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# PERFORMANCE AND EVALUATION OF ADSORPTION CHILLERS POWERED BY SOLAR ENERGY BY MEANS OF PTC'S IN JORDAN

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## ABSTRACT

An innovative idea is developed to increase the total output of CSP system and to improve its financial feasibility. The CSP system which is utilizing the DNI by means of PTC's is assembled to form a tri-generation solar system which is built and tested in the southern part of Jordan, With only one solar matrix the heat generated was used to generate electricity, distilled water, and cooling in summer or heating in winter. The system is comprised of a parabolic trough solar matrix installed on the Roof of 6000 $m^2$ building with total aperture area of 240$m^2$ The trough matrix heated thermal oil up to 260 °C which is used to generate superheated steam at 13.7 bar, and 210 °C. The generated steam powers a 20 HP steam engine which drives a 15KWe DC generator. The steam exiting the engine at 120 °C is then utilized to evaporate brackish water as it is condensed to complete the power cycle. The distillation process is then completed to generate distilled water at a peak rate of 150 liters/hr. The heat rejected from the distillation process is then stored in thermally insolated hydraulic storage tank and used to heat the space in winter or to power an innovative two-stage air cooled adsorption chiller at a capacity of 20KW of cooling at 12 °C chilled water boutput and 35 °C ambient. The performance of the adsorption chillers was conducted and determined, the COP and the normalized capacity of these chillers were obtained.

## 1. INTRODUCTION

Solar cooling technology has potential capabilities in the area where insolations levels are high and no firm electricity supply to power conventional systems. Thermal driven refrigeration cycles which are applied in chillers can provide a good solution in these cases (Nunez, 2010). Many researches on solar adsorption refrigeration have been conducted in the last two decades, and a number of solar adsorption refrigeration systems were successfully developed. Pons and etal. (1986) experimentally investigated a solar adsorption icemaker with 6 m2 solar collector/adsorber, which produced 30–35 kg of ice per day under the solar radiation of about 22 MJ/m2 day. Critoph (1988) studied the performance limitations of adsorption cycles for solar cooling. Luo and *et al* (2007) built and studied the performance of novel solar-powered adsorption cooling system for low-temperature grain storage. The chiller had a cooling power between 66 and 90 W per m2 of collector surface, with a daily solar cooling coefficient of performance (COPsolar) ranging from 0.096 tigeratoro 0.13. Headley *et al*. (1994) constructed a solar adsorption refrigerator powered by a combined parabolic concentrating solar collector with the net solar coefficient of performance COP of being about 0.02.

This study focused in the performance of an innovative idea which is developed to increase the total output of CSP system and to improve its financial feasibility. The CSP system which is utilizing the DNI by means of PTC's is assembled to form a tri-generation solar system which is built and tested in the southern part of Jordan, With only one solar matrix the heat generated was used to generate electricity, distilled water, and cooling in summer or heating in winter. The system is comprised of a parabolic trough solar matrix installed on the Roof of 6000 $m^2$ building with total aperture area of 240$m^2$ The trough matrix heated thermal oil up to 260 °C which is used to generate superheated steam at 13.7 bar, and 210 °C. The generated steam powers a 20 HP steam engine which drives a 15KWe generator. The steam exiting the engine at 120 °C is then utilized to evaporate brackish water as it is condensed to complete the power cycle. The distillation process is then completed to generate distilled water at a peak rate of 150 liters/hr. The heat rejected from the distillation process is then stored in thermally insolated hydraulic storage tank and used to heat the space in winter or to power an innovative two-stage air cooled adsorption chiller at a capacity of 20KW of cooling at 12 °C chilled water output and 35 °C ambient.

## 2. SYSTEM DESIGN AND OPERATION DESCRIPTION

### 2.1. Solar Tri-generation System

The components of the Solar Tri-Generation System (STGS) are shown in Figure 1. It consists of different and several components such as a 240 m2 of aperture area Parabolic Trough Collectors (PTCs), a 120 kWth boiler HX1 which serves as a steam generator, a steam engine of 20 hp coupled with an electric generator , desalination system, and two adsorption chillers of 10 kW each. Other components of the system are: an expansion tank contains the HTF, relief valves, level sight glass, a motorized three-way valves, regulating valves, HTF circulating pump, water pumps, tracking system, weather station and measuring devices (Pyranometer, Anemometer, Thermostat and Pressure Gages).

### 2.2. Solar Cooling System

The cooling system consists of two adsorption chillers, re-cooler, fan – coils evaporator, tanks for hot and chilled water are of capacity 750 liters and 200 liters respectively, pumps, measuring apparatus, and an interface card with software to receive the measuring signals and storing them in data file to be display as shown in Figure 2.

2.2.1. Adsorption Chillers

These chillers are called ADC-2P,each one has 10 kW cooling capacity and it operates at a low driving temperature which is the most preferred case. Figure 3 shows schematically the connections in this chiller (AL-Maaitah, 2009). The ADC-2P chiller is available in the local market with a chilling capacity of 10 kW and heating capacity of 30 kWth. This chiller has 0.33 rated cooling COP at nominal conditions where the inlet hot temperature, the inlet re-cooling temperature and the inlet chilled water temperature are 90°C, 35°C and 18°C, respectively and the flow rates of the same order were 1.25, 2.25 and 0.833 L/s. The two ADC-2p chillers are connected in the STGS to be the last production system in the plant; these chillers supply the chilled water tank with the required cold water to be used for air-conditioning applications.

2.2.2. Instrumentation and data acquisition

a number of sensors and instruments are utilized to acquire the data necessary to evaluate the performance of the solar adsorption chillers as shown in Figure (4). The solar cooling system also equipped with special monitoring system as shown in Figure 2. This system introduced by the Millennium Energy Industries to deal with the signals which come from the measurement devices such as temperature sensors, pressure sensors, and flow meters.The measuring points are basically shown in Figure.4.The measured data can be recorded in excel file to be represented graphically. On another hand, this monitoring system serves as a controller to operate the solar cooling system in optimum conditions through the pre-set points.

### 2.3. Operation principle of Solar Cooling System

Adsorption technique mainly involves a solid sorbent that attracts refrigerant molecules onto its surface by physical or chemical force and does not change its form in the process. The principle work of adsorption refrigeration cycle such as methanol/ activated Carbon which is typically used in our STGS depends on the solid sorbent (activated carbon) is continuously cooled and heated alternately to adsorb and desorb the refrigerant. The cooling cycle in the adsorption chiller which utilizes a pair of methanol/activated carbon as adsorbent and refrigerant respectively consists basically of evaporation and condensation processes, and also four sorbent beds. The starting of cooling cycle begins as soon as the driving hot water (coming from the condensation process of distillation water as a waste energy) enters the two beds, leading the active carbon beds to desorb the methanol that originally cohesive its surfaces then the desorbed methanol leaves the bed towards the other to bed for increasing the thermal efficiency thus the vapors of hot methanol enters the air cooled condenser to be cooled and condensed. The cold refrigerant liquid then flows towards the tubes of the evaporator to produce cooling. Moreover, the methanol vapor which returns back from the evaporator enter the beds to be adsorbed by the sorbent porous bed then it is cooled to increase the efficiency before switching over from adsorption to desorption mode as shown in Figure (3). These types of ADC-2p chillers are operated between two pressure levels (Low pressure at the evaporator side and high at the condenser side), and there are three temperature levels: the low temperature level of the chilled waters produced, the intermediate temperature level of the cooling waters that are used in rejecting the excess heat in the adsorber and condenser, and the third level is the high temperature of the driving waters that supplies the heat to the desorber. When two beds are fully charged and the other two beds are fully discharged, these partitions will interchange their functions to run continuously, thus producing chilled water (Almaaitah, 2009).

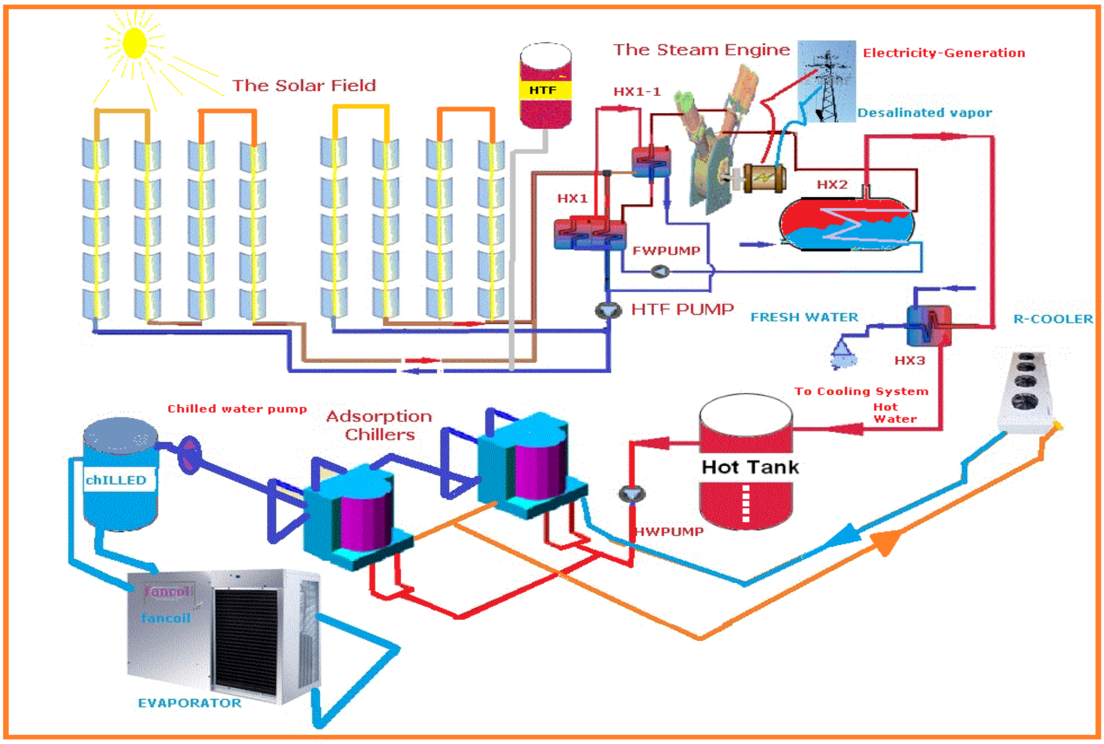



Figure 1.Components of the STGS

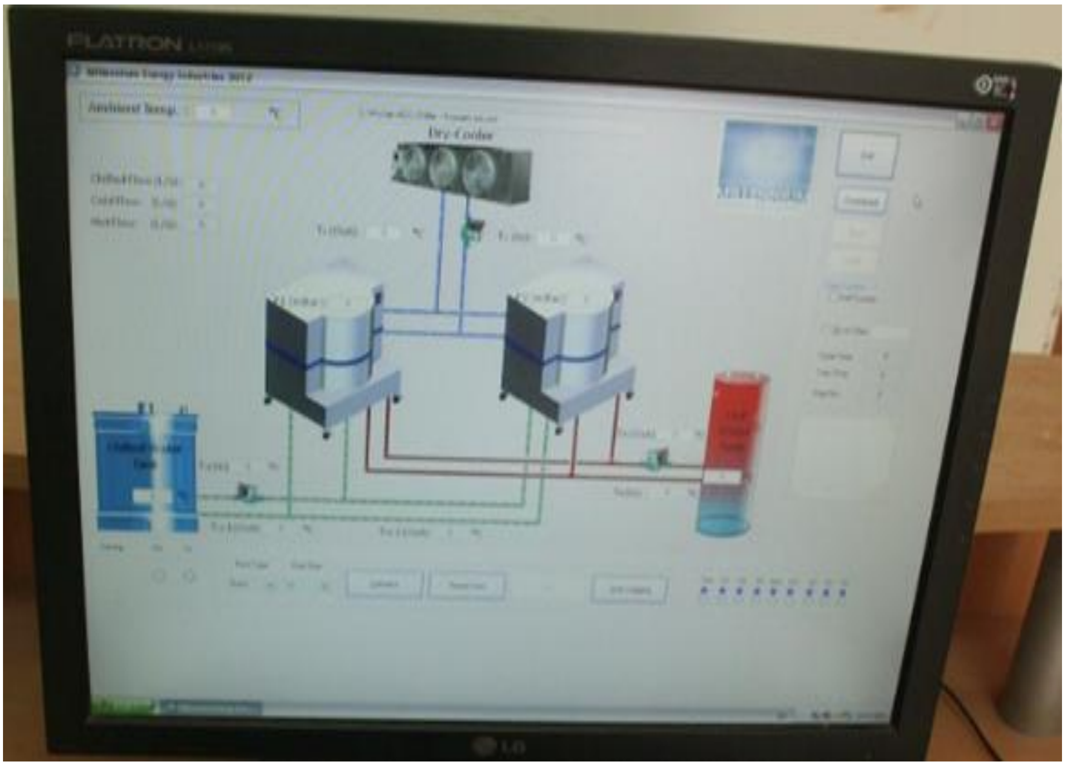



Figure 2.Components of the cooling system

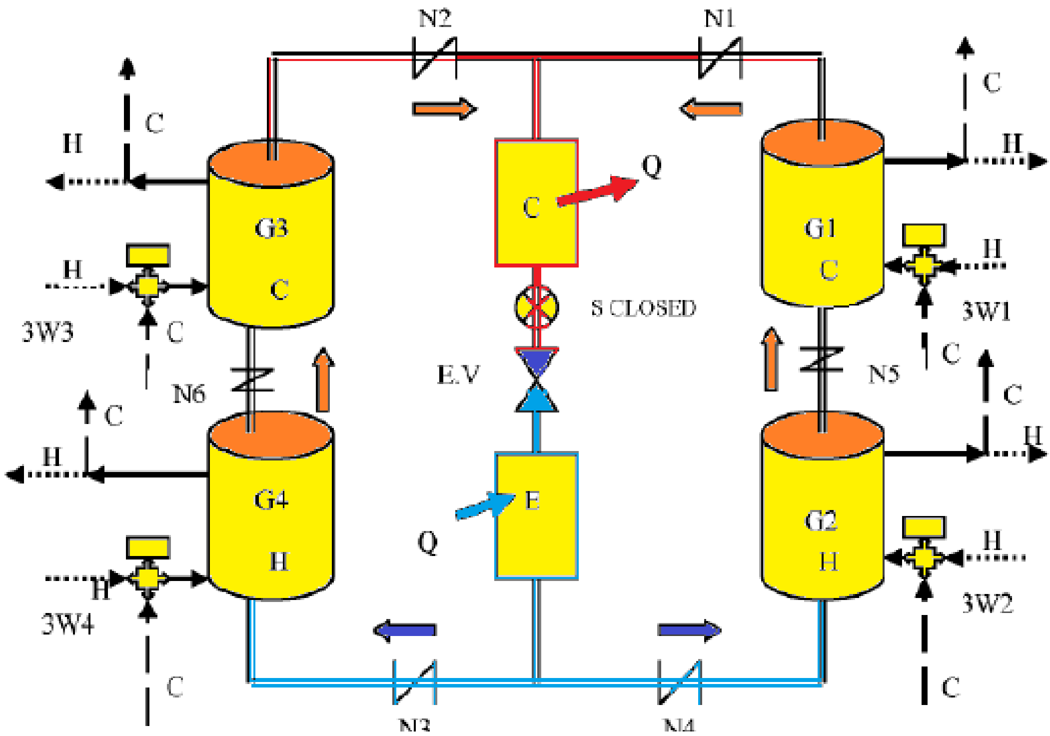


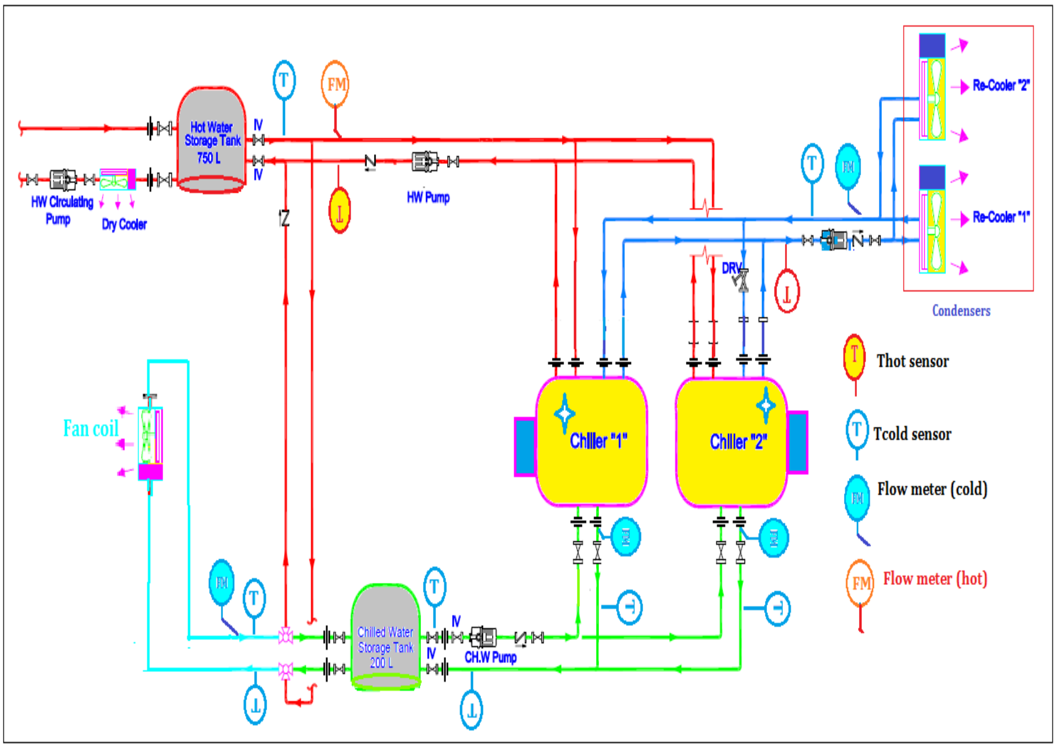

Figure 3. Schematic drawing of a two stage ADC-2P

## 3. EVALUATION OF THE EXPERIMENTAL PERFORMANCE OF THE SOLAR – POWERD ADC-2P CHILLERS

The solar power block is intentionally designed to utilize all possible waste energy from electricity generation step. This waste energy has a considerable amount as shown in the Figure 5. Large amounts of power are to be lost if the other steps of production are not being adopted. The estimated losses of the system without adopting the other steps of production would be around 80% of the thermal solar power which produced by the PTC solar matrix.

The STGS performance is conducted in clear sky day conditions as shown in figure 6, and also in cloudy sky day conditions as shown in figure 7.It is clearly shown in both figures a large amount of waste energy rate for the STGS are being utilized in operating the different systems of the STGS. In the clear sky day the average energy rate which is utilized in the solar cooling system for the chillers about 20 $kW_{th}$, while in cloudy sky day the average energy rate for heating purposes is about 40 $kW_{th}$ .

The normalized cooling capacity (Qc) and the normalized coefficient performance (COP) for different operation conditions are calculated and represented in figures 8-11.




4. Schematic drawing of a two stage ADC-2P connections

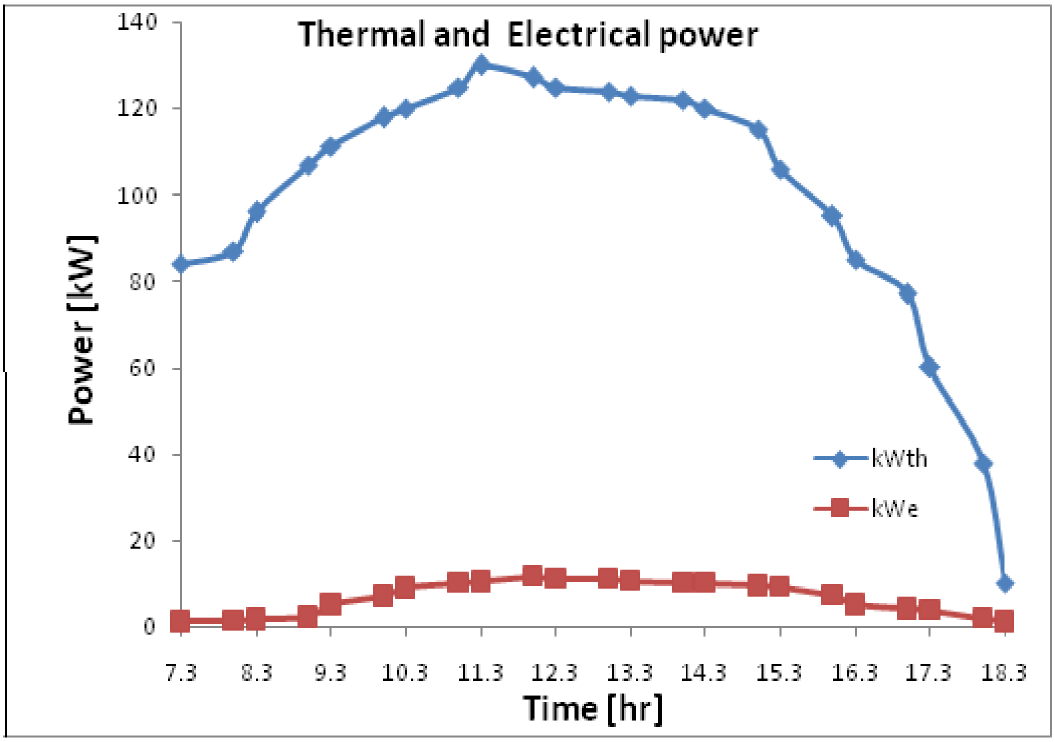



Figure 5. Thermal and Electrical Power of the STGS

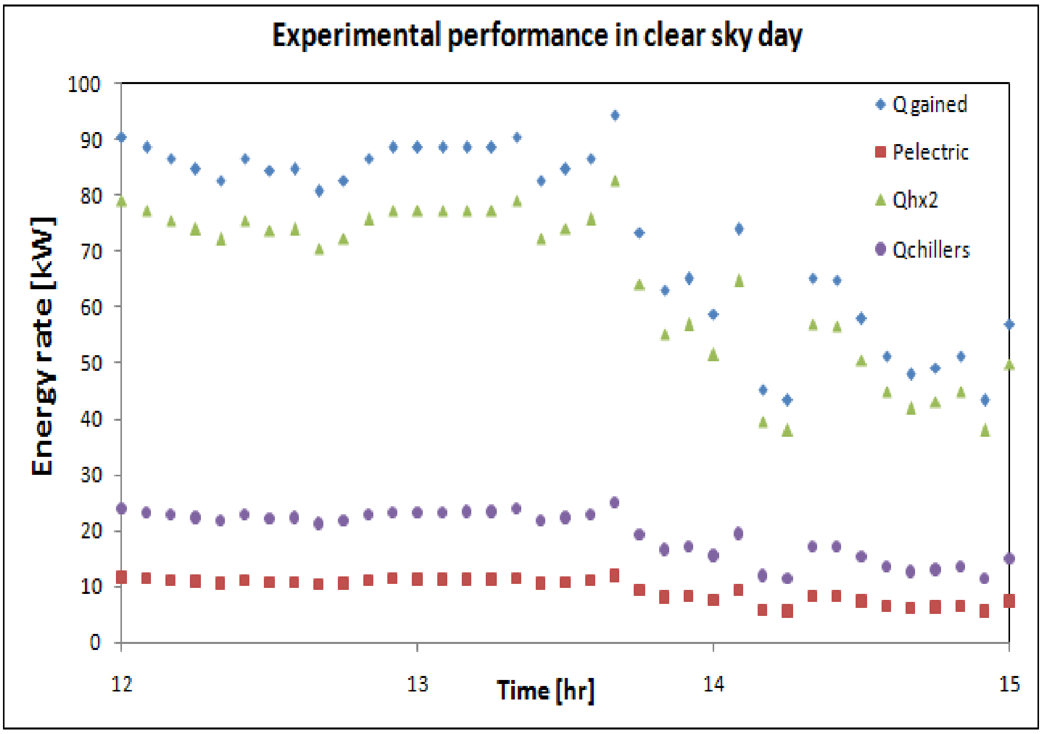



Figure. 6 Performance of the STGS in clear sky day

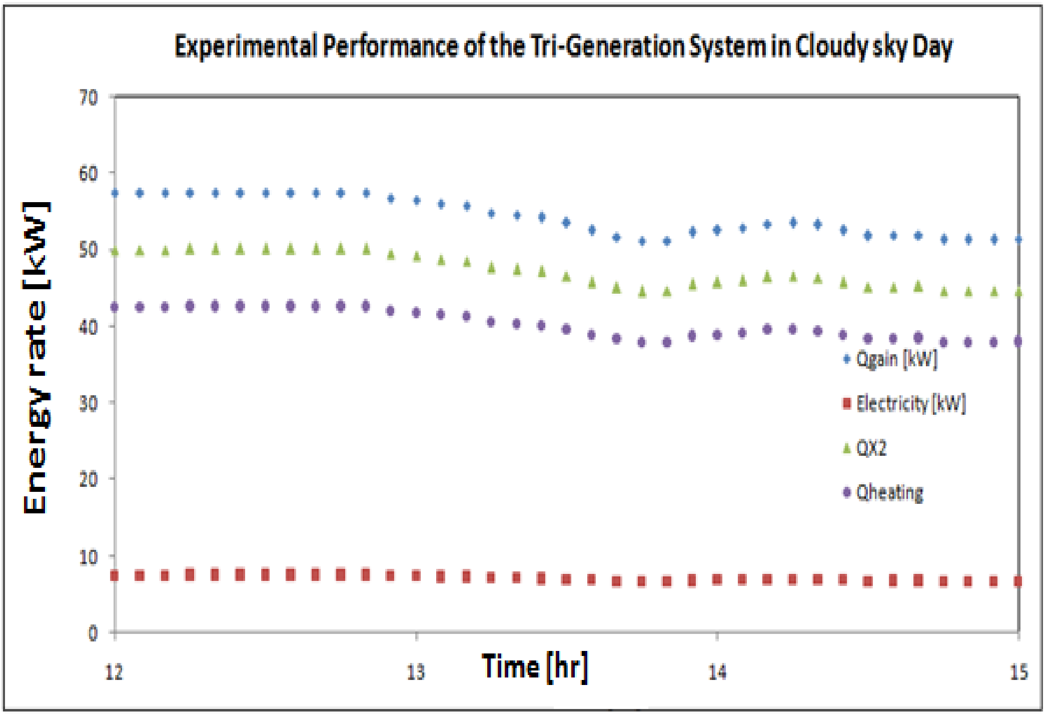



Figure 7. Experimental performance of the TGS in cloudy sky day

The normalized capacity for differnt condensation tempratures and different driven hot temperatures are shown in figures 8 and 9. It is observed that the normalized capacity increased when the driven hot temperatures are increased and at the same time the normalized capacity also decreased while the condensation temperatures are increased. Normalized COP values of the chillers in Fig.10 are higher than of COP in Fig.11, this is due to the higher hot driving temperature which is 95 [°C] while it is 65 [°C] in Fig.8. This higher driving hot temperature plays significant role in COP increasing for the adsorption chiller due to the shorter time which is needed to heat up the beds of the adsorption chiller, thus the methanol evaporates in higher rates which is leading to more refrigeration effects. Another important observation is shown in figures8- 10 where the higher values for the COP are obtained when the temperature of chilled water produced is increased; this is due to the fact that the capacity of the chiller also increased.

In figure 11 the capacity is increased when the chilled water temperatures also are increased at constant driven hot temperature.On other hand , the capacity decreased when the cold water temperature is increased.

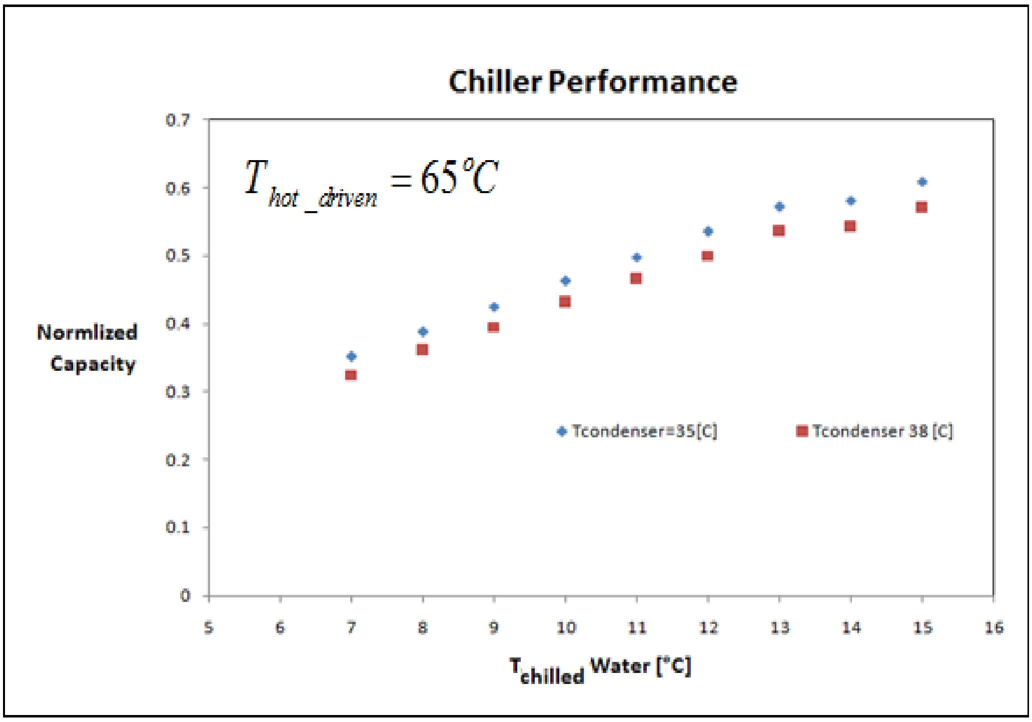



Figure 8. Experimental performance of the adsorption Chiller

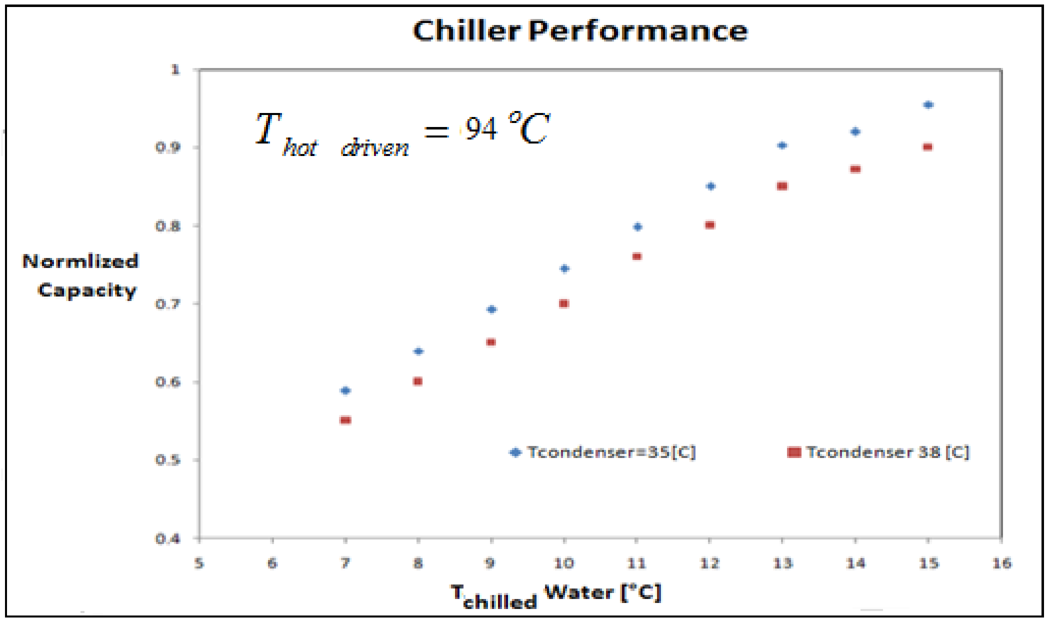



Figure 9 Experimental performance of the adsorption Chiller

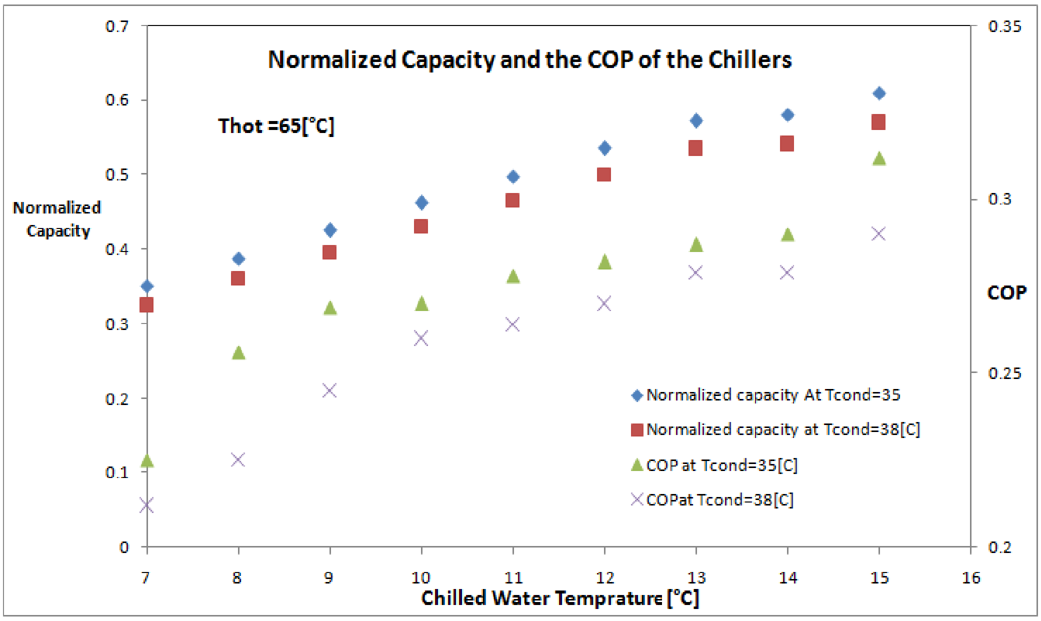



Figure10 Experimental performance of the adsorption chiller

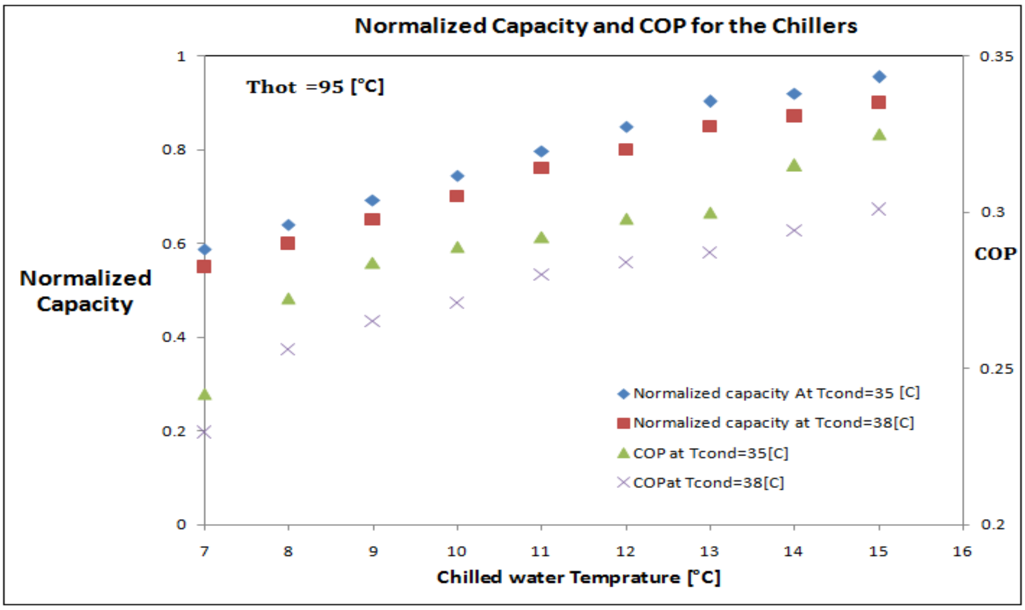



Figure11 Normalized capacity and COP of the adsorption chiller

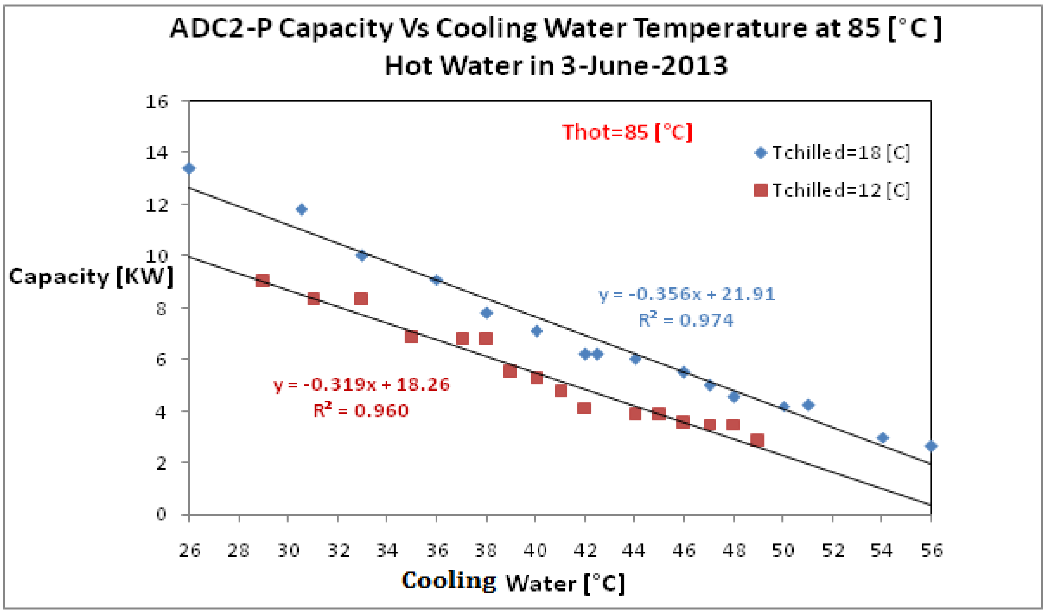



Figure 11Capacity of the adsorption chiller

Based on the experimental data a multi- variable analysis carried out, it was found that the COP for the adsorption chiller obeys the following formula:

$$COP = 0.043638 T_{chilled} - 0.00787 T_{cw} + 0.0010515 T_{hot} \quad (1)$$

On other hand, it was also found that the cooling capacity for the adsorption chiller obeys the following formula based on the experimental data.

$$\dot{Q}_{cooling} = 0.034638 T_{chilled} - 0.00887 T_{CW} + 0.10341 T_{HOT} \quad (2)$$

where

$T_{chilled}$ : Temperature of the chilled water in [°C]

$T_{cw}$ : Temperature of the cooling water in [°C]

$T_{hot}$ : Temperature of the hot water in [°C]

Chillers capacity produced in clear sky day is shown in figure 12.It is clearly could observed that the nominal capacities of these chillers are obtained in this day, it is almost around 20 kW.

Total annual evaluation for the STGS was carried out and it is shown in figure 13.The annual production of the two chillers were 35.1MW-hr.

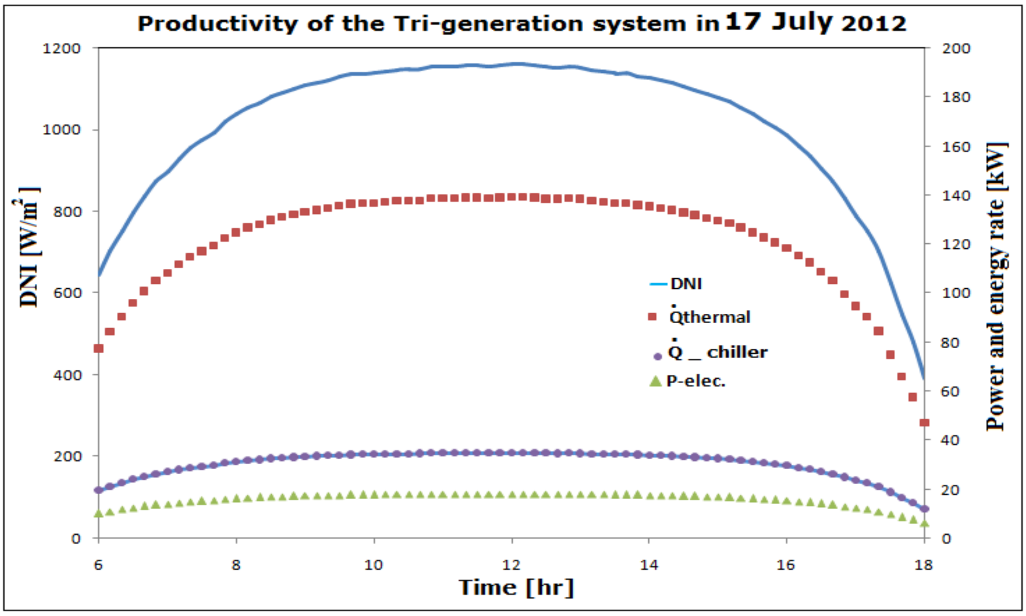



Figure 12 Energy rates of the adsorption chiller withen the STGS in clear sky day

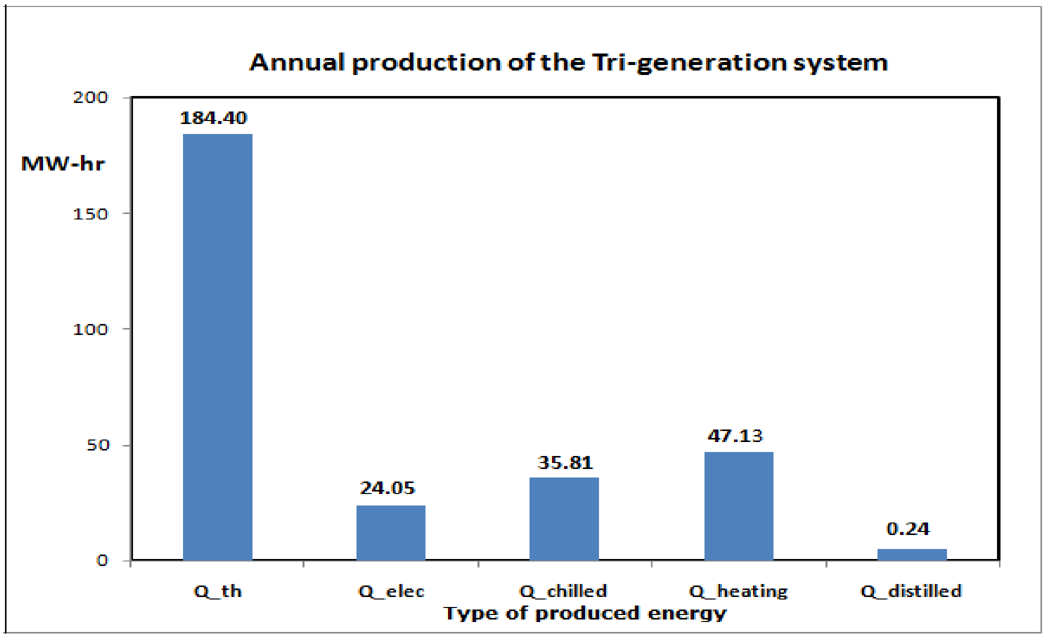



Figure 13 Annual cooling productionwithin the STGS

## 4. Conclusions:

The performance of the adsorption chillers was conducted and determined, the COP and the normalized capacity of these chillers were obtained. It was found that the best values of COP and the normalized capacity are 0.3, 0.91 respectively at hot water temperature of 95[°C] and chilled water temperature of 16 [°C] and Temperature of condensation or re-cooling of 35[°C]. While the lowest values of the COP and the normalized capacity were 0.21, 0.1 respectively at hot water temperature of 65[°C] and chilled water temperature of 7 [°C] and Temperature of condensation or re-cooling of 35[°C].

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