SIMULATION SOLAR ELECTRICAL GENERATION POWER PLANT BY USING PARABOLIC TROUGH IN BASRA CITY

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ABSTRACT

A simulation for a solar thermal electric generating system with parabolic trough collectors in Basra city is presented. This system consists of three parts: solar collector fields to heating the working fluid, a storage system to store the thermal energy, and power conversion system to convert the thermal energy to electrical. The simulation is presented for all parts. The energy conversion of solar radiation into thermal power along the absorber tube of the parabolic collector is studied. The coupling between the collector and the thermodynamic cycle is made up by heat exchangers, yielding the characteristic temperatures of the cycle. The conventional Rankine cycle is used as the thermodynamic cycle, whereby the electric power is calculated. All calculations are performed according to Basra climate's conditions for 21st of each month in 2007.Engineering Equation solver (EES) software is used in this simulation. Good agreements are obtained when comparing the results of the collector outlet temperatures and gross power of the current model with experimental data belonging to the Solar Electric Generating Systems (SEGS) installed in the Mojave Desert in southern California, whose solar field is composed by parabolic trough collectors. The analytical model developed combines precision and flexibility, making it an attractive tool for simulation and design of solar power stations in Basra city.

Keywords: Parabolic trough solar collector, power plant system, Basra city.

محاكاةُ محطة توليد الطاقة الكهربائية باستخدام المجمعات الشمسية ذات القطع المكافئ الوعائي في مدينةِ البصرة

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الخلاصة

يقدّمُ هذا البحث محاكاة لمنظومة توليد طاقة كهربائيةٍ حراريةٍ شمسيةٍ تستخدم المجمعات الشمسية ذات القطعّ المكافئ الوعائي (trough parabolic) في مدينةِ البصرة. تَشْملُ هذه المنظومةِ ثلاثة أجزاءِ: المجمع الشمسي المستخدم لتَسْخين المائع الناقل للحرارةَ و منظومة لخزنِ الطاقةَ الحراريةَ ومنظومة تحويل الطاقة الحرارية إلى طاقة كهربائيةِ، تم عَمل المحاكاة لهذه الأجزاء الثلاثة. وقد

تمت دراسة تحويلَ طاقةَ الإشعاعِ الشمسي إلى الطاقة الحراريةِ على طول الأنبوب الماصَ للمجمعِ الشمسي ذي القطع المكافئ الوعائي. إنّ الربطِ بين المجمعِ الشمسي والدورة الثرموديناميكية للمحطة (thermodynamic cycle) تم بواسطة المبادّلات الحراريةِ، للحصول على درجاتَ الحرارة المناسبة لعمل الدورةِ. وقد فَرض أن منظومة تحويل الطاقة مكونة من محطة بخارية كهربائية تعمل بدورة رانكن التقليدية (conventional Rankine cycle)، حيث تم حساب الطاقة الكهربائية لهذه المحطة. لعمل المحاكاة لهذه المحطة أُختيرَ يوم (21) من كل شهر لعام 2007 وافترض انه يوم صحو وخالي من الغيوم. كما تم تصميم وتحليل هذه المحطة وفقا لظروف مناخ مدينة البصرة. لعمل المحاكاة استعملت برمجيات Engineering Equation Solver (EES) **.** أوضحت المقارنة بين نَتائِجَ النموذجِ الحالي مع النَتائِجَ التجريبيةِ التي تَعُودُ إلى أنظمةِ توليد الطاقة الكهربائيةِ الشمسيةِ الموجودة في صحراءِ موبيف في جنوب كاليفورنيا، التي يتكون حقلها الشمسي مِن مجمعات شمسية ذات القطعّ المكافىءِ الوعائي، توافقا كبيرا. أن الدقّةِ والمرونةِ للنتائجِ التحليليةِ النموذجيةِ المتطورةِ التي تم الحصول عليها، تجعلها أداة جذّابة للمحاكاةِ وتشجع على تصميمِ محطاتِ الطاقة الكهربائية الشمسيةِ في مدينةِ البصرة.

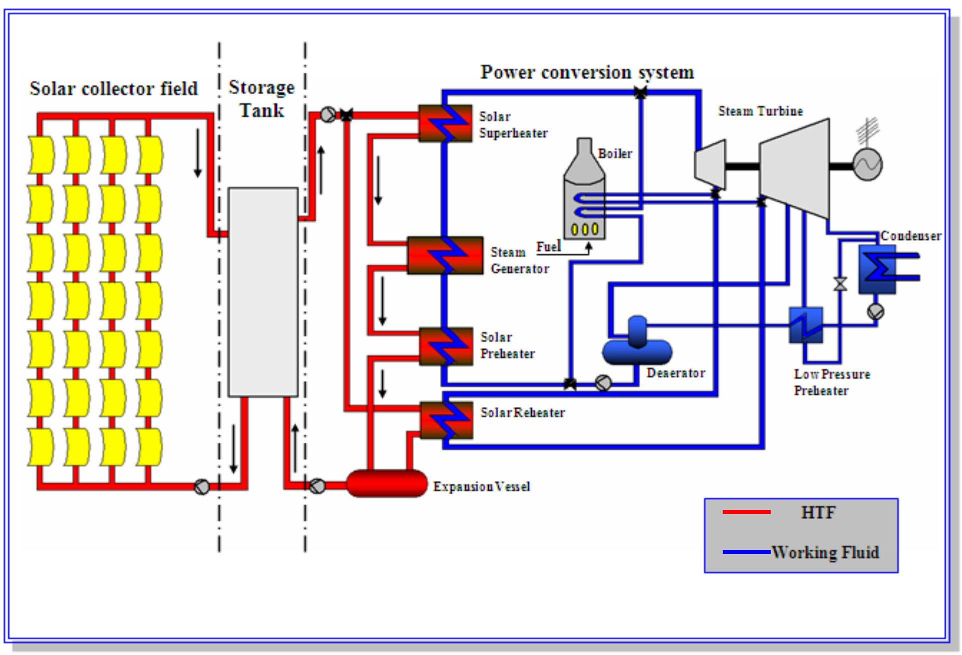
Nomenclatures

Symbol	Description
A	Apparent direct normal solar flux at the outer edge of the earth's atmosphere [W/m^2]
$A_{ABS,1}$	The cross-sectional area of the inside tube of the absorber[m^2]
A_{ABS}	The cross-sectional area of the absorber[m^2]
A_{ENV}	The cross-sectional area of the glass envelope [m^2]
B	Apparent atmospheric extinction coefficient
c_P	Specific heat at constant pressure[J/kg K**]**
$n_{collector}$	Total number of collectors in the field
$\overline{T}_{amb}$	The mean ambient temperature
UA	Overall heat loss coefficient between the tank and the environment [kJ/hr °C]
$\dot{V}_{HTF}$	Volumetric flow rate of the heat transfer fluid [m^3/s]
$\dot{m}$	Mass flow rate [kg/s]
ρ	The density [kg/m^3]

INTRODUCTION

Sustainable energy is energy that, in its production or consumption, has minimal negative impacts on human health and the healthy functioning of vital ecological systems, including the global environment. It is an accepted fact that solar energy is a sustainable form of energy, which has attracted more attention during recent years, as in Broesamle [1] 2001. Lippke 1995 [2] produced a detailed thermodynamic simulation model of the Solar Electric Generating System (SEGS) solar field and power cycle using easy simulation software (Lippke, 1995). The objective of this model was to simulate system behavior during part-load conditions (such as winter months and cloud covered days). Kribus et al. 1997 [3] demonstrated that the main results of a feasibility study of a combined cycle electricity generated plant, are driven by highly concentrated solar energy and high-temperature central receiver technology. Al-Sakaf 1998 [4] produced many international studies and experiences have been shown that the solar thermal power plants are the most economic form of the solar electricity generation. Almanza and Lentz 1998 [5] demonstrated that it is possible to generate electricity by direct steam generation in parabolic troughs. Saturated steam at 165 ^{o}C and 6.89 bars can be supplied to a 2.24 kW steam Stuart Swan motor of the two piston engine type in order to produce mechanical energy, as well as electric energy through a generator, using the recirculation process concept to produce steam. Beerbaum and Weinrebe 2000 [6] analyzed the potential and the cost-electiveness of centralized and decentralized Solar Thermal Electric (STE) generation in India. Comparing the levelized electricity costs (LEC) for STE with the corresponding LEC for the electricity generating options used at present, they find that STE is an economically viable technology under favorable conditions, i.e. in areas with high insolation levels and provided that capital is available at low interest rates.

A solar electric generating system (SEGS), shown in Figure (1), refers to a class of solar energy systems that use parabolic troughs in order to produce electricity from sunlight. The parabolic troughs are long parallel rows of curved glass mirrors focusing the sun's energy on an absorber pipe located along its focal line. These collectors track the sun by rotating around a north-south axis. The heat transfer fluid (HTF), an oil, is circulated through the pipes. Under normal operation the heated HTF leaves the collectors with a specified collector outlet temperature and is pumped to a central power plant area. There, the HTF is passed through several heat exchangers where its energy is transferred to the power plant's working fluid, which is water or steam. The heated steam is used in turn to drive a turbine generator to produce electricity. The facility discussed in this paper is the 30 MWe SEGS plant in Basra city.



Figure(1): Solar power plant system

THE PLANT MODEL

In the following the plant is divided into three subsystems: the solar collector field, the storage tank model, and the power plant model. All these models are shown schematically in Figure 1.

The Solar Collector Field

The thermal performance model of the SEGS parabolic trough plant is based upon a steady-state efficiency model for the collector using empirical coefficients [7,11].

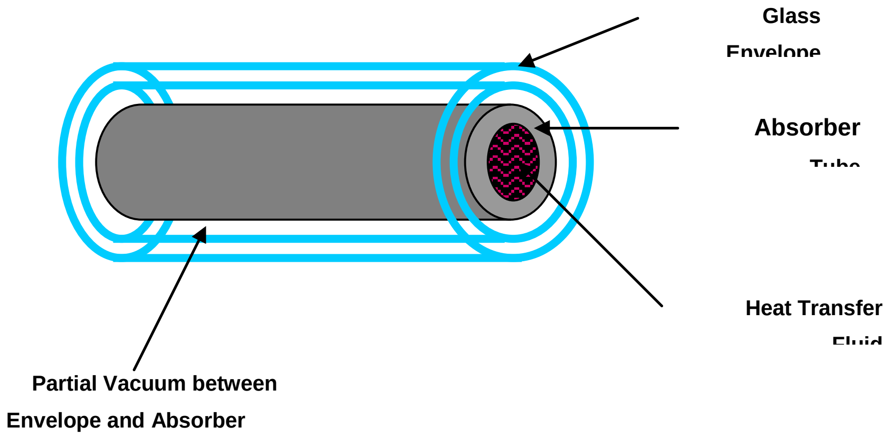


Figure 2: The Heat Collection Element

A detailed physical model for the collector is presented in this work. To derive the appropriate differential equations, the heat collection element (HCE) in Figure (2) is considered. The HCE consists of the absorber pipe in which the HTF flows. A glass envelope covers the absorber pipe, which is assumed to have no radial temperature gradients. Partial vacuum exists in the annulus between the absorber pipe and the glass envelope. A Transient energy balance for the HTF leads to the following partial differential equation for the HTF temperature:

$$\rho_{HTF} c_{P,HTF} A_{ABS,1} \frac{\partial T_{HTF}}{\partial t} = -\rho_{HTF} c_{P,HTF} \frac{\dot{V}_{HTF}(t)}{n_{collector}} \frac{\partial T_{HTF}}{\partial z} + Q_{gained} \qquad (1)$$

The distance along the collector is *z*, and *t* is the time. The boundary condition for equation (1) is:

$$T_{HTF}(0,t) = T_{HTF,inlet}(t) \qquad (2)$$

With $T_{HTF,inlet}$ as the HTF collector field inlet temperature. The initial condition for equation (1) is:

$$T_{HTF}(z,0) = T_{HTF,0} \qquad (3)$$

The differential equation for the absorber temperature is given through [12]:

$$\rho_{ABS} c_{P,ABS} A_{ABS} \frac{\partial T_{ABS}}{\partial t} = Q_{ABS,absorbed} - Q_{in.} - Q_{gained} \qquad (4)$$

The initial condition for equation (4.4) is:

$$T_{ABS}(z,0) = T_{ABS,0} \qquad (5)$$

The glass envelope is assumed to have no radial temperature gradients. The differential equation for the envelope temperature is given through [12, 13]:

$$\rho_{ENV} c_{P,ENV} A_{ENV} \frac{\partial T_{ENV}}{\partial t} = Q_{ENV,absorbed} + Q_{in.} - Q_{ex.} \quad (6)$$

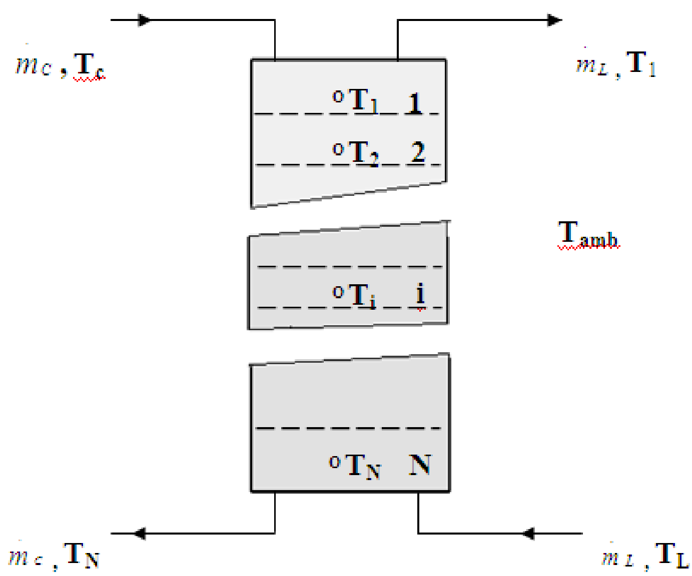
The initial condition for equation (4.6) is:

$$T_{ENV}(z,0) = T_{ENV,0} \quad (7)$$

The interacting dynamic of the temperatures given through the differential equations (1), (4) and (6) is determined by the heat transfer between the HTF, the absorber, and the envelope. The solar collector field model predicts the solar collector field outlet temperature well, especially for days with good weather conditions. Climate condition taken from the meteorological air of the city of Basra [14].

Storage Tank Model

For the simulation, the trough is assumed to provide heat to a thermal storage system. The advantage of having a thermal storage system is that it can store the thermal energy generated during the peak radiation hours for later use when solar radiation is unavailable. The simulation assumes that the tank may operate with significant degrees of stratification. The model approaches the thermal stratification of the tank by assuming that the tank consists of N fully-mixed volume segments, as shown in Figure 3. Higher values of N result in more stratification. For the special case of N=1 the tank is modeled as a fully mixed tank and no stratification effects are possible [15].



Figure(3): N-Node Tank

The governing differential equation for the ith node as follows [16, 17]:-

$$\dot{m}_i \frac{dT_{s,i}}{dt} = \left(\frac{UA}{c_P}\right)_i (T_{amb} - T_{s,i}) + F_i^C \dot{m}_C (T_C - T_{s,i}) + F_i^L \dot{m}_L (T_L - T_{s,i}) + F_i^1 \dot{m}_{m,i-1} (T_{s,i-1} - T_{s,i}) + F_i^2 \dot{m}_{m,i+1} (T_{s,i+1} - T_{s,i}) \quad (8)$$

Where the control functions are:-

F_i^C = 1, if fluid from heat source enters node i, 0 otherwise

F_i^L = 1, if fluid returning from load enters node i, 0 otherwise

F_i^1 = 1, if the netflow $\dot{m}_{m,i-1}$ enters node i from the node above

= -1, if the netflow $\dot{m}_{m,i-1}$ goes from node i to the node above

= 0, if there is no flowstream between node i and the node above

F_i^2 = 1, if the netflow $\dot{m}_{m,i+1}$ enters node i from the node below

= -1, if $\dot{m}_{m,i+1}$ goes from node i to the node below

= 0, if $\dot{m}_{m,i+1} = 0$

The Power Plant

In analyses of power cycle it is assumed that all flows of mass and energy are steady, so that the steady state conservation equations are applicable [18,19,20]. It is also assumed that all components are adiabatic and we neglect the usually small kinetic and potential energy differences between the inlet and outlet. The Rankine cycle is simplified as shown in figure 1 for easier modeling. The heat exchangers are considered to be a single heat exchanger instead of being divided into preheater, steam generator and superheater. It is now assumed that pure water is entering the single heat exchanger and superheated steam is leaving**.**

RESULTS AND DISCUSSION

The calculations were performed under Basra climate conditions for sunny days in 2007. Engineering Equation Solver software (EES version 6.287) was used to conduct the system calculations.
Figures (4-7) show the direct normal (I_{DN}) and direct (I_{DN} cosθ) solar radiation as a function of time. It is noted that I_{DN} increase from sunrise to reach a maximum value at mid-day after falling to reach zero at the sunset time. The component (I_{DN} cosθ) profile depended on the incident angle. Since the collector follow the sun path from east to west, the direct solar radiation (I_{DN} cosθ) increases at morning hours after a slightly decrease at mid-day due to non-zero incident angle. The useful solar radiation represents by (I_{DN} cosθ) is about 600 W/m^2 at the winter and 900 W/m^2 at the summer. Which represent a maximum value due to a small incident angle (about 6^o).
Figure (8) show the outlet fluid temperature of the collector during the four seasons. As it expected, the temperature profile related to the solar radiation component (I_{DN} cosθ) that absorbed by the collector tube.
Figures (10) and (11) show the gross power in[MW] vs. time for June and December, respectively, for pure solar plant and for solar plant that use storage tank.

In figures (12-15) the heat loss from the absorber tube increases with increasing of its length. This can be explained as for long absorber tube, the hydrodynamic losses of HTF flow increase and HTF of internal flow decreases which means increase in the heat losses to the surrounding.
Figures (16) and (17) show the relation between the efficiency of power cycle and month at (12:00 p.m.) for 21^{st} of each month in 2007 for the case of pure solar power plant cycle and for solar power plant supported by storage tank, respectively. It is noted that this efficiency reach to value about (35 %) during months from March to September in the case of pure solar power plant cycle. In case of solar power plant supported by storage tank, the efficiency has a similar value during the months from February to September.
Good agreements are obtained when comparing the results of the collector outlet temperatures and gross power for current model with experimental data belonging to the Solar Electric Generating Systems (SEGS) installed in the Mojave Desert in southern California [21], Figures(18) and (19) show the comparison of collector outlet temperatures and gross power on June respectively.

CONCLUSIONS

The most important conclusions that can be obtained from the present study are the followings:-

1- The solar field model shows that higher solar field outlet temperatures were achieved in the summer and spring for specified chosen days in 2007. The system model also shows that higher gross electric power production was achieved in summer and spring for specified chosen days in 2007.
2- The performance difference is more noticeable in the summer months than in the winter months.
3- The simulation is a reliable tool to predict the system performance under various environmental conditions.
4- The results of this study give guidance for the possible use of parabolic trough application for the Bio Sun project in Basra city.

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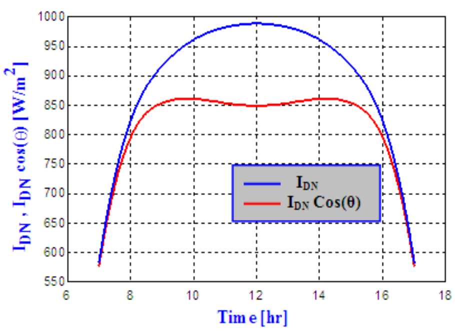

Fig. 4: The Direct Normal Radiation and its component vs. time for Basrah city on 21 March 2007

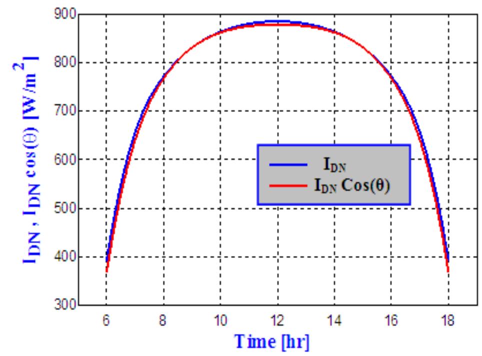

Fig. 5: The Direct Normal Radiation and its component vs. time for Basrah city on 21 June 2007

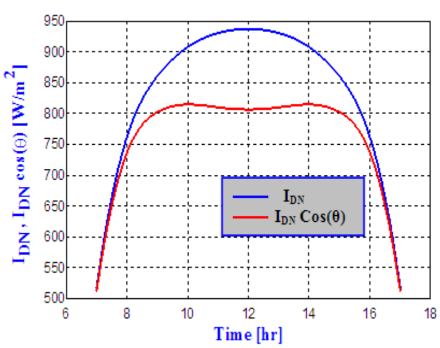

Fig. 6: The Direct Normal Radiation and its component vs. time for Basrah city on 21 September 2007

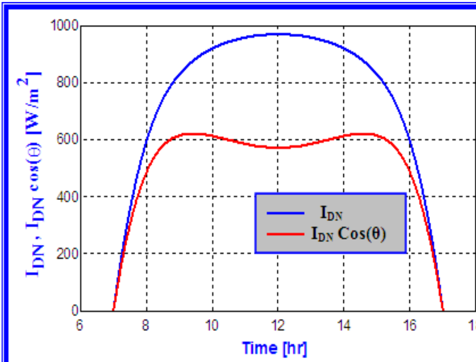

Fig.7: The Direct Normal Radiation and its component vs. time for Basrah city on 21 December 2007

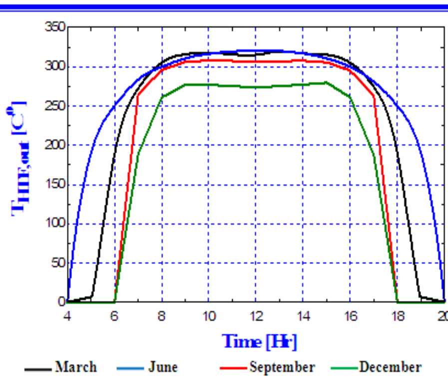

Fig.8: Collector outlet temperature vs. time on 21 2007 for four months..

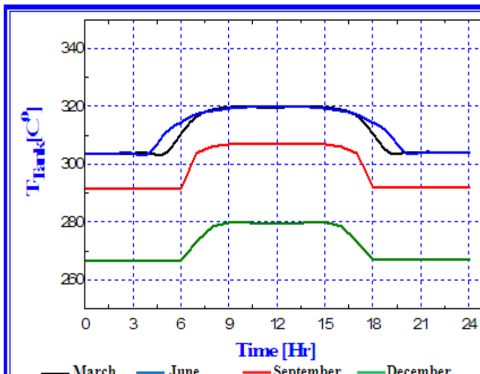

Fig. 9 : Storage Tank temperature vs. time on 21 2007 for four months.

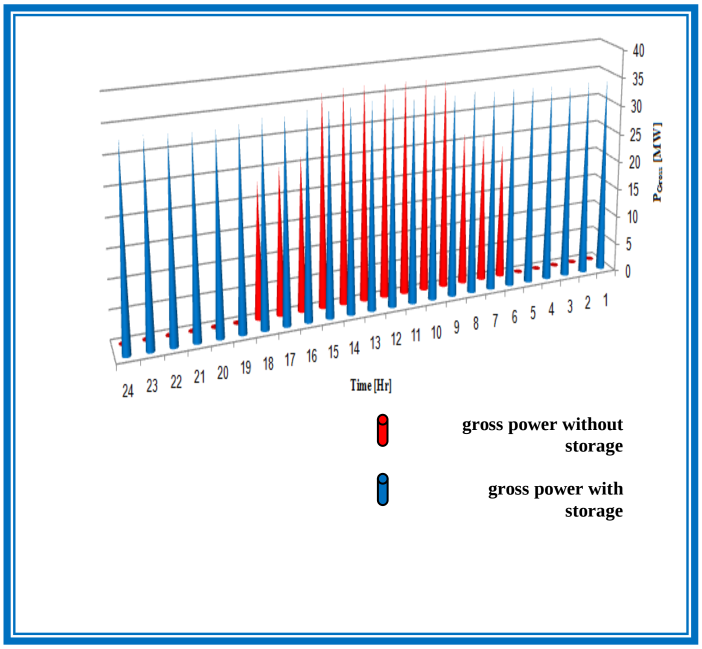

Figure (10): Calculated gross power output (with and without storage tank) vs. Time on 21 June 2007.

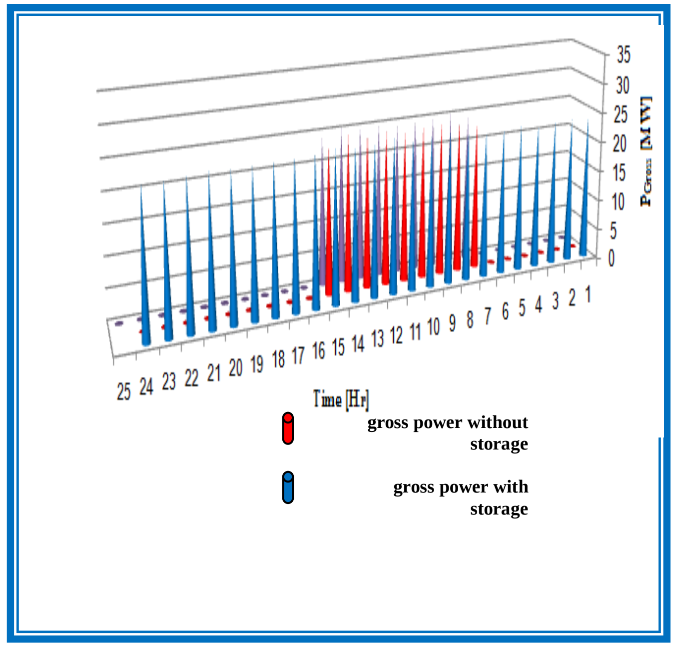

Figure (11): Calculated gross power output (with and without storage tank) vs. Time on 21 December 2007.

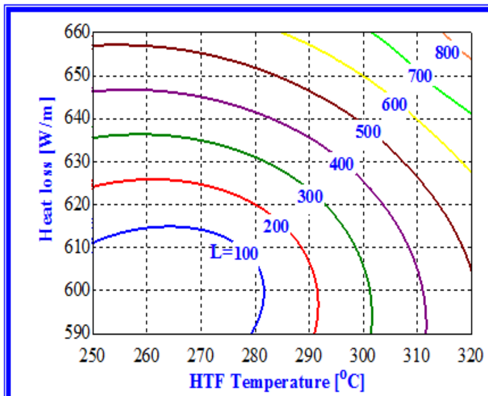

Fig.12: Heat Collector Element length lines (m) against overall heat losses and HTF Temperature on 21 March 2007.

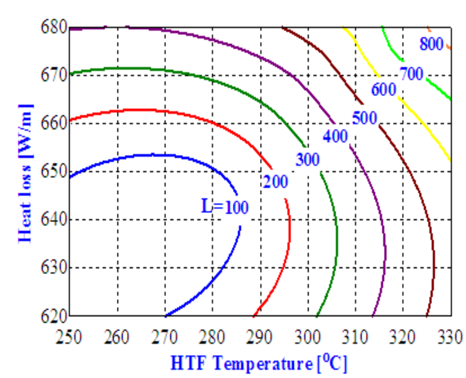

Fig. 13 : Heat Collector Element length lines (m) against overall heat losses and HTF Temperature on 21 June 2007.

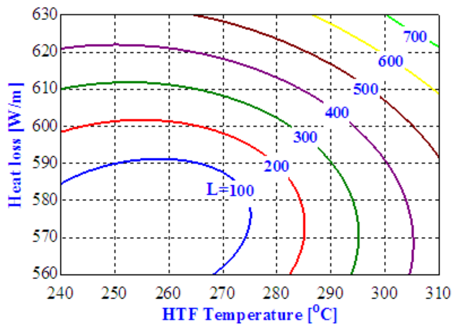

Fig. 14 : Heat Collector Element length lines (m) against overall heat losses and HTF Temperature on 21 September 2007.

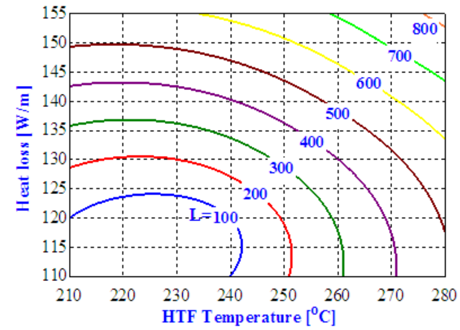

Fig. 15 : Heat Collector Element length lines (m) against overall heat losses and HTF Temperature on 21 December 2007.

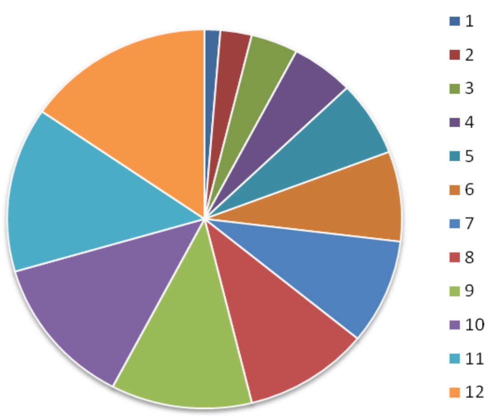

Fig. 16: The efficiency of the power cycle vs. months without storage tank.

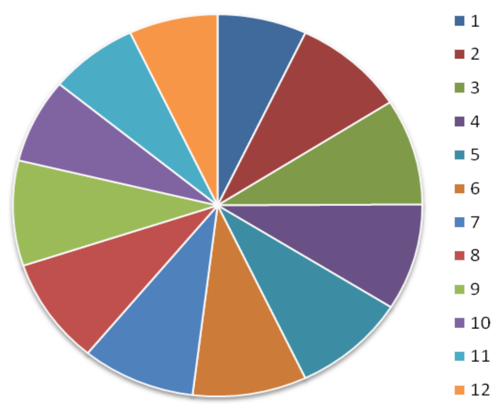

Fig. 17: The efficiency of the power cycle vs. months by using storage tank.

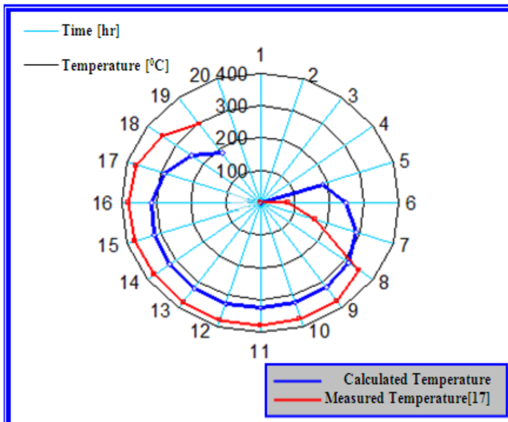

Fig 18 : Collector outlet temperature vs. time on June.

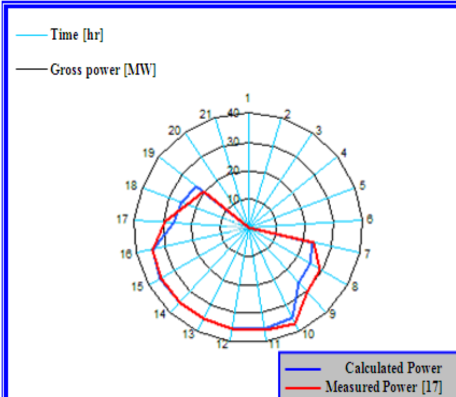

Fig. 19 : Gross power vs. time on June.