending a sheet of reflective material into a parabolic shape. A tracking mechanism must be reliable and able to follow the sun with a certain degree of accuracy. Various forms of tracking mechanisms, varying from complex to very simple, have been proposed. It is sufficient to use a single axis tracking of the sun, and thus long collector modules are produced. The collector can be oriented in an east–west direction, tracking the sun from north to south, or oriented in a north–south direction, tracking the sun from east to west [9]. The receiver of a parabolic trough is linear. Usually, a tube is placed along the focal line to form an external surface receiver. The size of the tube and therefore the concentration ratio is determined by the size of the reflected sun image and the manufacturing tolerances of the trough. The surface of the receiver is typically plated with selective coating that has a high absorption rate for solar irradiation but a low emittance for thermal radiation loss. A glass cover tube is usually placed around the receiver tube in order to reduce the convective heat loss from the receiver.

2 Plant description

The plant, as shown in Figure 1, is simply a parabolic trough solar system for multi applications. The plant for this limited capacity can be used for water distillation, space heating, cooling, and power generation. The solar thermal system loop consists mainly of the concentrated solar collector of type linear parabolic trough Soltigua Concentrating Solutions. The collector model is PTMx-36 model (net collecting area = 164 m^2) of total nominal capacity of 100 kWth. The Heat Transfer Fluid is thermal oil Seriola Eta by Total. The nominal temperature of the oil at receiver inlet is 200 ˚C and at receiver outlet 240 ˚C. The concentrated solar irradiation heats the heat transfer oil to a temperature of 240 ˚C. The heated oil is stored in a break tank to provide a stabilized operation for the heat consuming equipment. Part of the hot thermal oil is extracted to generate superheated steam at 200 ˚C and 6 bar through a locally made steam generator. The generated steam is fed to a small steam turbine of 1.2 kW nominal power output. The condensate of the steam leaving the turbine is used as distillate at a rate of 18 kg/h. The cost of subsystems is evaluated and analyzed. Table 1 shows the summary of the cost based on subsystems/components classified according to the nature of the energy outputs from the system.

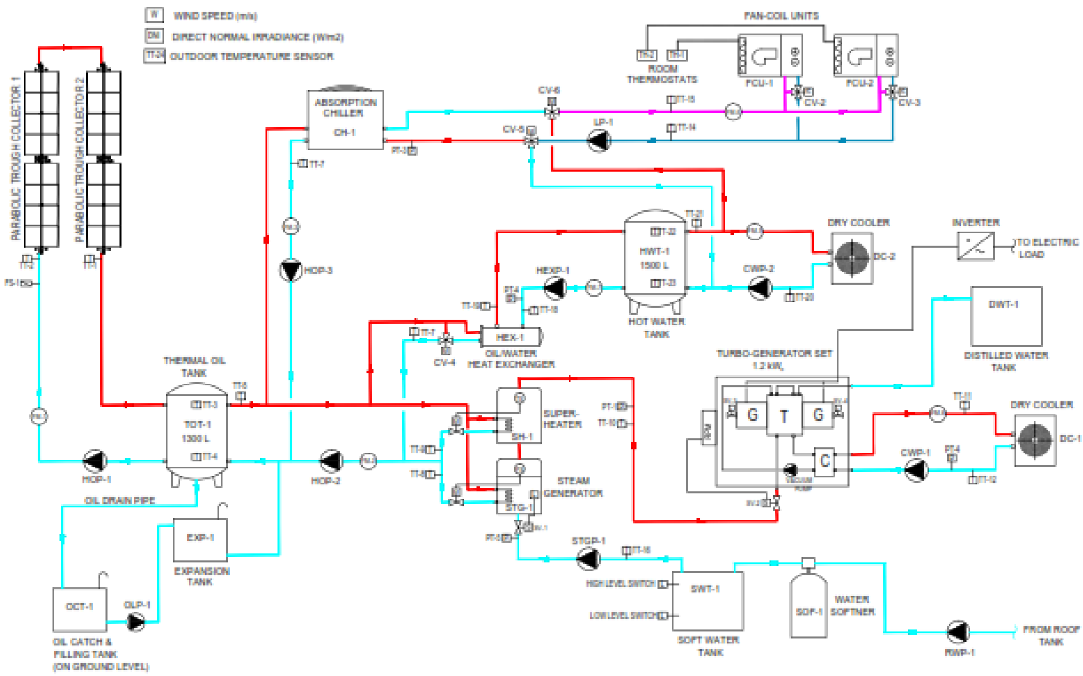

Figure 1: Schematic Diagram of the Plant

Distillation and steam generation circuit

All plant components are operated automatically Automatic Mode except for the steam turbo-generator set, which should be operated manually. As in Figure 1 shown, HOP-2 circulates the hot oil between TOT-1 and STG-1 & SH-1. Saturated steam at 6 bar is generated in STG-1 and superheated in SH-1 up to 200 °C. RWP-1 will deliver raw water from existing roof tanks through SOF-1 to the soft water tank. The water hardness is reduced to 50 ppm in this process in order to protect the steam generator against scaling. The water is fed into the steam generator via STGP-1.The Turbo-Generator Circuit_is operated manually and for demonstration only, as the system is not connected to the university network. The super heated steam is fed to steam turbine, which rotates at maximum speed of 30,000 RPM. The steam exits the turbine and is condensed in the condenser, which is cooled by water circulated between the condenser and DC-1 via CWP-1. The condensed steam is then transferred through the vacuum pump to the distilled water tank, where it is collected and used by the laboratories. The turbo-generator set generates DC electric power. The DC is converted to AC power in the inverter which is connected to the load.

Table 1: The selected plant components and capacity

No	Item	Type	Ref.	Capacity	Qty	Function
1	solar collector	Parabolic trough	PTC-1	85 kWth	2	heat source for the plant
2	chiller	air-cooled absorption	CHLR-1	17.1 kWco	1	generating chilled water for space cooling
3	turbo-generator set	steam driven	ST-1	1.2 kWe	1	electricity generation
4	steam generator	shell and tube heat exchanger	STG-1	18 kg/h, 6 bar	1	saturated steam generation
5	steam super heater	shell and tube heat exchanger	SH-1	18 kg/h, 6 bar, 200 °C	1	super-heating the saturated steam to drive steam turbine
6	fan-coil unit	2-pipe FCU	FCU-1	8.55 kW, total 5.8 kW sensible	2	space cooling and heating
7	dry cooler	horizontal	DC-1	12 kW	1	cooling the water exiting the steam condenser of turbine
8	dry cooler	horizontal	DC-2	43.4 kW	1	dissipating excess heat in hot water tank(HWT-1)
9	thermal oil pump	inline	HOP-1	1.32 L/s, 27.9 m	1	circulating HTF between collectors and oil tank(TOT-1)
10	thermal oil pump	inline	HOP-2	1.32 L/s, 27.9m	1	circulating HTF between coil tank (TOT-1) and steam generator (STG-1), super heater (SH-1), and heat exchanger (HEX-1)
11	thermal oil pump	inline	HOP-3	0.76 L/s, 7.2m	1	circulating HTF between coil tank (TOT-1) and the chiller(CHLR-1)
12	water pump	inline	LP-1	0.75 L/s, 10.9 m	1	circulating HTF between chiller CHLR-1, HWT-1 and FCU-1
13	water pump	inline	HEXP-1	0.3 L/s, 3.5 m	1	circulating HTF between HEX-1 and HWT-1
14	water pump	inline	CWP-1	0.29 L/s, 4.8 m	1	circulating HTF between DC-2 and HWT-1
15	water pump	inline	CWP-2	0.53 L/s, 7.2 m	1	feed pump for steam generator
16	water pump	vertical multistage	STGP-1	0.2 L/s, 65. 4m	1	boosting raw water pump into the softener
17	water pump	vertical multistage	RWP-1	0.4 L/s, 30.6 m	1	boosting raw water pump into the softener
18	hot water tank	cylindrical, steel	HWT-1	1500 L	1	hot water storage
19	thermal oil tank	cylindrical, steel	TOT-1	1300 L	1	thermal oil storage
20	distilled water tank	cylindrical, plastic	DWT-1	400 L	1	distilled water collection
21	soft water tank	cylindrical, plastic	SWT-1	400 L	1	soft water storage

3 Operation and Results

The plant components after installation are shown in Figure 2 (photo images at the end of this paper). The distillation cycle is operated manually and for demonstration only as the system is not connected to the university network. The plant is tested for the capacity of thermal production. Figure 3 and 4 show the operating conditions and outputs.

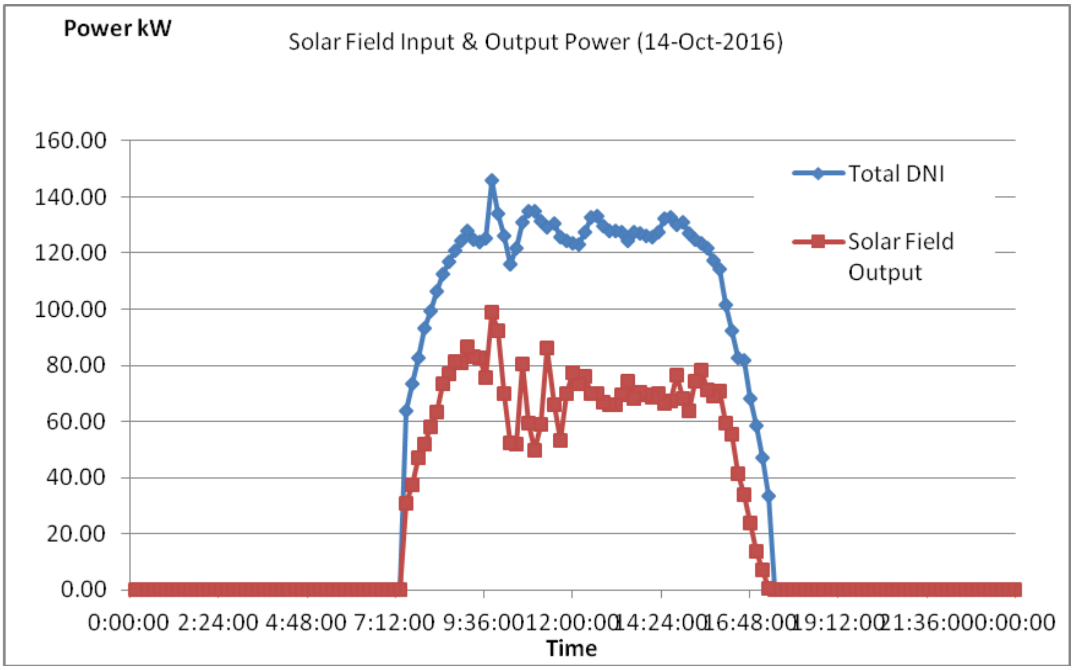

Figure 3: Solar Field Input & Output Power (14-Oct-2016)

The measured amount of produced distilled water is found to be 16.5 kg/h in average. The total amount for 8 h is 132 L/d. The total plant capacity is 100 kW thermal. In order to use this total capacity for producing distilled water, two operating pressures are used to estimate the amount of produced distilled water. Below is the theoretical thermal calculation for

1 bar absolute operating pressure and 25 °C inlet water temperature:

$$Q = m\,[Cp\,(t2 - t1) + hfg] \qquad (1)$$

Where are, *Q* the total plant capacity [kW], *m* the amount of distilled water [kg/s], *Cp* the water specific heat [kJ/kg.K]; *t2* the saturation temperature of steam at working pressure [^{o}C], *t1* the inlet water temperature [°*C*], and *hfg* the evaporation enthalpy of steam at working pressure [kJ/kg]. For 8 working hours, the total amount of produced distilled water is 1,120.6 L /d. Using the equation (1) for 1 bar and for 8 working hours, the total amount of producing distilled water is calculated to 1,088.8 L/d.

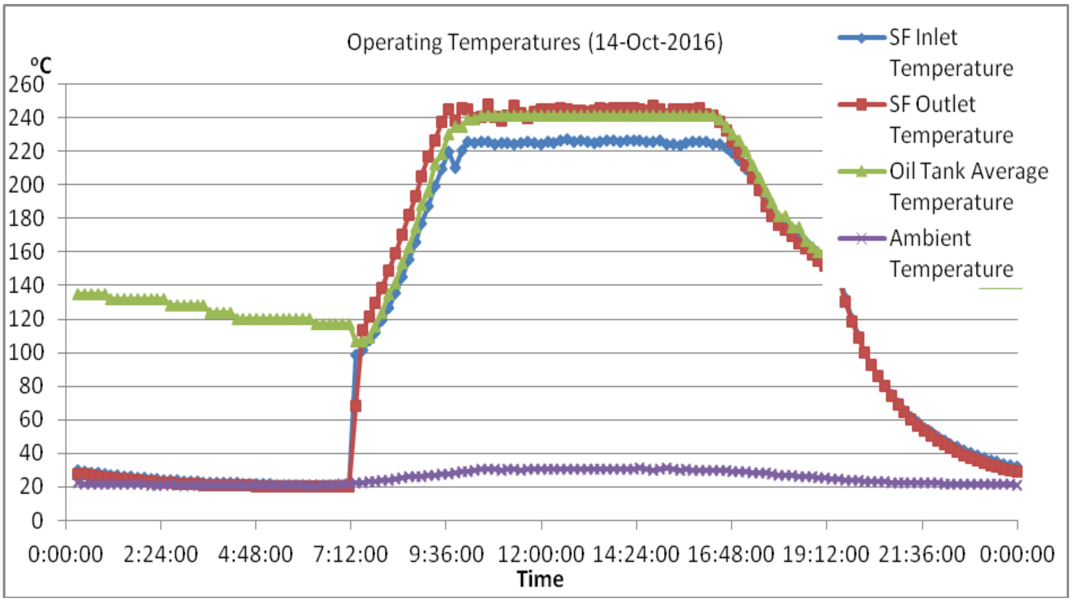

Figure 4 Operating Temperatures (14-Oct-2016)

4 Conclusions

The plant was operated and tested under the design conditions. It was found that the amount of produced distilled water under the experimental conditions was as expected. For the full plant operation for water distillation application, the amount of produced water was about 10 L/d per one kW of installed capacity. With these figures, this type of solar-thermal preparation of distilled water for laboratories in similar climate regions like in the MENA Region seems to be appropriate and sustainable.

4 Acknowledgments

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Figure 2: Distillation plant and its components