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Using Solar Energy and Photovoltaic Power in Air-Conditioning Processes by Adsorption Technique

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Abstract

The research is present the heat-driven adsorption chiller performance by using low temperature water which be extracted from the solar energy through using photovoltaic solar panels and solar thermal collectors as a main energy source. The adsorption system employs the silica gel-water as the adsorbent. Also this system has an advantage such as the maintenance is low, no major parts movement and environmental friendly. The numerical simulations have been carried out for heat sources temperatures ranged between 60-80°C, chilled water and cooling from 15 °C to 35 °C respectively. Program in FORTRAN was built to achieve the numerical simulation for adsorption system. The results indicated the coefficient of performance for lower hot water temperature is increased with time processes of heating or cooling. The refrigeration capacity for high hot water temperature is increased with time processes of heating or cooling while the effect of low hot water temperature is low.

Keyword: photovoltaic, solar energy, Adsorption

استخدام الطاقة الشمسية والطاقة الكهروضوئية في عمليات تكييف الهواء بواسطة تقنية الامتزاز

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المستخلص

يقدم البحث الحالي دراسة أداء منظومة تبريد تعمل بتقنية الامتزاز باستخدام ماء ساخن بدرجة حرارة واطئة يمكن الحصول عليها من الطاقة الشمسية وذلك من خلال استخدام طاقة الخلايا الشمسية والمجمعات الشمسية كمصدر اساسي لطاقة النظام .

تستخدم المنظومة الماء-هيلام السيليكا كمكثّف لعمل النظام. الفائدة الرئيسية لاستخدام أنظمة التبريد التي تعمل بتقنية الامتزاز هي عدم وجود أجزاء متحركة ، تحتاج إلى صيانة قليلة إضافة إلى إنها صديقة للبيئة. المحاكاة العددية نفذت لمصدر ذي درجة حرارة تتراوح بين 60 °C الى 80 °C ودرجة حرارة الماء المثلج وماء التبريد من 15 °C إلى 35 على الترتيب، لإنجاز الحل للمحاكاة العددية تم بناء برنامج بلغة فورتران 90 لإنجاز المحاكاة العددية، النتائج بينت إن معامل الأداء يزداد مع الزمن عند درجة حرارة الماء الساخن الواطئة. سعة التبريد تزداد مع زمن اشتغال المنظومة لحالة درجة حرارة الماء العالية.

الكلمات المفتاحية :- الطاقة الكهروضوئية، الطاقة الشمسية، الامتزاز

Introduction

In Iraq, the refrigeration and air condition systems are major energy consumers. These systems normally use CFCs as working fluid that induces ozone depletion and consequently greenhouse effect. The solid adsorption system is considerably an alternative way to reduce of CFC usage [1].

Adsorption cooling equipment can be converted for using -heated fluids with solar, also the modification was suggested for high performance applications of solar is not have major design changes. The adsorption equipment represent the majority of units used in solar air-conditioning systems in future. The water sent to the absorption generator is heating by solar collectors and photovoltaic array, the DC power supplied by PV require battery for energy storage, and fed to one or more resistive elements that are immersed in a water storage tank. The coefficients of performance used for solar adsorption equipment will be the same as those used for the steam-driven adsorption equipment, since no boiler losses are involved [2,3]

Carl Munters develop the adsorption cycle, and is often known as the Munters system. This system drying the air with various kinds of crystals, salts, silica gel, or zeolite. Heat and moisture are typically exchanged between an exhaust air stream and air stream using a heat exchange wheel and a drying wheel as shown in figure (1) [4].

In order to keep the heat exchange is cool, the exhaust air takes ambient air to humidifies and cools it. Additional heat from a solar or gas source is added to the air stream passing through the heat exchange wheel, because the air is still not hot enough to drive the moisture out of the drying wheel, so that Through the drying wheel the hot air are passes to evaporates moisture from the desiccant, and the moist, heated air is exhausted to the atmosphere [5].

In Iraq, the solar cooling was initiated since 30–35 years ago; however, none of commercially system was demonstrated though many works were being done. The major difficulties needed to overcome were its naturally non-continuous processes, requirement of maintain vacuum conditions and leakage problems. This research work has focused on the development of a combined solar/solid adsorption system, which was prediction for hot water and cooling production. The system was theoretically study, and coefficient of performance (COP) was estimated as well as its operational performance.

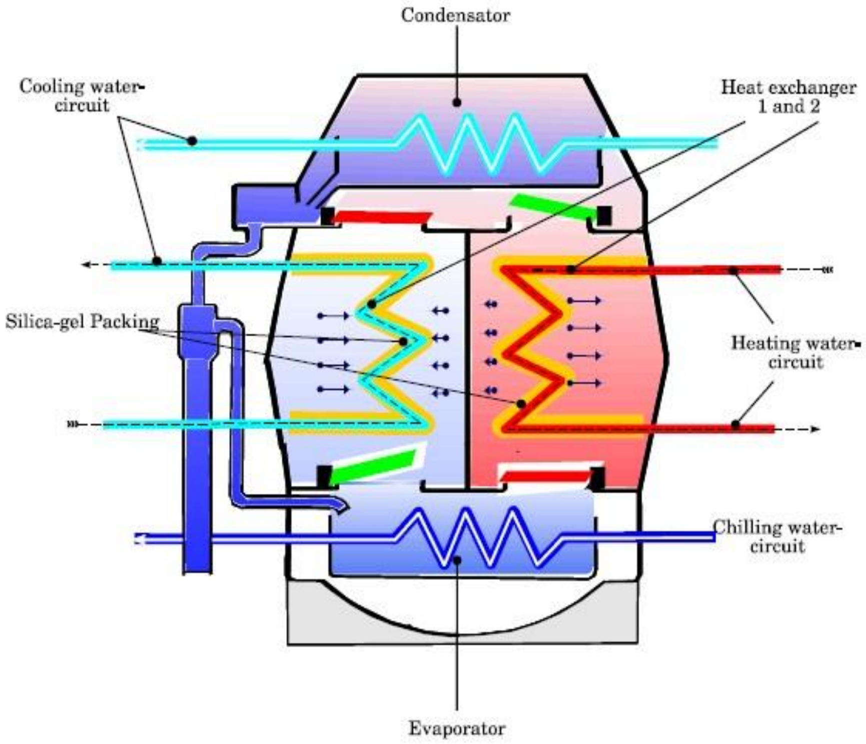

Figure (1): Schematic diagram of absorber system [4].

Objective of Research

Many adsorption systems were developed by various research groups to improve their coefficient of performances (COP). The solar adsorption system, the schematic diagram is shown in figure (2) .Due to of the low regeneration temperature of silica gel and the high latent heat of vaporization of water, the silica gel–water has been selected as the adsorbent–adsorbate pair. And to improve the cooling effect, a strategy of mass recovery cycle is proposed. This study is different from the conventional mass recovery cycle because no cooling process and heating during the process of mass recovery in conventional mass recovery cycle. In this strategy additional cooling accelerate the desorption/adsorption and heating process; therefore the system improving the cooling output.

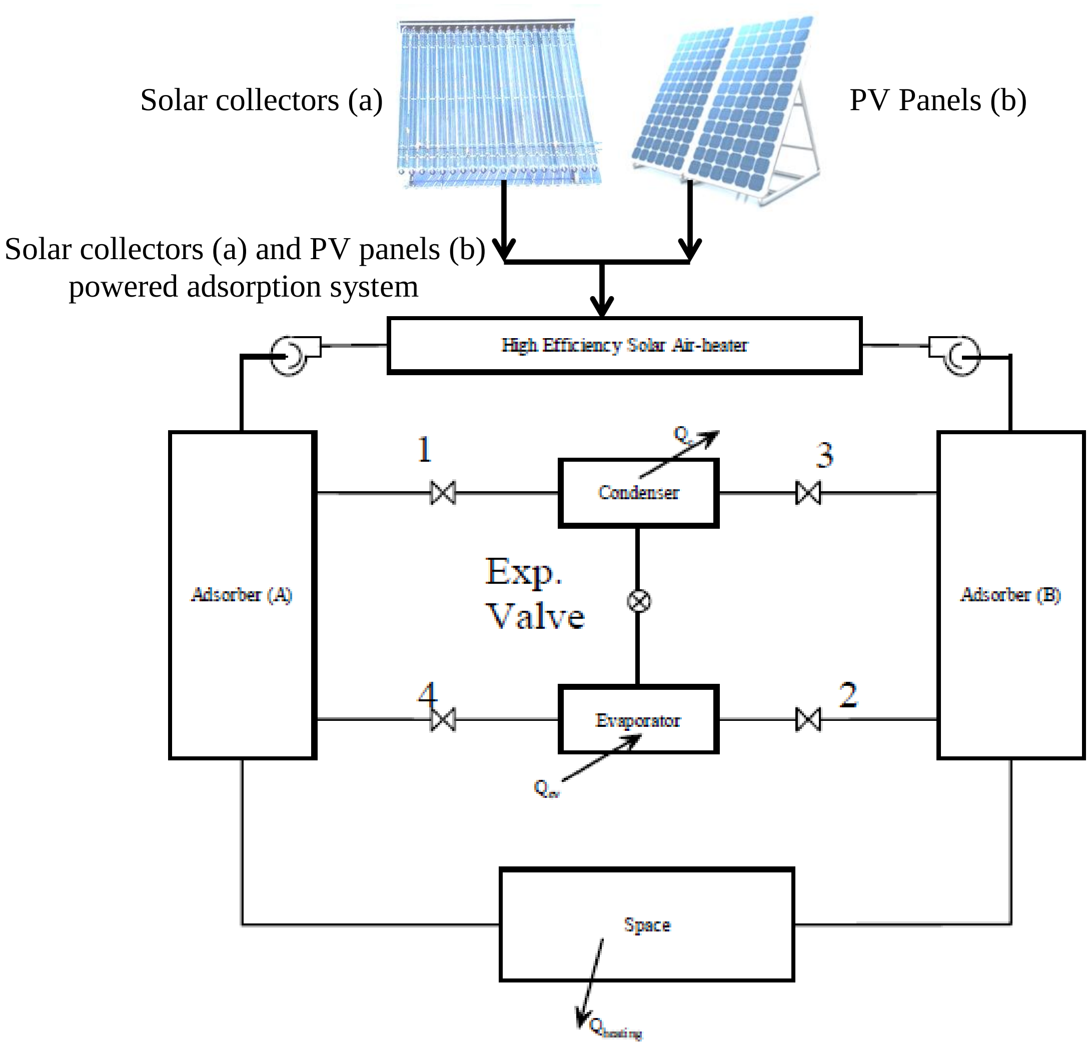

Figure (2): Block diagram for proposed system [5].

Mathematical Model

The mathematical model is built according to the model described in [7] . The assumptions of this model are:

1. uniform the temperature and the pressure through the adsorbed whole
2. the water is a uniformly adsorbed
3. difference of the pressure are neglected between the absorber and condenser .
4. the saturated vapor inside the chamber.
5. the system has no heat loss to environment.

Components of the system used in the current study and shown in Figure (2) of the following parts: Photovoltaic solar panel, Solar collector system, in turn, consists of the complex solar thermal reservoir, Adsorption cooling system, Pumps and control equipment, Air handling unit or fan coil unit. Photovoltaic (PV) convert the solar radiation to electricity in terms of direct current (dc) using semiconducting materials. In adsorption system can be powered using PV where the PV panels produce dc electrical which is coupled to the electrical heater of the adsorption system. The main concerns in designing a PV adsorption system include suitably matching the electrical characteristics of the electrical heater powered the adsorption system with the available voltage and current being produced by the PV panels. The electricity production rate of being generated by a PV panels is typically based on solar radiation of 1000 W/m^2 and temperature of 25°C. Moreover, the electricity produced by a PV panels is as a parameter as the solar energy from which it is powered [8].

Basic governing equations used in the mathematical model to represent the system mathematically. To calculate the solar energy collected, where collected of solar energy and is represented mathematically as follows [9]:

$$Q_{Coll} = TF\dot{m}_c C_p \left(T_{f,o} - T_s\right) \qquad (1)$$

Where TF represents a conversion function to control the temperature and is equal to one of eight in the morning until ten at seven and is zero for the rest of the hours [9].

The efficiency of solar collector for both photo-voltaic collectors and solar thermal collectors can be defined as following:

$$\eta_{coll} = \frac{Q_{useful}}{A_a I_a} \qquad (2)$$

Where, Q represents the output energy, A is aperture area of solar collector, *I* represents solar radiation.

The efficiency of the photo-voltaic panels can be defined by the following equation as:

$$\eta_{PV} = \eta_R \left[1 - \beta\left(T_C - T_R\right)\right] \qquad (3)$$

Where, η_R represents the reference efficiency at 0 °C, β is a coefficient of variation of the photo-voltaic efficiency, T_C is the temperature of photo-voltaic cell/panel, and T_R is the reference temperature. The available commercial photo-voltaic panels were ranged between 10-17% and it can produce 1.5 kWh/m^2.day where the current is proportional to the light contact area.

The temperature of the photo-voltaic can be calculated based on the assumption of the absorbing temperature of plate equal to panel temperature according to the following equation:

$$T_{PV} = T_i + \frac{1 - FRQ_T}{F_R U_L}\left[1 - \beta\left(T_C - T_R\right)\right] \tag{4}$$

Where, T_i represents the inlet temperature, F_R is heat removal factor, Q_T is total energy, U_L loss coefficient, and A_c is the panels area.

$$m_s C_p \frac{dT_s}{dt} = \dot{m}_c C_p\left(T_{w,o} - T_s\right) + \dot{m} C_p\left(T_R - T_s\right) + (UA)_s\left(T_a - T_s\right) \tag{5}$$

Where

$$T_s = \frac{T_{s1} + T_{s2}}{2}$$

$$\frac{dT_s}{dt} = \left(\frac{\dot{m}_c C_p}{mC_p} T_{co} + \frac{\dot{m}_L}{mC_p} T_r + \frac{(UA)_s}{mC_p} T_a\right) - \left(\frac{\dot{m}_c C_p}{mC_p} + \frac{\dot{m}_L}{mC_p} + \frac{(UA)_s}{mC_p}\right)\left(\frac{T_{s1} + T_{s2}}{2}\right) \tag{6}$$

Where

$\dot{m}$ Mass flow rate, $\dot{m}_c$ Water mass flow rater through solar collector,

$\dot{m}_L$ Water mass flow rate from storage tank

The adsorption rate can be written as [7]

$$x = 0.346\left(\frac{P_s T_w}{P_s T_s}\right)^{1/1.6} \tag{7}$$

(1) the adsorber/desorber energy balance written as:

$$\frac{d}{dt}\left\{\left[m_a\left(C_a + C_{p,w}x\right) + C_{cu}M_{tube,ad} + C_{al}M_{fin,ad}\right]T_a\right\} = m_a \Delta h \frac{dx}{dt} +$$

$$(1-\delta)C_{wv} m_a \frac{dx_{ads}}{dt}\left(T_e - T_a\right) + \dot{m}C_{p,w}\left(T_{ad,in} - T_{ad,out}\right) \tag{8}$$

$$\frac{T_{ad,out} - T_a}{T_{ad,in} - T_a} = e^{\left(\frac{-KA_{ad}}{\dot{m}_w C_{p,w}}\right)} \tag{9}$$

where δ=1 for desorption process and δ=0 for adsorption process, k is thermal conductivity

(2) the condenser energy balance

$$c_{cu} m_c \frac{dT_c}{dt} = \delta \begin{bmatrix} -Lm_a \frac{dx_{des}}{dt} + c_{wv} m_a \frac{dx_{des}}{dt} (T_c - T_a) \\ + \dot{m}_{cool} C_{pw} (T_{cool,in} - T_{cool,out}) \end{bmatrix} \tag{10}$$

$$\frac{T_{cool,out} - T_c}{T_{cool.in} - T_e} = e^{\left(\frac{-KA_c}{\dot{m}_{cool} C_{p,w}}\right)} \tag{11}$$

(3) the evaporator energy balance

$$\frac{d}{dt}\left[(C_{pw} m_{e,w} + C_{cu} M_e) T_e \right] = (1-\delta)\left[-LM_a \frac{dx_{ads}}{dt} + \dot{m}_{chill} C_{p,w} (T_{chill,in} - T_{chill,out}) \right] +$$
$$\delta \left[\theta C_{p,w} (T_e - T_c) m_a \frac{dx_{des}}{dt} - (1-\theta) L m_a \frac{dx_{des}}{dt} \right] \tag{12}$$

$$\frac{T_{chill,out} - T_e}{T_{chill,in} - T_e} = e^{\left(\frac{-KA_e}{\dot{m}_{chill} C_{p,w}}\right)} \tag{13}$$

where

$\theta = 1$ *for* $T_c \leq T_e$ *and* $\theta = 0$ $T_c > T_e$

(4) the equilibrium liquid refrigerated in evaporator

$$\frac{dm_{e,w}}{dt} = M_{e,o} - M_a \frac{dx}{dt} \tag{14}$$

(5) the mass equilibrium equations in process recovery

$$-m_a \frac{dx_{des}}{dt} + \dot{m}_{e,evap} = \dot{m}_{e,cond} + m_a \frac{dx_{ads}}{dt} = \dot{m}_{mr} \tag{15}$$

The evaporator energy equation in

$$\frac{d}{dt}\left[(C_{p,w} m_{e,w} + C_{cu} m_e) T_e \right] = -L\psi + \upsilon \dot{m}_{chill} C_{p,w} (T_{chill,in} - T_{chill,out}) \tag{16}$$

where

$\psi = \dot{m}_{e,evap}$ for the chamber desorbing and $\psi = \dot{m}_{e,cond}$ for the chamber adsorbing

And $\upsilon = 1$ for $T_e \leq T_{chill,in}$ and $\upsilon = 0$ for $T_e > T_{chill,in}$

We can calculate The pressure in the chambers by this equattion:

$$P_{wv,des} - P_{wv,abs} = \frac{v_{wv} \dot{m}_{mr}^2}{2A^2} \tag{17}$$

the equation of Van Der Waals is calculate parameters of water vapor:

$$\left(P_{wv} + \frac{a}{v^2} \right) (v - b) = RT_{wv} \tag{18}$$

And the Refrigerating capacity Performance as follows:

$$Q_{ref} = \frac{\int_0^t C_{p,w} \dot{m}_{chill} \left(T_{chill,in} - T_{chill,out}\right) dt}{t_{cycle}} \tag{19}$$

heating power is

$$Q_h = \frac{\int_0^t C_{p,w} \dot{m}_h \left(T_{h,in} - T_{h,out}\right) dt}{t_{cycle}} \tag{20}$$

the performance of coefficient calculate from [10]

$$COP = \frac{Q_{ref}}{Q_h} \tag{21}$$

$$COP_h = \frac{\left(M_{wt} C_{p,w} \frac{dT_{wt}}{dt} + Q_{ads}\right)}{I_T A + Q_{aux}} \tag{22}$$

Results and Discussion

Figures (3), (4) and (5) show temperature profiles for hot, cooling and chilled water temperature for $\dot{m}_h$ = 0.6 kg/sec, $\dot{m}_c$ = 1.4 kg/sec and $\dot{m}_{ch}$ = 0.7 kg/sec respectively. These represent process of heating or cooling. The outlet temperature of hot water is approach to the inlet temperature after adsorber. Figure (6) show hot water effect inlet on the coefficient of performance and change it with operating time of adsorption system, we show increase of COP at $T_{h,w}$=60 ºC and decrease at $T_{h,w}$=80 ºC and we show opposite behavior for refrigeration capacity (RC) in figure (7).

Figure (8) show the behavior of coefficient of performance with time of mass recovery of hot inlet water temperature at 60 ºC and 80 ºC respectively, we show increase the performance coefficient and with increasing the inlet temperature hot water and the steady state of mass recovery reach at 140 sec approximately. The same behavior in figure (9) for refrigeration capacity. Figures (10) and (11) show variation of refrigeration capacity and the performance coefficient with hot water temperature at chilled water 15 ºC and 20 ºC respectively, we show increase coefficient of performance with increase hot water temperature and the same behavior for refrigeration capacity.

Figure (12) show the behavior the performance coefficient with cooling water temperature, found the coefficient of performance is decreased with increased cooling water temperature, the behavior in figure (13) for refrigeration capacity.

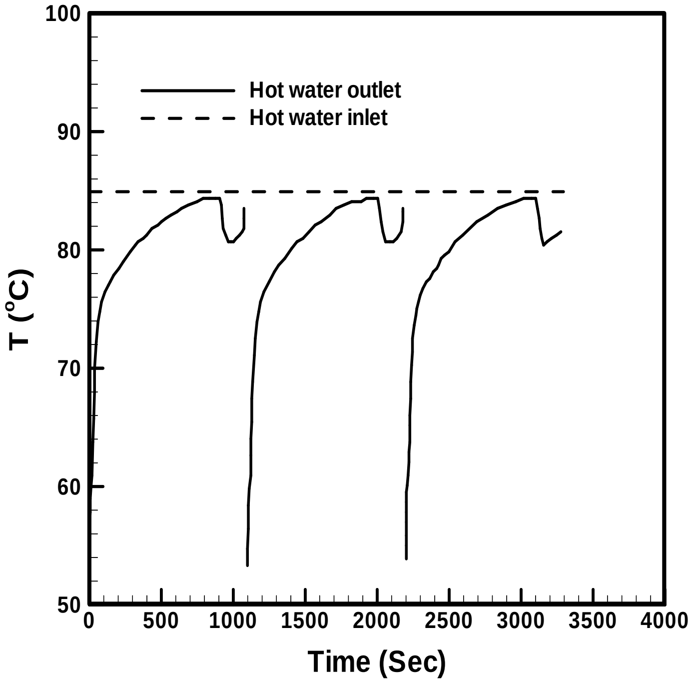

Figure (3): variation of hot temperature profile with operating time.

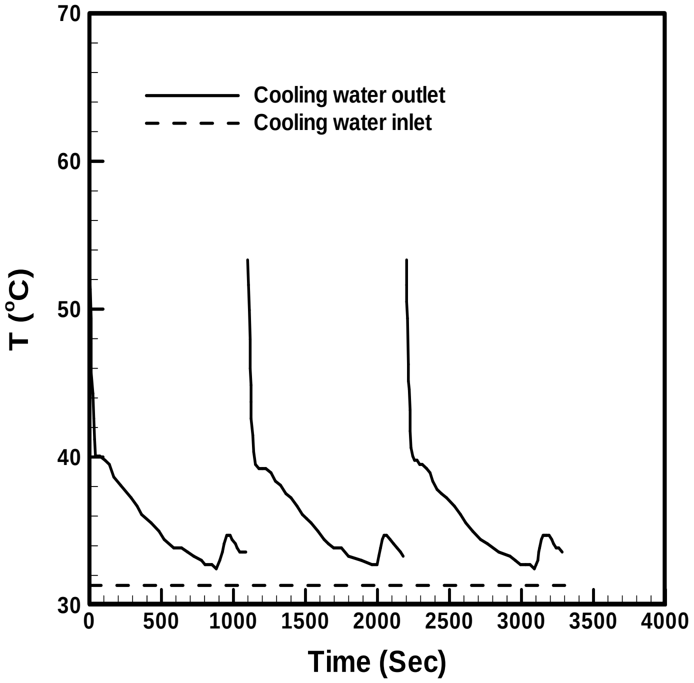

Figure (4): variation of cooling temperature profile with operating time.

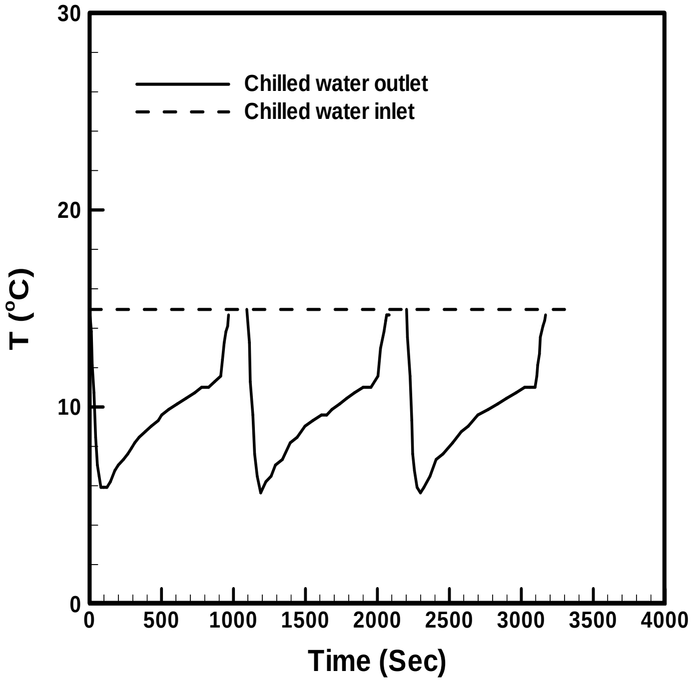

Figure (5): variation of chilled water temperature profile with operating time.

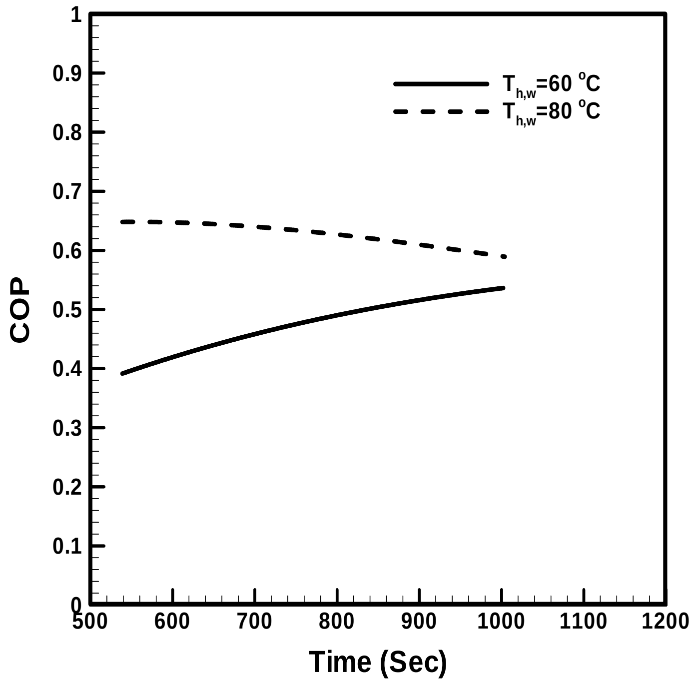

Figure (6):Variation of cooling time with coefficient of performance at different hot water inlet.

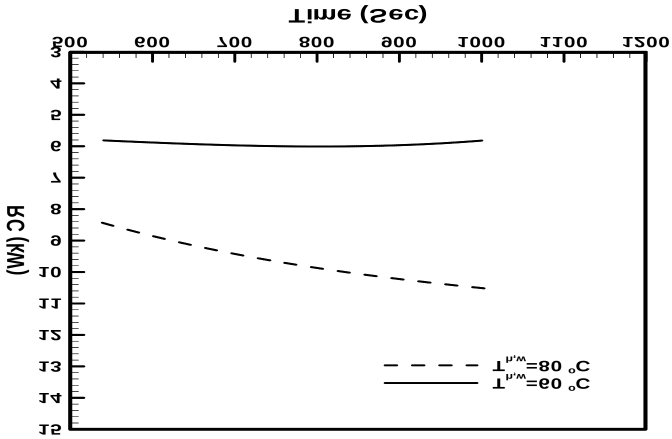

Figure (7):Variation of cooling time with refrigeration capacity at different hot water inlet.

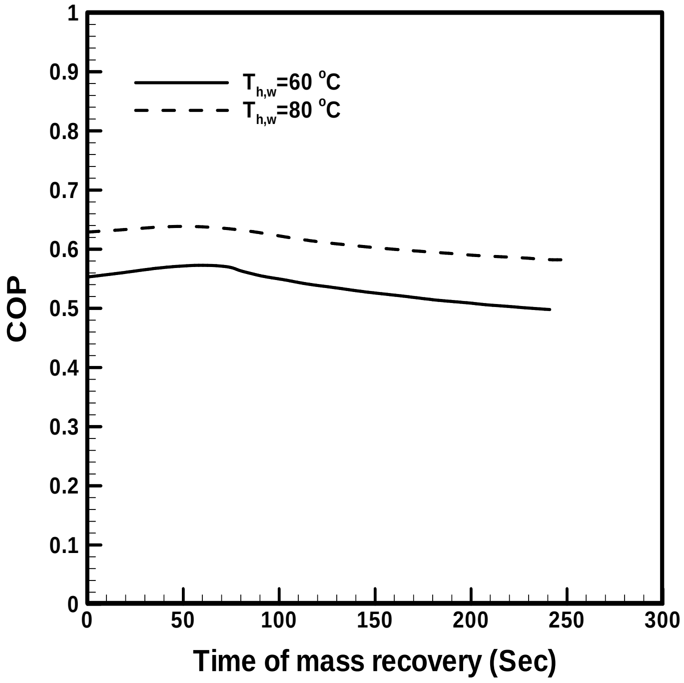

Figure (8): Variation of mass recovery time with coefficient of performance at different hot water inlet.

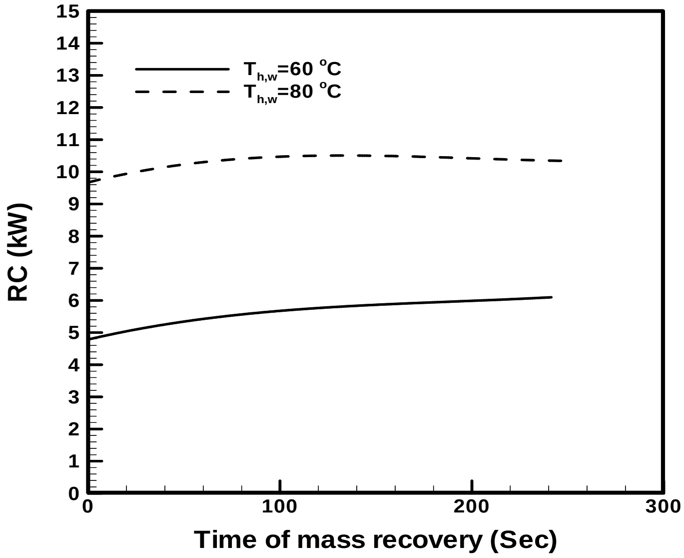

Figure (9):Variation of mass recovery time with refrigeration capacity at different hot water inlet.

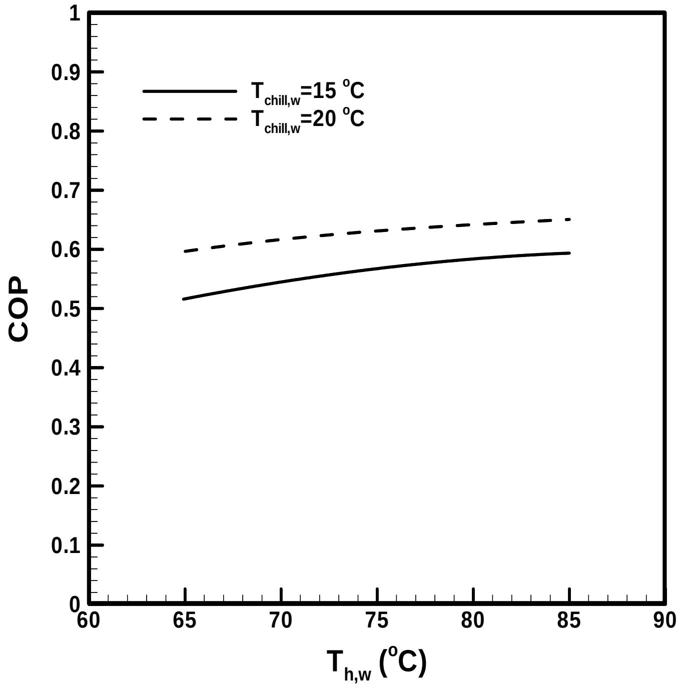

Figure (10): Variation of hot water inlet temperature with coefficient of performance at different chilled water inlet.

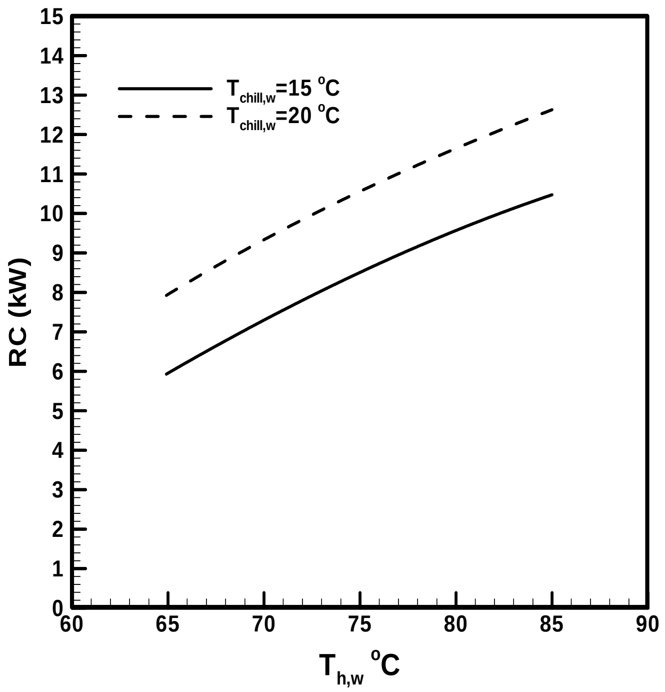

Figure (11): the temperature of inlet hot water and refrigeration capacity

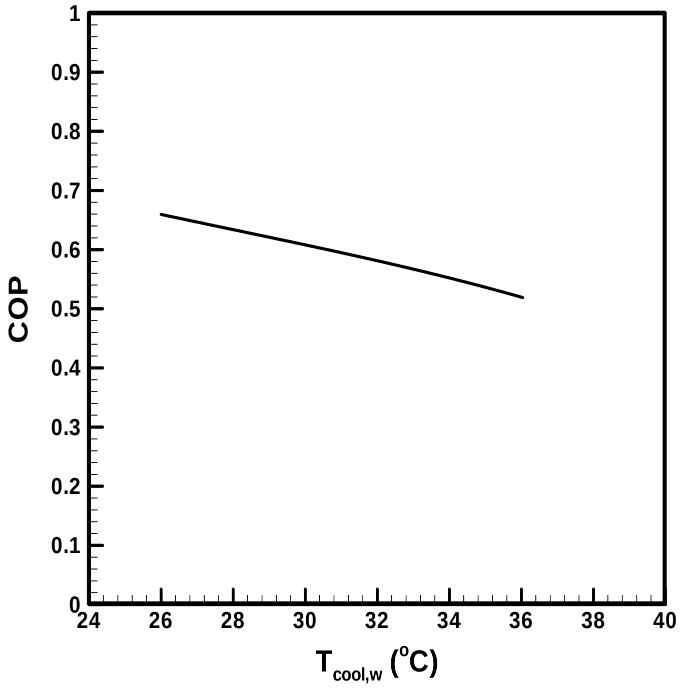

Figure (12): Variation of water cooling temperature with coefficient of performance.

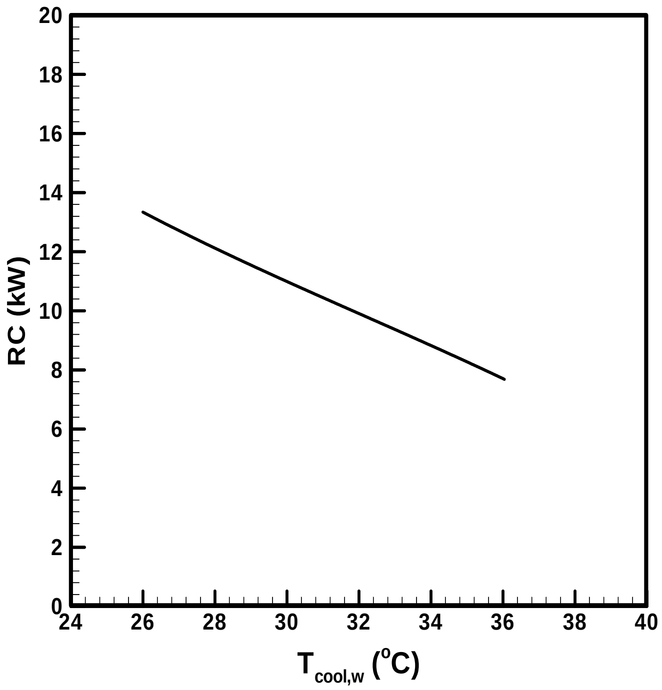

Figure (13): The cooling water temperature Variation with refrigeration capacity.

Conclusion

There is a significant amount from solar energy can be used at temperatures below 100 °C based on PV technology and thermal collectors. The exploitation of such energy can lead to a significant in energy saving which leads to reducing CO2 emissions and the consumption of fossil fuel. This work investigated ability of using the low-temperature heat sources like solar energy in adsorption system powered by solar collectors and PV panels. The extract of the mathematical model is difficult due to the empirical characteristics of adsorption theory, nonlinear system identification of adsorption processes. The COP for lower hot water temperature is increased with time processes of heating or cooling. The RC (refrigeration capacity) for high hot water temperature is increased with time processes of heating or cooling while the effect of low hot water temperature is low. The time of mass recovery reach at 150 sec. The COP and RC at chilled water temperature 20 ºC is greater than it's from 15 ºC. COP is decrease with increased cooling water temperature and the same behavior for RC.

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