THERMODYNAMICS PERFORMANCE AND HEAT TRANSFER ANALYSIS OF PARABOLIC TROUGH COLLECTOR IN SOLAR POWER PLANT

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FACULTY OF ENGINEERING
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RESEARCH REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF ENGINEERING

FACULTY OF ENGINEERING
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2013

UNIVERSITI MALAYA
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Field of Study: Renewable Energy, Heat transfer

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Abstract

Today, solar energy can play a vital role in the world. Parabolic trough collector is one type of solar devices that play an important role in the power system. The main components of parabolic trough collector are curve mirror and receiver system. Iran is one of the potential countries that use parabolic trough power plant system. In this research thermodynamics performance like exergy and thermal efficiency will be considered on the first, tenth, fifteenth, twentieth, twenty-fifth and thirtieth of September. Iran will be considered as a case study in whole time. Then, heat transfer in different parts of receiver system will be analyzed at 250˚C. Based on some experimental tools, temperature and mass flow rate and solar parameter, can be estimated when it comes to thermodynamics and heat transfer values. The result shows that the value of exergy and thermal efficiency on the first of September is the highest. Second law efficiency on the first of September at 12 noon is around 10% and the value of exergy at that time is approximately 15.5kJ/kg in collector system. The value of convection heat transfer between the heat transfer fluid and the receiver pipe was around 15.5kW in 250˚C.

Abstrak

Kini, tenaga solar boleh memainkan peranan penting di dunia. Pengumpul palung parabola adalah satu jenis peranti solar yang memainkan peranan penting dalam sistem kuasa. Komponen utama pengumpul palung parabola adalah cermin melengkung dan sistem penerima. Iran adalah salah satu daripada negara berpotensi yang menggunakan lojikuasa sistem palung parabola. Dalam kajian ini pada prestasi termodinamik seper ti exergy dan kecekapan haba akan dipertimbangkan dalam satu, 5,10,15,20,25 dan 30 daripada September dalam masa keseluruhan akan dipertimbangkan pada satu negara contoh Iran. Iran akan dianggap sebagai kajian kes dalam keseluruhan masa. Kemudian, pemindahan haba di bahagian-bahagian berlainan dari sistem penerima akan dianalisis pada 250˚C. Berdasarkan beberapa alat eksperimen, suhu dan kadar aliran jisim dan solar parameter boleh dianggarkan apabila datang kepada termodinamik dan nilai pemindahan haba. Hasil menunjukkan bahawa nilai exergy dan kecekapan haba pada satu September merupakan yang tertinggi. Kecekapan hukum kedua pada satu September pada pukul 12 petang adalah sekitar 10% dan nilai exergy pada masa itu kira kira 15.5kJ/kg dalam sistem pengumpul. Nilai pemindahan haba perolakan antara cecair pemindahan haba dan penerima paip adalah sekitar 15.5kW dalam 250˚C.

Acknowledgement

I take this opportunity to express my profound gratitude and deep regards to my guide (Dr. Irfan Anjum Magami) for exemplary guidance and constant encouragement throughout the course of this thesis. Also, I thank my wife (Najmeh Azizabadi) for her constant encouragement without which this theses would not be possible.

OMID AFSHAR

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Nomenclature

a: accommodation coefficient (-)

b: interaction coefficient (-)

c_p: specific heat capacity (J/kg°K)

c_{fi}: Cloudy factor (-)

D_o: outside receiver pipe diameter (m)

D_{pi}: inside diameter of the receiver pipe (m)

D_{go}: outside glass envelope diameter (m)

D_{gi}: inside glass envelope diameter (m)

f_{pi}: friction factor for the inside surface of the receiver pipe, inside diameter of the receiver pipe (-)

g: gravitational constant (m/s^2)

h: convection heat transfer coefficient ($W/m^{2o}C$)

i: number of days (-)

I: solar radiation (W/m^2)

I_b: solar beam radiation (W/m^2)

I_d: solar diffuse radiation (W/m^2)

I_o: average solar radiation (W/m^2)

k: thermal conductivity (W/m°C)

k_{air}: thermal conductivity of air (W/m°C)

k_f: thermal conductivity of fluid (W/m°C)

k_{pipe}: thermal conductivity of pipe (W/m°C)

k_T: incident solar angle (-)

L: length (m)

L_c: critical length (m)

m: mass flow rate (kg/s)

n: day of year (-)

N: number of collector (-)

Nu: Nusselt number (-)

P: annulus gas pressure (Pa)

Pr: Prandtl number (-)

Q_i: heat absorbed (W)

Q_s: heat received (W)

Q_u: heat absorbed to receiver (W)

R_b: optimum azimuth angle (-)

Ra: Rayleigh number (-)

Re: Reynolds number (-)

T_a: ambient temperature (K)

T_o : environment temperature (K)

T_s : solar temperature (K)

T_{fi} : inner temperature (K)

T_{fo} : outlet temperature (K)

V: velocity (m/s)

W_0: aperture area (m)

X_i : exergy absorbed (W)

X_c : exergy received (W)

Y: intercept factor (-)

Greek:

δ: Declination value (-)

θ: incidence angle (º)

θ_z : zenith angle (º)

Φ: latitude angle (º)

β: slope (º)

γ : surface azimuth angle (º)

ώ : hour angle (º)

η :efficiency (-)

τ : cover transmission (-)

a : receiver absorptivity (-)

λ: mean-free-path between collisions of a molecule (m)

ν: kinematic viscosity (m^2/s)

ρ: density (kg/m^3)

б: StefaneBoltzmann constant (W/m^2K^4)

ε_{po}: receiver pipe selective coating emissivity (-)

ε_{gi}: glass envelope emissivity (-)

1. Introduction

1.1.Background

Today, solar energy can play a vital role in the world. There was a huge revelation in the human’s life after solar energy was introduced as the main source of energy. After a few years, using solar energy became usual in the world. It would not be surprised when solar energy is used by some of the electrical appliances like water heater, oven or even the refrigerator and ice-maker. Just like many other forms of energy, solar energy can be used in the industrial sector. It is very important because solar energy is introduced as the clean energy when it comes to greenhouses gases. After several years, a useful key for reduction pollution into environment was found although the thermal efficiency was not high. However, these technologies were developed and engineers and scientists try to improve the thermal energy considerably.

Solar energy exploitation and related new technologies are assuming as an increase interest for industrialized countries where medium-to-long term production of low cost energy with reduced emissions is carried out. Indeed, several solar energy power plants have been designed and are currently under testing in many countries. An Italian law assigned to Ente Nazionale per l'Energia Atomica (National Agency for Atomic Energy) -ENEA- the mission to develop an R&D program of systems able to take advantage of solar energy as a heat source at high temperature. One of the most relevant objectives of this research program is study of Concentrating Solar Power (CSP) systems operating in the medium temperatures, i.e. about 550°C, directed towards the development of a new and low-cost technology to concentrate the direct radiation and efficiently convert solar energy into high temperature heat (Giannuzzi et al., 2007). After the solar energy was globalized and could find its special seat among industrial and scientific sector, the majority of firms and companies had some idea about how to increase and improve that type of technology. The most important factor is relating to collector and photovoltaic section. Using the parabolic trough collector was one of the initial methods. It was used in power plant, thermal and cooling systems. By using new technologies like nanofloid and phase change material (PCM) are tried to improve efficiency of this kind of collector. As far as parabolic trough collectors are concerned, the main applications are industrial process heat, domestic hot water, air conditioning and refrigeration system, pumping irrigation water and desalination (Fernández-García et al., 2010).

Trough collector is one of the collectors that are used in the solar energy systems. As long as its background is considered, it had been used in the small power systems in Spain in 1981. Parabolic solar collectors able to generate temperatures greater than 500˚C, were initially developed for industrial process heat applications (Bakos, 2006).

1.2. Concentrated solar power plant

In 1866, Auguste Mouchout used a parabolic trough to produce steam for the first solar steam engine. The first patent for a solar collector was obtained by the Italian Alessandro Battaglia in Genoa, Italy, in 1886. Over the following years, inventors such as John Ericsson and Frank Shuman developed concentrating solar-powered devices for irrigation, refrigeration, and locomotion. In 1913 Shuman finished a 55 HP parabolic solar thermal energy station in Maadi, Egypt for irrigation. The first solar-power system using a mirror dish was built by Dr. R.H. Goddard, who was already well known for his research on liquid-fueled rockets and wrote an article in 1929 in which he asserted that all the previous obstacles had been addressed (Corporation, 1929).

One of the types of concentrating solar power plant is called Fresnel reflector system. Its components are flat plate collectors and one tower. A receiver has been designed on top of this tower. After contacting sun's rays to flat plate collector, sun's rays are reflected to receiver and caused to change the temperature (Feuermann and Gordon, 1991). Figure 1.1 shows the schematic of Fresnel reflector system (Nixon and Davies, 2012).

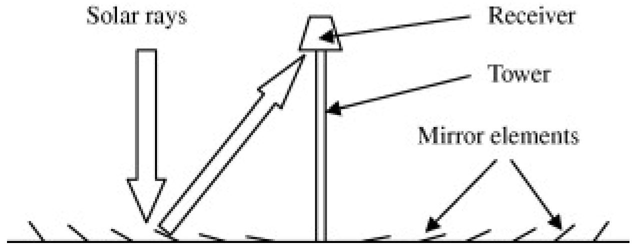

Figure 1.1, Schematic of Fresnel reflector system (Nixon & Davies, 2012)

Other types of concentrating solar power plant are called dish stirling system. It has been made by dish mirrors that are known as reflectors system and solar receiver system as the focal point. The most important advantage of this system is in the commercial field where electricity is generated by off-grid technology. Therefore, solar dish stirling technology can respond to this type of issues in this area (Abbas et al., 2011). Figure 1.2 demonstrates the schematic of solar dish system and Figure 1.3 shows the flowchart of this type of system. (Abbas et al., 2011).

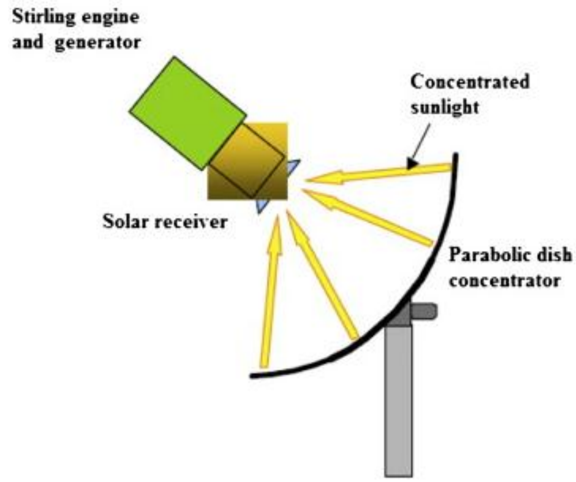

Figure 1.2, Schematic of solar dish system (Abbas, et al., 2011)

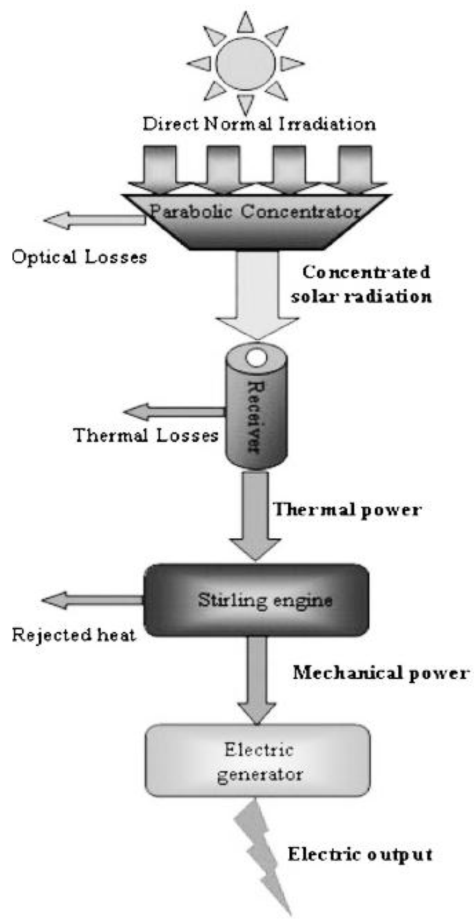

Figure 1.3, Flowchart of solar dish system (Abbas, et al., 2011)

The main components of parabolic trough collector include collector, receiver, flexible Joint and some of the components that are known as holder devices (Feldhoff et al., 2012; Li and Wang, 2006). The collector surface comprises of reflector mounted on support structure. Most of the solar parameters are defined by this part. For instance, the optical efficiency for tube absorber depends on the distance of the focal point and aperture area. By changing the physical collector parameter, the value of optical efficiency can be changed (Feldhoff et al., 2012). When it comes to movement of reflector it is divided to three different groups. The first group is reflector which moves left to right. The second group is parabolic collector that moves from north to south or up to down. Normally this kind of collector is used in power solar system. The last group is called constant and there is no movement. The solar efficiency of the third group is less than another group. The reason is they are fixed and they are not able to get the maximum efficiency from sun (Bakos, 2006).

Figure 1.4, Sample of holder and support in PTC (Feldhoff et al., 2012; M. Li & Wang, 2006)

Some of the components like bearings and pylons can play a vital role in solar parts. Pylons are usually defined as the holder and they are one of the type of bearing that are located in the rotation part where parabolic trough collector moves with the sun (Thomas, 1996). Pylons are normally between 16kg to 19 kg for parabolic trough collector (Geyer et al., 2002). They are fixed by supports and have three different parts and they are able to rotate to z axis. Figure 1.5 shows the fact of rotating of pylon in parabolic trough collector system (Bakos et al., 2001).

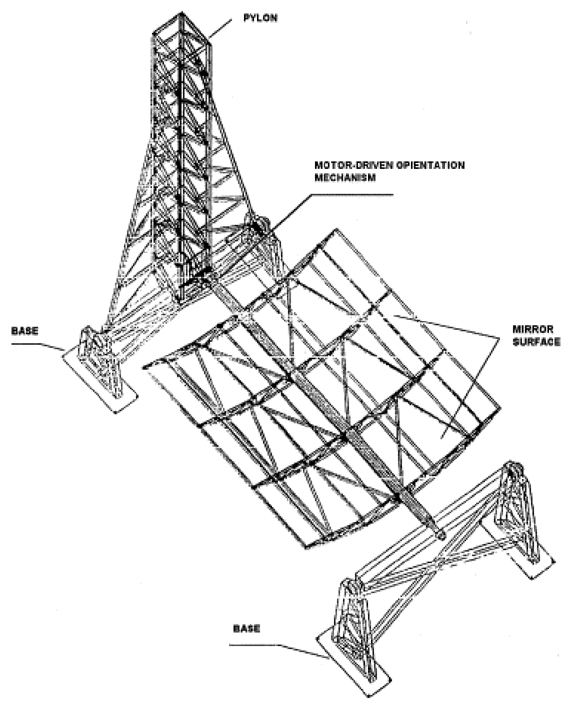

Figure 1.5, Fact of rotating of pylon in parabolic trough collector system (Bakos et al., 2001)

The most important part of trough collector is its receiver. It is made up of stainless steel tube and covered by the glass enveloped in order to decrease heat lost (He et al., 2012). Oil flows into the receiver tube and the absorber which is installed between oil fluid and glass enveloped, cause to rising oil enthalpy. (Fernández-García et al., 2010). Normally the receiver of Solar Thermal Electric Generation System (STEGS) is made by steel heat absorption pipe and coated by black chrome material (Cohen, 1993; Odeh et al., 1998). in solar power plant system, oil that is flowing in the inner tube, has low viscosity. In some case water is used instead of synthetic oil. the most important advantages of water is its price when it is compared by synthetic oil. but on the other hand synthetic oil insensitive to dust and dirt (Almanza et al., 1998). Receiver has been made by three different components. First layer is called glass cover that transferred heat radiation to receiver tube. Envelope glass that is located between glass cover and receiver tube and the value of heat losses are depend on its material. Last tube is called receiver that oil or water is working that. The schematic of receiver tube is demonstrated by Figure 1.6 (Kalogirou).

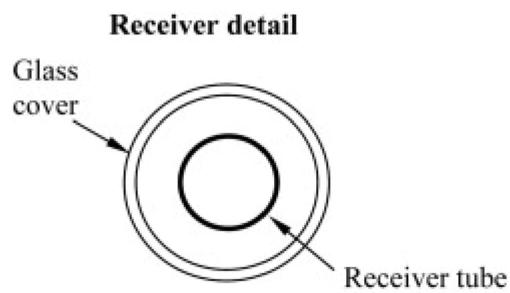

Figure 1.6, The schematic of receiver tube (Kalogirou)

In 1870, one Swedish engineer designed a parabolic trough collector that was 3.35m long and around 5m wide (Fernández-García et al., 2010; Llorente García et al., 2011). In the mid of 1990, using the absorber system between enveloped glass and oil fluid was applied in order to reduce heat transfer in receiver tube (Padilla et al., 2011). Besides that, instalation of parabolic trough collector system via Direct Steam Generation method (DSG) with heat exchanger system in solar power plant was applied.

In this research the main component of parabolic trough solar collector were considered and parabolic trough solar power plant was known as new technique in solar technology. As a literature review, thermodynamics performance and heat transfer analysis will be considered. Some of the new techniques that are caused to improve thermal efficiency in power plant system in some of countries are reviewed. Also, new techniques and methods that are caused to decrease of heat losses value in receiver system are considered.

Since, Iran is known as one of the countries that uses parabolic trough solar power plant, thermodynamics performance like value of energy received, exergy, first and second law efficiency are be estimated by some of proper associating data. Also, the value heat transfer like conduction, convection and radiation in different part of receiver tube will be analyzed. Last but not least, some of new techniques like using of phase change material (PCM) and Nano fluid will be introduced.

1.3.History of parabolic trough solar power plant

Nowadays, solar power plant system is designed by different types of collector. Some of them use the solar flat collector another one is designed by the concentrated solar collecotr. According some of global reports, the maximum electricity generated has been reported at Spain that had been designed in 2007 and it is able to generate approximately 20 MW electricity including 50 hectares of area (energy, 2007). First time, in mid of 1991, the newest type of concentrated solar collector, that was called parabolic trough collector, was made. It has been concerned to two main components. Mirror surface and receiver tube are two main components (Fisher and Lupfert, 2006).

Table 1.1 shows the countries which are using parabolic solar power plant system (energy, 2005).

Table 1.1, Parabolic trough collector power planet

Name	Foundation	Capacity (MW)	Location	Country	Note	Reference
Shiraz, Iran	2008	0.25 to 0.5(currently)	shiraz	Iran		(Baghernejad and Yaghoubi, 2010)
Yazd ,Iran	2009	17(until 21,nov,2010)	Yazd	Iran	World's first solar combined cycle power plant	(Baghernejad and Yaghoubi, 2010)
Solar Energy Generating Systems	1980	354	Mojave Desert California	USA	Collection of 9 units	(Price et al., 2002; Wiese et al., 2010)
Solnova	2010	50	Seville	Spain	Solnova 1.3,4 completed May,Aug 2010 Solnova 1 is Predicted to generate 114.6 GWh annually	(Poullikkas, 2009)
Palma del Rio Solar Power Station	Dec 2010 and July2011	50	Cordoba	Spain	phase1,2	(Wiese et al., 2010)
Extresol Solar Power Station	Feb-Dec 2010	50	Torre de Miguel Sesmero (Badajoz)	Spain	phase1,2	(Romero and González-Aguilar, 2011)
Andasol solar power station	2008-2011	50	Granada	Spain	phase1(2008),2(2009),3(2011)	(Fernández-García et al., 2010; Michels and Pitz-Paal, 2007)
Ivanpah Solar Power Facility	2013	370	San Bernardino County, California	USA	Under construction	(Amspacher, 2011; Schwartz, 2012)
Solana Generating Station	2013	280	West of Gila Bend, AZ	USA	Under construction (6 heat storage)	(Goffman, 2008; Johnson, 2009b)
Nevada solar power plant	2007	64	Eldorado Valley	USA		(Wiese et al., 2010)

Majority of parabolic solar power plants are divided to two different parts. The first one is parabolic trough collector system that including of reflector, holders and receiver system and second part is rankine cycle that is known as famous cycle for thermodynamics power system (Singh et al., 2000a). Figure 1.7 and shows schematic of parabolic trough collector system which has been combined by rankine system (Singh et al., 2000a).

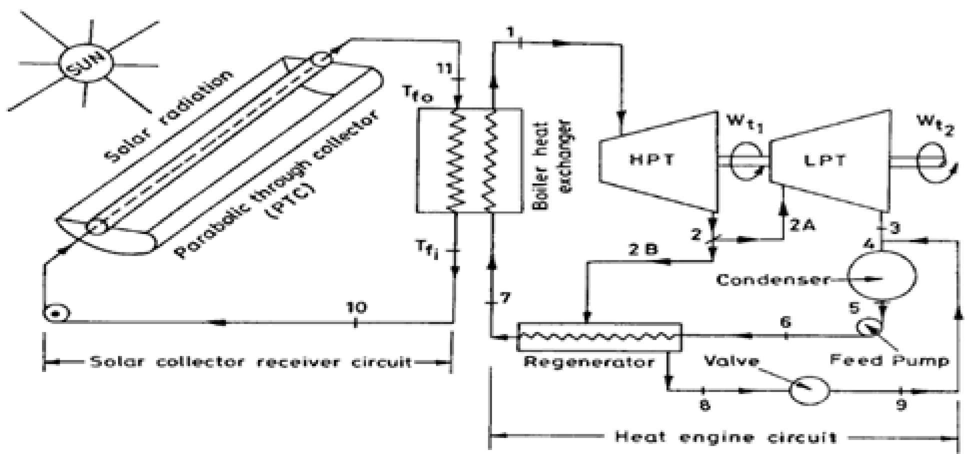

Figure 1.7, Schematic of parabolic trough collector system which has been combined by rankine system(Narendra Singh, et al., 2000).

All of thermodynamics parts have been illustrated by Figure 1.8. It has been made by to two different parts. There is oil part that has parabolic trough collector system and rankine parts that is known as thermodynamics cycle. The most important part in power plant system is called heat exchanger device where hot oil in solar cycle and water fluid in rankine system are able to exchange their temperature. .

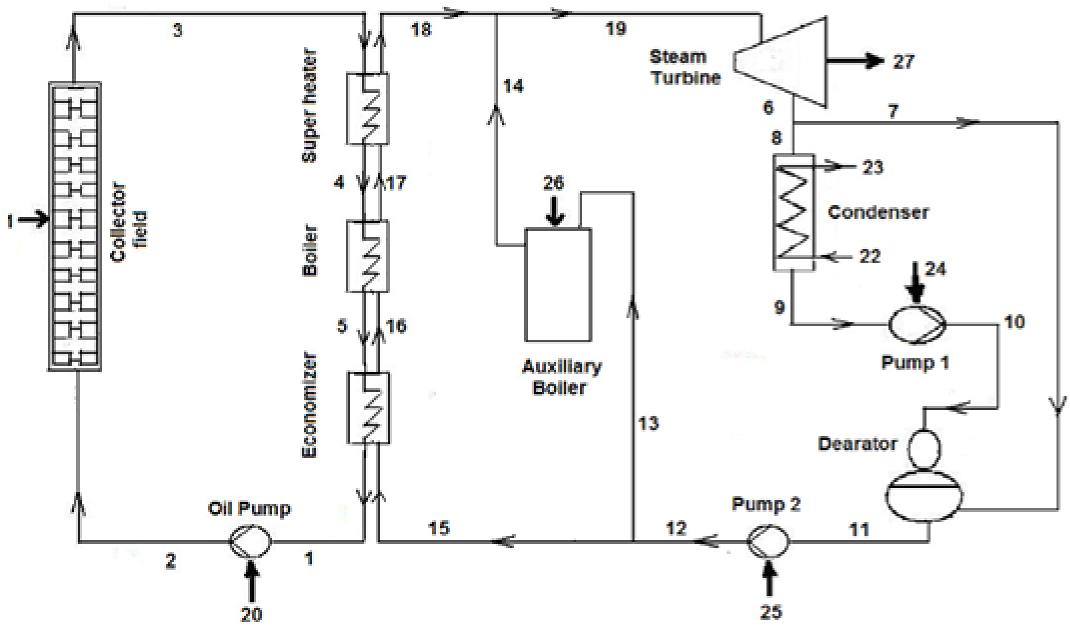

Figure 1.8, The schematic of oil parts and Rankine parts

Iran is one of the countries that have proper potential in the field of solar energy. According to one research that had been done in University of Bu- Ali Sina in 2007 (Sabziparvar and Shetaee, 2007), the annual solar radiation is approximately 100MJ/m^2/year. Shiraz is one of the cities where solar power plant is located there. This power plant is located in the shiraz city, that its location is in the southern part of Iran at the latitude 29° and 36', and longitude 52° and 32'. This city has more than 3000 hours of sunshine annually with average daily irradiation of 20MJ/m^2 (Yaghoubi et al., 2009). Its power plant was operated in 2008 and its capacity is around 250kW.

1.4.Objectives

In this research following objectives are considered as finding of thermodynamics parameters and heat transfer analysis in solar cycle system. Since, Iran is known as one of the countries that uses parabolic trough solar power plant, thermodynamics performance like value of energy received, exergy, first and second law efficiency are be estimated by some of proper associating data on first, fifth, tenth, fifteen, twentieth, twenty- fifth and thirtieth of September are estimated. Also, the value heat transfer like conduction, convection and radiation in different part of receiver tube will be analyzed. Last but not least, some of new techniques like using of phase change material (PCM) and Nano fluid will be introduced.

2. Literature review

2.1.Thermodynamics approach

One of the important solar power plant applications is generating of electricity. Although, the value of thermal efficiency in fossil power plant is higher than solar power plant, its value depends on thermodynamics parameter in rankine system. However, it can be caused to generate of greenhouse gases into environment (Yang et al., 2011). On the other hand, thermal efficiency is so low when it comes to solar power plant. There are several ways to increase of thermal efficiency of power plant system. Since, thermal efficiency of the system depends on solar efficiency of parabolic trough system, by increasing solar efficiency can improve total efficiency. Since, solar power plant has been designed by thermodynamics cycle, first law efficiency, second law efficiency and exergy can play vital role in this type of structure. Normally, solar efficiency value is defined in solar cycle where it has been designed by parabolic trough collector and receiver. That value depends on several factors.

According to research that had been done Federal de Pernambuco University in Brazil, the absorber in receiver can play an important role in increasing or decreasing thermal efficiency. It can be found that when receiver tube is coated by evacuated tube thermal efficiency is higher than when the case is non- evacuated (Rolim et al., 2009). Using of $CaO/CaCo_3$ as the absorber system prove that claim. Application of this kind of absorber and using Brayton cycle instead of rankine cycle had been proposed by industrial researcher in New Zealand in 2012. Although, this was only one model and was simulated, the result was so significant. Thermal efficiency reached from 15% to approximately 40% (Edwards and Materić, 2012). It had great effect on solar efficiency of the system. In some of the case, like Spain where is used parabolic trough collector system in its power plant system, using of two or more receiver systems, could have a proper effect on improving of thermal efficiency (Imenes et al., 2006).

Besides that, other physical factors like changing aperture area size or length of focal point can change the value of solar efficiency in parabolic trough collector system. According to research in one of the university in Italy in 2011, these types of factors should be introduced in collector part like mirror with, length and focal length (Sansoni et al., 2011). Thermal efficiency is very important in design of solar power plant system. It has effect on economic assessment of solar designing system. It can be said that increasing of thermal efficiency has great effect on steam turbine capacity and that capacity is caused to improve of economic assessment in power plant system (Hosseini et al., 2005).

According to one research that had been done in Indian Institute of Technology in Delhi in 2012, optimize of solar efficiency is caused tothermal efficiency in rankine cycle is improved and heat losses values in different parts of rankine cycle is reduced. According to its research when solar efficiency is optimized in solar cycle, oil pressure working will be also optimized and finally thermal efficiency is increased in rankine cycle. For instance, in solar power plant that is located in India, when oil pressure increased from 90bar to 105bar, thermal efficiency of pump system will increase from 15% to 26% (Reddy et al., 2012). Some of the case studies that had been studied in Technical University of Sofia in 2011, the best efficiency was obtained when the high pressure heaters were used in rankine cycle in solar power plant system and thermal efficiency reached from 23% to 39% (Popov, 2011).

Shadowing and cloudy factor are known as important factors that are able to change solar efficiency. Obviously, these types of factors are known as negative factors, if those values are considerable. It can be found that, they can reduce thermal efficiency considerably when those values are estimated more than 0.5. Shadowing and clouding factor that are defined as the blocking factor are depending on radial and angular distance of aperture area and also potential of solar energy area (Wei et al., 2010). Besides that, other factors like airflow speed, rising temperature and pressure increase are caused to improve solar efficiency (Cao et al., 2011). As far as temperature factor is considered, total efficiency will be maximized when the saturated water temperature in the boiler is maximized. According to experimental test in Dakin university in Australia, when the saturated temperature reached to above 200˚C, thermal efficiency are estimated around 20% (You and Hu, 2002).

Phase Change Material technique (PCM) is known as a proper way for increasing thermal efficiency in power plant system. It is used in some of the countries that have good solar potential energy. Paraffin is chosen as the PCM used in solar power system. It is divided to several groups. Among of them Heneicosane has the biggest melting point and density value. Its density is 788 kg/m^3. Table 2.1 includes the thermo physical properties of various paraffin types taken from (Amspacher, 2011; Michels and Pitz-Paal, 2007).

Table 2.1, Thermo physical properties of various paraffin types taken from (Amspacher, 2011; Michels & Pitz-Paal, 2007)

	Melting Point (K)	Latent Heat of Fusion (KJ/Kg)	Density (Kg/m3)	Specific Heat Solid (J/molK)	Specific heat liquid (J/molk)
Hexadecane	291.25	236	770	479.6	501.5
Heptadecane	295.05	214	775	467.4	534.3
Octadecane	301.25	244	779	485.4	564.4
Nonadecane	305.15	222	782	514.6	618
Eicosane	309.75	248	785	544.3	658
Heneicosane	311.35	213	788	570.7	698

As it can be seen different characteristics of various PCM materials will affect the performance of the PCM unit. For different values of melting temperature as well as different heat of fusion, different exergetic efficiency would be obtained. Mass of the thermal storage unit is also effective on the efficiency since it might influence the generation of entropy. As indicated in other literatures like that by Li et al. the melting point plays a significant on the efficiency. Therefore using PCM seems to somehow improve the performance of a solar power plant.

Nanofluid is known as a proper way for increasing thermal efficiency in power plant system. However most of the literature includes analysis of convection for nanofluids and a few works have been done to cast light on the irradiation functionality of nanofluid. Thus more work seems essential on the optical properties of nanofluids and the way they behave under radiation specially when used in solar collectors. In a research by Otanicar et al.(Johnson, 2009a), the effect of nanoparticle suspension in a fluid was investigated for direct absorption of solar radiation numerically as well as experimentally. They concluded that the efficiency of would be augmented by 5% when a nanofluid is used. The authors also outlined that the performance may be further enhanced by increasing the volumetric concentration of particles. The effect of using Al_2O_3/water nanofluid on the performance of a flat solar collector was also investigated by Yousefi et al.(Goffman, 2008) The authors concluded that an increase of 28.3% in the overall efficiency was possible by using a nanofluid with 0.2% volumetric concentration. The effect using surfactants was also studied to see its influence on the fluid properties during direct absorption. An augmentation of 15.63% was mentioned when surfactant were used in the suspension.

Another factor that is considered in thermodynamics approach is defined as the exergy. Exergy plays a vital role in solar power plant system when it comes to second law efficiency. Exergy analysis can be known as a proper factor in order to analyze of useful energy based on second law of thermodynamics(Lior, 2002). Just like to solar efficiency part, some of negative factors like cloudy factors, speed of windy and shadowing can be reduced exergy value in solar power system (Kumar and Tiwari, 2011). As the result, when exergy value is reduced, thermal efficiency will be decreased.

When it comes to solar power plant system, exergy can be calculated for each different component. For instance, it can be found for collector system, boiler, pumps and turbines system. According to research that was done in university of Ontario technology in 2010 (Regulagadda et al., 2010), exergy value was estimated for each different thermodynamics instrument. Result illustrated, the value of exergy was related to temperature and pressure of each components. Among of those components, exergy value was the highest in the boiler system. Perhaps, the working value in boiler section was the least when it was compared with turbine or pump system and heat absorbed value was higher than the value of one in heat exchanger (Regulagadda et al., 2010). However, by increasing of the numbers of extraction stages, exergy value will be reduced in boiler device (Ying and Hu, 1999). For finding exergy value in turbine cycle, it is function of pressure inlet in the rankine cycle. it can be said that, when the pressure is increased, the value of exergy should be rose and when temperature inlet in pump system is increased, exergy efficiency is also improved in rankine cycle (Al-Sulaiman et al., 2011). The exergy value and second law of efficiency results can be shown into environment science. The value of Carbone dioxide gases CO_2 which is known as the one of the greenhouse gases, is 62000 tones less in solar power plant system when it was compared with the fossil power plant(Suresh et al., 2010).

The most important factor in solar devices is to attend and estimated of maximum and minimum of exergy losses value. According to research that was done by University of Delhi in 2010 (Gupta and Kaushik, 2010), the maximum exergy losses occur in the solar collector. It can be found that; solar collector is the first device for receiving solar energy and the exergy value is depends on energy absorbed value by this device. Since, majority of negative factors like windy and cloudy factors can have effect on collector directly, it can be seen the maximum exergy losses value in this section. Unlike parabolic trough system, the value of exergy losses in receiver system is so low. Since, receiver system is equipped by envelop glass and absorber system, it can be absorbed the most value energy from parabolic system. One of the proper strategies for increasing exergy value in collector system is known as PCM technique. As it was mentioned before, Paraffin is chosen as the PCM used in solar power system. Since, this type of material has great entropy generation (because, it has high melting point) the exergy value can increased considerably (Amspacher, 2011; Michels and Pitz-Paal, 2007).

Phase Change Material technology (PCM) is defined as a proper way to increase of second law efficiency and improve of exergy. According to one research that was done by (Li et al., 2012), by using of phase change material technique efficiency increased dramatically. The useful efficiency in the first stage was approximately 19%. But by increasing of phase change material stage, thermal efficiency is improved more than two times. It reached to 58% when the phase change material changed to two stages (Li et al., 2012). Secondly, by doubled of PCM stages the melting temperature reduced considerably. It can be said that, PCM in the first stage will be able to reach melt temperature to 1000K in the boiler section. But when it comes to second stage, the melt temperature is reduced by 750K(Li et al., 2012).

Unlike parabolic trough collector system, this scenario is completely different for tower systems. According to research that was done by institute of electrical engineering in Beijing in 2011(Xu et al., 2011), the maximum of exergy value occur in receiver system and minimum value was reported in tower system. Since, flat plate collectors are used for this system, the exergy value in this type of collector is well when it was compared with parabolic trough collector system. Also, exergy efficiency has a big effect on heat transfer irreversibility of the collector system and ambient air in collector system. When it comes to parabolic trough collector system, exergy is function of two factors. It can be said that the value of exrgy in receiver and collector system are function of unavoidable fluxes like radiate and convective heat transfers (Calise et al.).

By comparison between flat plate collector and parabolic trough collector system in case of exrgy efficiency, we realize that the maximum exergy efficiency is approximately 17% to 49% when it comes to flat plate collector system (Hosseini et al., 2013). It can be increased by applying phase change material system to 58%(Hosseini et al., 2013). On the other hand, when parabolic trough collector system is considered, exergy efficiency can reach to 58% with excluding of PCM. It can be found that, parabolic trough collector system can have higher efficiency in thermodynamics approach rather than solar flat collector and photo voltaic system. In parabolic trough collector system exergy efficiency plays an important role. By finding solar exergy in concentrating system, we would find inefficient parts and factors that is led to it and optimum operating condition (Badescu, 2007).

2.2.Heat Transfer approach

George C. Bakos (Bakos, 2006) investigated and experimented to improve the two-axis Sun tracking system for parabolic trough collector (PTC).The result shows thermal efficiency of collector under the tracking better than fixed surface in the same whether condition. The efficiency will be increased up to 46% by rotating collector.

M.J. Montes et al(Montes et al., 2009) investigated five parabolic trough collectors with different size on a conventional synthetic oil parabolic trough plant without hybridization and thermal storage to optimize economically. The result shows that the solar multiple must be large enough to ensure a certain range where the solar thermal plant is operating at nominal conditions, but it should not be very great. It also observed improving the efficiency by means of more complex power cycles leads to significant investment savings in the solar field size.

Adopting the Monte Carlo Ray-Trace Method (MCRT Method) calculated the solar energy flux distribution on the outer wall of the inner absorber tube of a parabolic solar collector receiver successfully. It shows that the non-uniformity of the solar energy flux distribution is very large. Z.D. Cheng et al,(Cheng et al., 2010; Cheng et al., 2012) calculated and analyzed Three-dimensional numerical simulation of coupled heat transfer characteristics in the receiver tube by combination of the MCRT Method once with the FLUENT software and another time with the Finite Volume Method (FVM). From the experiment of Dudley et al respectively, this analysis is based on the heat transfer fluid and physical model of Syltherm 800 liquid oil and LS2 parabolic solar collector. After taken Temperature dependent properties of the oil and thermal radiation between the inner absorber tube and the outer glass cover tube and by comparing with test results from three typical testing conditions, the result showing average is within 2% difference. After validating the model on three typical test conditions, the no-wall model, the no-radiation model and the unabridged model are also simulated to give a further explanation of the coupled heat transfer mechanism in the receiver tube. The results show that the radiation loss in Model 3 is up to 153.70W m^{-2}. For improving the efficiency of collector the radiation loss should be reduced as much as can. Then the temperature distributions of the absorber tube outer surface and the effects of direct normal irradiance, Reynolds number and emissivity of the inner tube wall on heat transfer characteristics can be investigated. η' and η always agree well with each other which also prove that they used the reliable models and methods for feasible and the numerical results.

Gabriel Morin et al (Morin et al., 2011) compared the electricity generation costs, efficiency and heat loss between the Linear Fresnel Collector (LFC) and Parabolic Trough Collector (PTC). The study shows that the costs for a linear Fresnel collector is around 78 and 216 €/m^2 (or from 28% to 79% relative to PTC field cost) to reach cost-parity at assumed reference solar field costs of 275 €/m^2 for the PTC. Some of the different design such as Primary mirror field, height of the receiver above the primary mirror field and Heat transfer fluid and maximum operating temperature level. After modeling of two cases the

Parabolic Trough vacuum receiver shows much lower heat losses than the atmospheric Fresnel receiver. And there is different in the power block due to the Fresnel daily steam generation characteristics, there are more part load operation hours. In addition, the peak heat production around solar noon leads to a higher dumping rate for the Linear Fresnel during hours with high irradiation.

C. Kerkeni et al, (Kerkeni et al., 2002) calculated that main heat losses occur in collector's field by 71.8% which installed in 1984 in Tunisia. This plant has revealed the limits of converting solar thermal energy into electricity at low temperatures. Measurements taken for the different components of the plant have shown that the annual electric energy production represents about 0.6% of the incident solar energy. Previous calculations and studies show that when hot-water at 165C flows through a 6m by 2.3m PTSC with 900 W/m^2 solar insulation and 0 incident angle, the estimated collector efficiency is about 55%. The thermal losses from the collector receiver are functions of operating temperature. Depending on the receiver's configuration and operational conditions, the thermal losses through PTSC are changed in different ways.

M. Prakash et al(Prakash et al., 2009) experimented and did a numerical study of the steady state convective losses occurring from a downward facing cylindrical cavity receiver between 50 ^{0} C and 75 ^{0} C (for experimental) and 50^{0}nC and 300 ^{0} C (for numerical) temperature into the receiver with different angel. The experimental and numerical result show the good agreement with maximum error of 14%.it can be said that the result of heat lost when there is no wind is lower than included windy factor.

Narendra Singh et al, (Singh et al., 2000a) which study energy analysis of solar thermal power and calculate losses of system and compared results. The result shows in

Table 2.2, which the percentage energy loss in heat engine circuit (72.37%) is more than the collector (32.65%) and also more than collector-receiver assembly (56.30%). In fact, it shows that the high quality energy is lost in collector-receiver assembly but energy lost in heat engine is part of low quality energy.

Table 2.2, The percentage of energy loss in different part of solar power plant

Subsystem	Energy loss (%)	First law efficiency (%)
collector	32.65	67.36
receiver	35.12	64.88
collector-receiver	56.3	43.7
Boiler heat exchange	0	100
Heat engine	72.37	27.63
Overall system	87.93	12.07

Ming Qu (Ming Qu, 2006) has modeled calculated a PTSC system which included 50% water and 50% propylene glycol among three losses: conduction, convection and radiation, the convection loss from absorb tube to supporting structures is the largest; the next is the radiation loss from glass envelope to ambient air; the relative smaller is the convection loss from glass envelope to ambient air.

S.D.Odeh (S. D. Odeh) simulated a model by TRANSYS to determine the annual performance of a typical trough configuration under Australian conditions. This study illustrates and analyzes parabolic though collector of which used in LUZ plant and water are operating with synthetic oil. The study result for thermal losses shows that the high thermal loss from the absorber tube outer wall to evacuated glass tube occurs by radiation and second part of loss from the collector takes place between absorber tube and the ambient via the vacuum bellows and supports. He proved that at wind speed of 3m/s the measured and computed values are very close in the temperature range between 250- 400 °C which covers the operation range of a typical power plant.

3. Methodology

3.1. Solar measuring instruments

Since, Iran is located in north hemisphere and in September, it has the hottest weather (September is in summer time for north hemisphere countries), therefore, this month was chosen to collect solar data. Be sides that, among of summer months, September has a minimum cloudy factor (According to Table 3.3). Randomly, 1^{st}, 5^{th}, 10^{th}, etc was chosen because the values of temperature and pressure between 1^{st} to 5^{th} and 5^{th} to 10^{th} were mostly similar.

In this investigation, heat transfer and conversion model for high-temperature solar cavity receiver can be explained by some of the experimental method like Monte- Carlo ray tracing technique. In this investigation, experimental work is necessary. Therefore, some of data that are exported by experimental work can play a vital role. In order to measure mass flow rate, mass flow controllers monitoring might be a properly experimental set up.

Some of devices like semiconductors, liquid crystal panels, and light emitting diodes are used for a wide range of applications in a number of industries and manufacturing in solar panels and fuel cells. The accurate measurement and control of gases in these manufacturing processes dramatically improves the efficiency of the process and in turn saves energy and improves productivity. Mass follow controller monitoring is engaged in the development of mass flow controllers for state-of-the-art manufacturing processes including semiconductor, photovoltaic and led manufacturing and continues to develop products that meet customer needs. A sample of mass follow controller monitoring has been shown by Figure 3.1.

Figure 3.1, Sample of mass follow controller monitoring

In this research, the value of mass flow rate is needed. That value important because, it is one of the factor for calculating of energy and exergy received in solar cycle. Therefore, the value of mass flow rate of oil into receiver tube can be measured by mass flow controller for whole time. Mass follow controller monitoring has two holes. One is related to inlet liquid and another one is about exit liquid. Since, there is no slope in receiver tube, so mass flow rate value are same in all of parts. This device can be connected to inlet port in receiver system. Inlet port that has been equipped in below of device, is matched by extra hose and another port is joint to inlet receiver port by extra hose. Then, digital screen can show the number that is known as value of oil mass flow rate. It is tested every one hour at considering days of September and that value is recorded for calculating of energy and exergy received in solar cycle. The mass flow rate can be measured by digital number that has been mentioned in Figure 3.1.

. Another device that must be considered in methodology of parabolic trough collector system is called pyrometer with a short wavelength. Since, heat transfer value is so important, acquisition system short wavelength pyrometer gauge is considered. Short wavelength pyrometer gauge is special tools for measuring liquid temperature of metal between 250˚C to 1800˚C.

The instrument has maximum value storage, minimum value storage, average and difference function as well as an acoustic alarm. The high quality optics enables the measurement of small objects from 4 mm, in combination with the close-up lens even from 1.25 mm. The short wavelength pyrometer gauge is a robust, digital and accurate pyrometer with built-in data logger (750 values) for noncontact temperature measurement on metals, ceramics, graphite etc. with a temperature range of 250 to 1800°C. The instrument is equipped with a laser targeting light; the size of the laser spot has approximately the size of the measuring spot.

In this research, for measuring of sky and environment temperature, this instrument was used. Values of sky temperature were collected in each solar hour. Providing this kind of data (sky and environment temperature) is necessary for calculating exergy received and absorbed in collector and receiver system that are known as thermodynamics factor. This instrument is equipped by a digital screen which is shown the exact value of sky temperature by pushing a bottom which turn on a wavelength optical into the sky. The optical system contains filters that restrict the wavelength-sensitivity of the devices to a narrow wavelength band around 0.65 to 0.66 micons. The short wavelength pyrometer gauge has some of advantages like; easy to handle, large illuminated LC display, laser aiming, built-in data logger, long temperature range, high accuracy, fast temperature detection, only 20 ms, measurement of smallest objects from 1.25 mm, integrated additional functions, USB interface, analyzing software PortaWin (option). Besides that, some of typically application like, preheating, tempering, hardening, normalizing, forging, brazing, sintering, welding, rolling and founding has been important rather another similar devices. Other filters reduce the intensity so that one instrument can have a relatively wide temperature range capability. Then, digital screen can show the number that is known as value of sky temperature. It is tested every one hour at considering days of September and that value is recorded for calculating of energy and exergy received in solar cycle. A sample of short wavelength pyrometer gauge has been illustrated by Figure 3.2;

Figure 3.2, Sample of short wavelength pyrometer gauge

Since, temperature and pressure are the main factors for determining of thermodynamics parameters, some of digital devices for measuring temperature and pressure are needed. According to heat convection theory that states value of Prandtel number and Nusselt number are function of pressure value, so the accuracy value of hot oil pressure in receiver system play a vital role in this research.

In this research, oil temperature in inlet and out let of receiver system is important. For measuring of inlet and outlet oil temperature in receiver system, solar temperature gauge is necessary. For this purpose, this device is installed into receiver tube. This instrument is equipped by one digital screen and one hole. Also it is possible to measure of solar temperature receive by parabolic system. It is installed on first (where oil is entered) and end (where hot oil goes into heat exchanger) of receiver system where hot oil flow into the tube. Then, digital screen will show the number that is known as value of oil temperature. It is tested every one hour at considering days of September and that value is recorded for calculating of energy and exergy received in receiver and parabolic cycle.

. In this research the values of inlet and outlet temperature were collected in each solar hour. Providing this kind of data is necessary for calculating exergy received and absorbed in receiver system. Sample of solar temperature and pressure gauge have been demonstrated by Figure 3.3.

Figure 3.3, Solar temperature gauge

By using of pressure gauge system, the pressure of oil system is measured in each time. Since, there is no slope in receiver tube, so pressure drop is disregarded in all of the length. It is installed on receiver system where hot oil flow into the tube. In this research the value of hot oil pressure is very important in receiver system because the value of heat convection between glass envelop and receiver tube is imposable, if pressure value is unknown. It can be said that, the value of Prandtel number is depends on pressure oil. Digital screen that is above of instrument, will show the number that is known as value of oil pressure. It is tested every one hour at considering days of September and that value is recorded for calculating of energy and exergy received in receiver cycle. Sample of solar pressure gauge have been demonstrated by Figure 3.4.

Figure 3.4, Solar pressure gauge

Another part of methodology is defined by calculation method where it is necessary to obtain some of the solar parameters, thermodynamics and heat transfer parameters. Therefore, in additional of survey data and some obtaining data that are being estimated by experimental instrument, some of basic equations which are related to solar, thermodynamics and heat transfer science are necessary.

3.2.Solar parameter

In this research, some governor equations are so important because all of solar parameters can be illustrated by them. Solar power plant system is divided to two different cycles. The oil cycle and the water cycle that is similar to ranking cycle. The main component of oil cycle can be defined as the collector and receiver (Singh et al., 2000b).

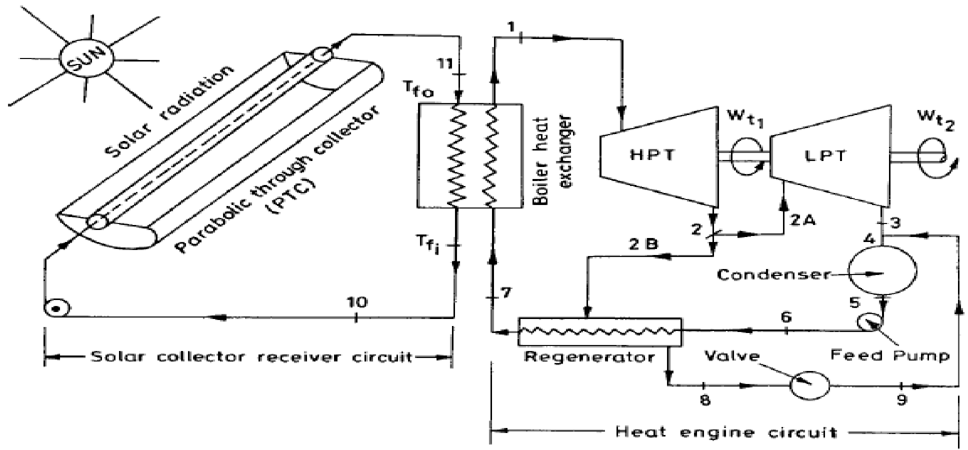

Figure 3.5, Schematic of The oil cycle and the water cycle

When it comes to solar collector, it is necessary to calculate beam and diffuse radiation to obtain the value of heat for the collector and receivers part. According to Duffie (Duffie and Beckman, 1980; Duffie and Beckman, 2006), the value of declination (δ), and angle of incidence (θ), and zenith angle (θ_z) are important;

$$\delta = 23.45 \text{ Sin } (360\frac{284+n}{365}) \quad (1)$$

$$\text{Cos } \theta = \text{Sin } \delta \text{ Sin } \Phi \text{ Cos } \beta - \text{ Sin } \delta \text{ Cos } \Phi \text{ Sin } \beta \text{ Cos } \gamma + \text{ Cos } \delta \text{ Cos } \Phi \text{ Cos } \beta \text{ Cos } \acute{\omega} + \text{Cos } \delta \text{ Sin } \Phi \text{ Sin } \beta \text{ Cos } \gamma \text{ Cos } \acute{\omega} + \text{ Cos } \delta \text{ Sin } \beta \text{ Sin } \gamma \text{ Sin } \acute{\omega} \quad (2)$$

$$\text{Cos } \theta z = \text{Cos } \Phi \text{ Cos } \delta \text{ Cos } \acute{\omega} + \text{ Sin } \Phi \text{ Sin } \delta \quad (3)$$

For finding (n) (= day of year) in equation (1), following table must be used. For this purpose, first (i) (=the number of day for each month) is determined. Then, by using related formula for each month, the value of (n) will be estimated. As an example, (n) in 5^{th} of September, would be 248 (i=5and n=243+5).

Table 3.1, The value of number of days per months (Duffie and Beckman, 1980; Duffie and Beckman, 2006)

Month	n for i^{th} day of month
January	i
February	31+i
March	59+i
April	90+i
May	120+i
June	151+i
July	181+i
August	212+i
September	243+i
October	273+i
November	304+i
December	334+i

Collector system is included of parabolic trough collector and receiver system. Irradiation equation for collector and receiver system is estimated by following equation,

$$I_b=I_o*(1-C_{fa})\{1-e^{[-0.075\left(\frac{\pi}{2}-\theta_z\right)]}\} \quad (4)$$

$$\frac{I_d}{I}=0.9511-0.1604k_T+4.388k_T^2-16.638k_T^3+12.336k_T^4 \quad \text{for } 0.22<k_T<0.8 \quad (5)$$

$$R_b=\frac{Cos\theta}{Cos\theta_z} \quad (6)$$

3.3.Thermodynamic parameter

For finding thermodynamics parameters, the value of sky temperature that have been collected by short wavelength device and temperature received and absorbed in receiver system that were collected by solar temperature gauge in different time are necessary. By finding temperature, exergy received and absorbed thermal efficiency for collector and receiver system will be estimated.

When it comes to collector system, there are considered the value of energy received by the collector system (Qi), energy absorbed by the collector (Qs), exergy received by the collector system, percentage of exergy loss and second law efficiency for this system (Yaghoubi et al., 2003). In this research The value of energy and exergy received by the collector and energy absorbed by the collector are separated and will be calculated by the following equations (Orel et al., 1997). Since, thermal efficiency is function of heat received and absorbed, finding those value by equations (7) and (8) for collector system are considered.

$$Q_i=(I_b\ R_b)W_0\ LM \quad (7)$$

$$Q_s=N.I_b.R_b(\tau.a)[\beta.Y+\frac{D_0}{W_0-D_0}] \quad (8)$$

$$\eta=\frac{Q_S}{Q_i} \quad (9)$$

$$X_i=Q_i[1-(\frac{T_0}{T_S})] \quad (10)$$

$$X_c=Q_s[1-(\frac{T_0}{T_i})] \quad (11)$$

$$\eta=\frac{X_c}{X_i} \quad (12)$$

The value of energy and exergy received by the receiver system and energy absorbed, will be estimated by the following equations (Yaghoubi and Mokhtari, 2007).

$$Q_u=N.m.C_p(T_{fo}-T_{fi}) \quad (13)$$

$$\eta=\frac{Q_u}{Q_s} \quad (14)$$

$$X_c=Q_s[1-(\frac{T_0}{T_s})] \quad (15)$$

$$X_u=N.[m.(h_{fo}-h_{fi})-T_o(S_{fo}-S_{fi})] \quad (16)$$

$$\eta=\frac{X_u}{X_c} \quad (17)$$

The overall second law efficiency of the collector and receiver system can be calculated by the following equation;

$$\eta= \eta_c.\eta_r \quad (18)$$

The rankine cycle is including of turbine, pumps, heat exchanger and boiler. According to first and second law of thermodynamics, the value of output power and efficiency can be estimated by the following formulas;

$$Q_T-W_T=(H_{out}-H_{in}) \quad (19)$$

$$X_T=m_w.[\Delta H-T_o(\Delta S)] \quad (20)$$

$$\eta=\frac{W_T}{W_{Re}} \quad \text{(for the Turbine)} \quad (21)$$

$$\eta=\frac{VP}{H} \quad (22)$$

3.4.Heat transfer parameter

The heat collection element (HCE) consists of an absorber surrounded by a glass envelope. The absorber is typically stainless steel tube with a selective absorber surface which provides the required optical and radioactive properties. Selective surfaces combine a high absorbance for solar radiation with low emitted for the temperature range in which the surface emits radiation.

The heat transfer model is based on an energy balance between the heat transfer fluid and the surrounding. Figure 3.6 shows the heat transfer in a cross section at the solar collector and the thermal resistance model used in the heat transfer analysis. The solar energy reflected by the mirrors is absorbed by the glass envelope and the absorber surface. A part of energy absorbed into the absorber is transferred to the heat transfer fluid by forced convection; remaining energy is transferred back to the glass envelope by radiation and natural convection and lost through the support brackets by conduction as well. The heat loss coming from the absorber passes through the glass envelope by conduction and along with the energy absorbed by the glass envelope is lost to the environment by convection and to environment by radiation.

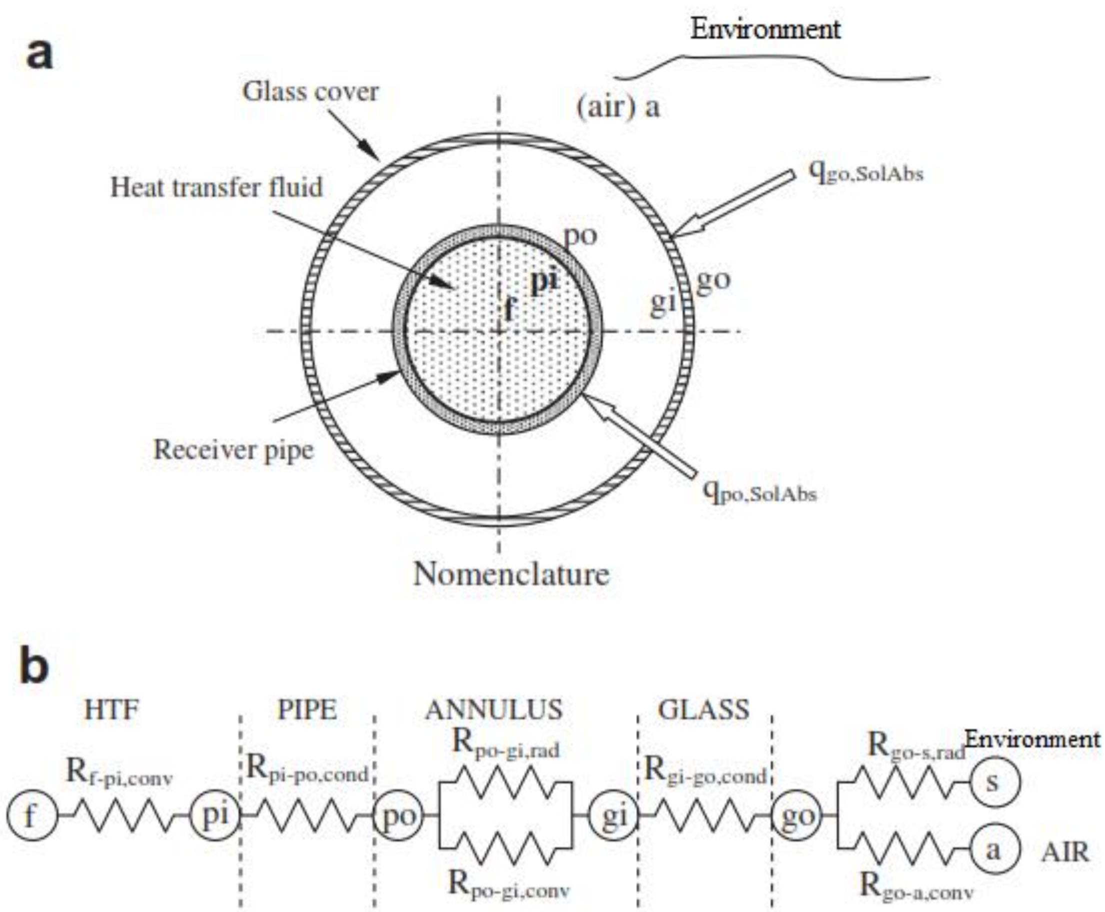

Figure 3.6, Heat transfer in a cross section at the solar collector and the thermal resistance model used in the heat transfer analysis

According to heat transfer theory, convection heat transfer between heat transfer fluid and receiver pipe is estimated by following equation;

$$q_{f-pi,conv} = h_f \pi D_{pi}\left(T_{pi} - T_f\right) \tag{23}$$

$$h_f = NuD_{pi}\frac{k_f}{D_{pi}} \tag{24}$$

$$Nu_{Dpi} = \frac{\frac{f_{pi}}{8\left(Re_{Dpi}-1000\right)Pr_f}}{1+12.7\sqrt{\frac{f_{pi}}{8}}\left(Pr_f^{\frac{2}{3}}-1\right)}\left(\frac{Pr_f}{Pr_{pi}}\right)^{0.11} \tag{25}$$

$$f_{pi} = \left[1.82log\left(Re_{Dpi}\right) - 1.64\right]^{-2} \tag{26}$$

$$Re = \frac{VD}{\nu} \tag{27}$$

$$Pr_f = \frac{c_p\mu}{k} \tag{28}$$

$$\nu = \frac{\mu}{\rho} \tag{29}$$

Heat conduction loss through the receiver pipe is calculated by following equation (Lienhard, 2011).

$$q_{pi-po,cond} = \frac{2\pi k_{pipe}\left(T_{pi}-T_{po}\right)}{ln\left(\frac{D_{po}}{D_{pi}}\right)} \tag{30}$$

As it was mentioned before, there is some heat transfer between receiver and glass envelop that are known as heat convection and radiation. Convection heat transfer is function of annual pressure and annual vacuum is estimated by following equation (Ratzel et al., 1979).

For vacuum annually:

$$q_{po-gi,conv=\pi D_{po}}h_{po-gi}\left(T_{po}-T_{gi}\right) \tag{31}$$

$$h_{po-gi} = \frac{k_{std}}{\frac{D_{po}}{2ln\left(\frac{D_{gi}}{D_{po}}\right)}+b\lambda\left(\frac{D_{po}}{D_{gi}}\right)+1} \tag{32}$$

$$b = \frac{(2-a)(9\gamma-5)}{2a(\gamma+1)} \tag{33}$$

$$\lambda = \frac{2.331\times10^{-20}(T_{po-gi}+273)}{Pa\delta^2} \tag{34}$$

For pressure annually

$$q_{po-gi,conv} = \frac{2\pi k_{eff}}{ln\left(\frac{D_{gi}}{D_{po}}\right)}\left(T_{gi} - T_{po}\right) \tag{35}$$

$$\frac{k_{eff}}{k_{ag}} = 0.386\left(\frac{Pr_{po-gi}}{0.861+Pr_{po-gi}}\right)^{\frac{1}{4}}\left(f_{cyl}Ra_{Dpo}\right)^{\frac{1}{4}} \tag{36}$$

$$f_{cyl} = \frac{\left[ln\left(\frac{D_{gi}}{D_{po}}\right)\right]^4}{L_c^3\left(D_{gi}^{-0.8}-D_o^{-0.8}\right)^5} \tag{37}$$

$$L_c = \frac{D_{gi}-D_{po}}{2} \tag{38}$$

Last but not least radiation heat transfer is estimated by following equation (Touloukian and Makita, 1970).

$$q_{po-gi,rad} = \frac{\sigma\pi\left(T_{po}^4-T_{gi}^4\right)}{\left(\frac{1}{\varepsilon_{po}}+\left(\frac{\left(1-\varepsilon_{gi}\right)D_{po}}{\varepsilon_{gi}D_{gi}}\right)\right)} \tag{39}$$

When it comes to heat transfer from the glass envelope to the atmosphere that is defined as convection heat transfer, two separate cases can be assumed. There is heat convection without wind and heat convection with wind.

$$q_{go-a,conv} = h_{go-a}\pi D_{go}\left(T_{go} - T_a\right) \tag{40}$$

$$h_{go-a} = \frac{k_{air}}{D_{go}}Nu_{Dgo} \tag{41}$$

Heat transfer convection without wind:

$$Nu_{Dgo} = \left[0.6 + \frac{0.387 Ra_{Dgo-a}^{0.166}}{\left\{1+\left(\frac{0.559}{Pr_{go-a}}\right)^{\frac{9}{16}}\right\}^{\frac{8}{27}}}\right]^2 \tag{42}$$

$$Ra_{Dgo} = \frac{g\beta(T_{go}-T_a)D_{go}^3}{v_{go-a}^2} Pr_{go-a} \tag{43}$$

$$\beta = \frac{1}{T_{go-a}} \tag{44}$$

Heat transfer convection including the wind:

$$Nu_{Dgo} = C Re_{Dgo}^m Pr_a^n \left(\frac{Pr_a}{Pr_{go}}\right)^{0.25} \tag{45}$$

N=0.36, m= 0.6, C=0.26

3.5.Survey Data

The data that are used in this research are associated with the collector parameter. Some of the data are related physical parameters of solar system like aperture area, length of collector and etc. these kind of data are useful for finding beam radiation, zenith angle, heat received for collector and receiver system. These data have been mentioned in the Table 3.2;

Table3. 2, Physical parameters of PTC in Shiraz

Collector parameter	**Value**	**Collector parameter**	**Value**
Length (L)	4.2m	Mirror reflectivity (β)	0.873
Width	3.4m	Cover transmission (τ)	0.96
Aperture (W0)	3.1m	Cover emissivity	0.88
Focal length	0.88m	Receiver absorptivity (a)	0.94
Outer diameter of receiver (Do)	4.2cm	Intercept factor (Y)	0.93
Inner diameter of receiver (Di)	3.5cm	Collector heat remover factor (FR)	0.98
Outer diameter of cover	7cm	Concentration ratio (CR)	14
Inner diameter of cover	6.7cm	Rim angle	90

Shiraz solar power plant has 256 pieces of parabolic trough collectors that are joined each six piece of parabolic trough and all of parabolic length for each row is estimated around 25m.

3.6.Solar parameter data

This power plant is located in the shiraz city, that its location is in the southern part of Iran at the latitude 29° and 36', and longitude 52° and 32'. This city has more than 3000 hours of sunshine annually with average daily irradiation of 20MJ/m2. According to Yaghoubi, (Yaghoubi and Mokhtari, 2007) the values of collector slope (β) for this type power plant system is estimated 45˚.

Since, the value of surface azimuth angle is calculated 90˚ in sunrise and 270˚ in sunset. Obviously, that value is defined zero when the time is at noon. for north hemisphere location, Shiraz solar power plant follows from this theory.

According to Yaghoubi (Yaghoubi and Jafarpur, 1990), the value of cloudy factor for different months in shiraz is estimated by following table. Also, the value of K_T is around 0.69.

Table 3.3, The value of cloudy factor in Shiraz for different months (Yaghoubi and Jafarpur, 1990)

Month	Cloudy factor
January	0.342
February	0.307
March	0.347
April	0.381
May	0.223
June	0.147
July	0.195
August	0.184
September	0.131
October	0.13
November	0.239
December	0.306

Since, the September month is considered for this research, the value of cloudy factor is around 0.131.

3.7.Thermodynamics and heat transfer parameters

The current fluid into the receiver tube is VP1-oil that all of physical properties can be found by the following table. This oil is known as industrial oil and it is used special for power system. Its liquid use range is between 12.5˚C to 400˚C and its vapor use range is between 258˚C to 400˚C. It can be used as a liquid heat transfer fluid or as a boiling-condensing heat transfer medium up to its maximum use temperature.

The temperature range is used for this research is between 200˚C to 250˚C that occur at noon in the summer times. Since, physical properties of this oil are function of temperature, therefore, the value of maximum temperature oil that have been exported by solar temperature gauge is around 250˚C

Table 3.4, Physical properties of VP1-oil

Physical properties	value
ρ (kg/m^3)	$-0.90797\times T+0.000781\times T^2-2.367\times10^{-6}\times T^3+183.25$
c_p (kJ/kg˚k)	$0.002414\times T+5.9591\times10^{-6}\times T^2-2.9879\times10^{-8}\times T^3+4.4172\times10^{-11}\times T^4+1.498$
K (W/m^2˚k)	$-8.19477\times10^{-5}\times T-1.92257\times10^{-7}\times T^2+2.5034\times10^{-11}\times T^3-7.2974\times10^{-15}\times T^4+0.137743$
ν (m^2/s)	$EXP((544.149/(T+144.43))-2.59578)\times10^{-6}$

All of physical properties are related to fluid temperature. It can be found that all of those values are not constant and are function of VP1- oil temperature. Besides that, all of physical properties that are related to receiver construction and tube material are important. Since, receiver material is made by AISI 316L, its physical properties can be found by the following table.

Table 3.5, Physical properties of AISI 316L

ρ_{pipe}	Pr_{pipe}	K_{pipe}	B_{pipe}
8000kg/m^3	5.45 (T=250˚C)	0.617 W/m^2˚k	$1.62*10^{-5}$ ˚k^{-1}

All of the heat transfer parameters that are constant for receiver tube have been collected by following table;

Table 3.6, Heat transfer parameters for receiver tube

Physical parameter	symbol	value	Ref
Speed of oil into the tube	V(m/s)	0.655	(M. Yaghoubi and moosavi, 2001)
molecular diameter of annulus gas	δ(cm)	$3.55*10^{-8}$	(Marshal, 1976)
Annulus gas pressure	P(Pa)	0.013	(Marshal, 1976)
ratio of specific heats for the annulus gas	γ	1.39	(Kalogirou, 2012)
thermal conductivity of the annulus gas at standard temperature and pressure	K_{std} (W/m^2°k)	0.02551	(Kalogirou, 2012)
accommodation coefficient	a	0	(Kalogirou, 2012)
acceleration	g(m/s^2)	9.81	-
glass envelope emissivity	ε_g	0.9	(Lienhard, 2011)
receiver pipe selective coating emissivity	ε_{pipe}	0.75	(Lienhard, 2011)
thermal conductivity of the air	K_{air} (W/m^2°k)	0.0251	(Lienhard, 2011)
Ambient temperature	T_a (˚k)	303	-

3 Result and Discussion

4.1 Solar parameter

The value of solar parameters will be estimated as a final result of this study. Since, considering days are first, fifth, tenth, fifteenth, twentieth , twenty fifth and 30th of September, the value of incident of declination is estimated by equation (1) and the day of year is exported by Table (3.1). These primary solar results have been illustrated by Table (4.1). Since, the value of latitude is known as parameter of geographical location, the value of Φ=29°36’.

Table 4.1, The solar parameters result for different days

Days	**Day of year(n)**	**δ**	**Φ**
First of September	244	7.724	29°36’
5th of September	248	6.183	29°36’
10th of September	253	4.215	29°36’
15th of September	258	2.217	29°36’
20th September	264	0.202	29°36’
25th September	268	-1.815	29°36’
30th September	273	-3.818	29°36’

The value of angle of incidence (θ), zenith angle (θ_z), the hour angle (ώ) and solar radiation (I) are estimated by equations (2) to (6) and have been illustrated by Table 4.2 to 4.8. Those values are sorted for 1st, 5th, 10th, 15th, 20th,25th and 30th of September.

Among of those solar data, the values that have been calculated in 12 noon are the most. Obviously, the negative point like cloudy factor, speed of wind and shadowing factors are the least at 12 noon of each day.

Table 4.2, The value of solar parameters result for first of Sep

First of September						
Time	**w**	**γ**	**θ**	**Θ_z**	**I_b**	**I_d**
7	-75	90	118.174	73.176	598.021	249.63
8	-60	75	102.191	60.150	745.312	249.63
9	-45	60	82.566	47.422	800.006	249.63
10	-30	45	61.344	35.527	820.211	249.63
11	-15	30	40.407	25.826	827.463	249.63
12	0	0	23.364	21.636	829.290	249.63
13	15	-15	33.894	25.826	827.4631	249.63
14	30	-30	54.11	35.527	820.211	249.63
15	45	-45	76.038	47.422	800.006	249.63
16	60	-60	97.417	60.150	745.312	249.63
17	75	-75	116.584	73.176	598.021	249.63
18	90	-90	130.851	86.221	205.858	249.63

Table 4.3, The value of solar parameters result for 5th of Sep

5th of September						
Time	**w**	**γ**	**θ**	**Θ_z**	**I_b**	**I_d**
7	-75	90	118.9	73.915	584.577	249.63
8	-60	75	102.53	60.92	740.04	249.63
9	-45	60	82.602	48.3	797.735	249.63
10	-30	45	61.0831	36.57	819.08	249.63
11	-15	30	39.733	27.156	826.752	249.63
12	0	0	21.823	23.177	828.685	249.63
13	15	-15	32.908	27.156	826.753	249.63
14	30	-30	53.614	36.563	819.079	249.63
15	45	-45	75.85	48.3	797.735	249.63
16	60	-60	97.503	61	740.04	249.63
17	75	-75	117.006	74	584.58	249.63
18	90	-90	131.733	87	169.435	249.63

Table 4.4, The value of solar parameters result for 10th of Sep

10th of September						
Time	**w**	**γ**	**θ**	**Θ_z**	**I_b**	**I_d**
7	-75	90	119.776	74.870	566.020	249.63
8	-60	75	102.950	61.924	732.659	249.63
9	-45	60	82.656	49.409	794.506	249.63
10	-30	45	60.782	37.928	817.444	249.63
11	-15	30	38.932	28.882	825.718	249.63
12	0	0	19.855	25.145	827.801	249.63
13	15	-15	31.706	28.882	825.718	249.63
14	30	-30	53.019	37.928	817.444	249.63
15	45	-45	75.621	49.409	794.506	249.63
16	60	-60	97.603	61.924	732.659	249.63
17	75	-75	117.514	74.870	566.020	249.63
18	90	-90	132.821	87.935	119.704	249.63

Table 4.5, The value of solar parameters result for15th of Sep

15th of September						
Time	**w**	**γ**	**θ**	**Θ_z**	**I_b**	**I_d**
7	-75	90	120.6	75.9	545.5	249.63
8	-60	75	103.4	63.0	724.4	249.63
9	-45	60	82.7	50.6	790.8	249.63
10	-30	45	60.5	39.4	815.5	249.63
11	-15	30	38.2	30.7	824.5	249.63
12	0	0	17.9	27.1	826.8	249.63
13	15	-15	30.6	30.7	824.5	249.63
14	30	-30	52.5	39.4	815.5	249.63
15	45	-45	75.4	50.6	790.8	249.63
16	60	-60	97.7	63.0	724.4	249.63
17	75	-75	118.0	75.9	545.5	249.63
18	90	-90	133.9	88.9	65.3	249.63

Table 4.6, The value of solar parameters result for 20th of Sep

20^{th} of September						
Time	**w**	**γ**	**θ**	**Θ_z**	**I_b**	**I_d**
7	-75	90	121.5	76.9	522.8	249.63
8	-60	75	103.8	64.1	715.1	249.63
9	-45	60	82.8	51.8	786.6	249.63
10	-30	45	60.3	40.8	813.3	249.63
11	-15	30	37.5	32.5	823.1	249.63
12	0	0	15.8	29.2	825.5	249.63
13	15	-15	29.5	32.5	823.1	249.63
14	30	-30	52.0	40.8	813.3	249.63
15	45	-45	75.2	51.8	786.6	249.63
16	60	-60	97.8	64.1	715.1	249.63
17	75	-75	118.4	76.9	522.8	249.63
18	90	-90	134.9	89.9	6.2	249.63

Table 4.7, The value of solar parameters result for 25th of Sep

25^{th} of September						
Time	**w**	**γ**	**θ**	**Θ_z**	**I_b**	**I_d**
7	-75	90	122.04	77.56	506.03	249.63
8	-60	75	104.02	64.81	708.07	249.63
9	-45	60	82.85	52.70	783.39	249.63
10	-30	45	60.15	41.88	811.64	249.63
11	-15	30	37.11	33.74	821.97	249.63
12	0	0	14.46	30.55	824.59	249.63
13	15	-15	28.80	33.74	821.97	249.63
14	30	-30	51.63	41.88	811.64	249.63
15	45	-45	75.09	52.70	783.39	249.63
16	60	-60	97.83	64.81	708.07	249.63
17	75	-75	118.74	77.56	506.03	249.63
18	90	-90	135.57	90.58	-37.15	249.63

Table 4.8, The value of solar parameters result for 30th of Sep

30th September						
Time	**w**	**γ**	**θ**	**Θ_z**	**I_b**	**I_d**
7	-75	90	123.05	78.91	471.23	249.63
8	-60	75	104.50	66.29	693.35	249.63
9	-45	60	82.96	54.39	776.51	249.63
10	-30	45	59.94	43.91	807.94	249.63
11	-15	30	36.44	36.16	819.53	249.63
12	0	0	11.82	33.18	822.48	249.63
13	15	-15	27.62	36.16	819.53	249.63
14	30	-30	51.09	43.91	807.94	249.63
15	45	-45	74.87	54.39	776.51	249.63
16	60	-60	97.92	66.29	693.35	249.63
17	75	-75	119.24	78.91	471.23	249.63
18	90	-90	136.77	91.87	-125.67	249.63

The negation value for solar beam radiation means there is no solar radiation for particular hours. Since, Iran is located in north hemisphere, as we are going forward through September the length of the days(Solar time) will be decreased. Therefore the best time for getting the highest beam radiation would be first of September. According to Figure 4.1 that has been estimated by solar experimental work at 12 noon, the solar beam radiation is the highest value rather than other times.

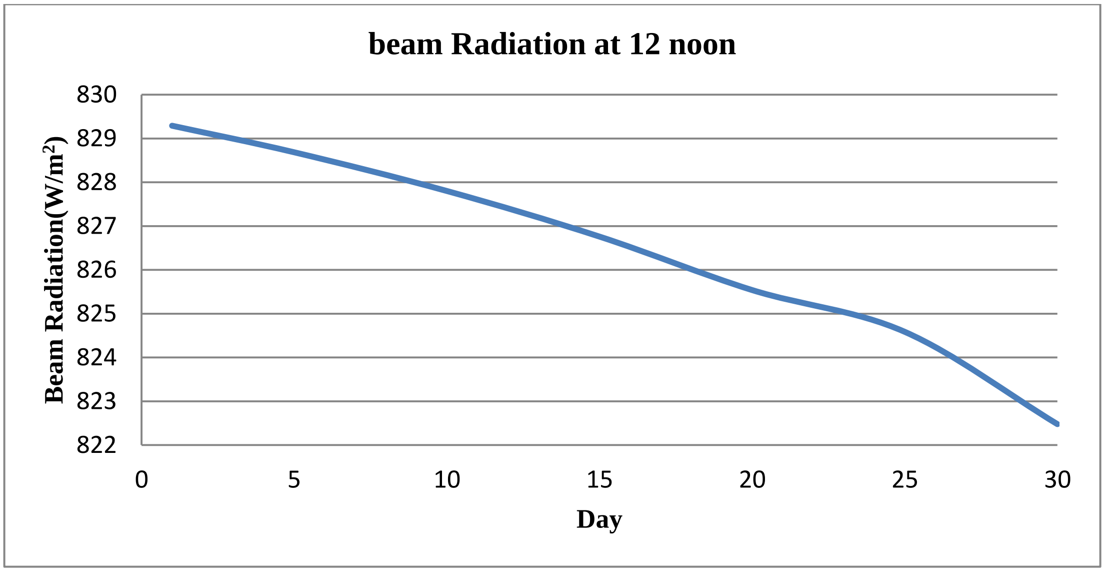

Figure 4.1, Solar beam radiation at 12 noon

As it was mentioned before, the highest value of solar beam radiation is defined for first of September and the lowest value is end of September.

4.2 Thermodynamics results for collector system

By using of short wavelength pyrometer gauge that is able to measure temperature for collector system, inlet collector temperature and outlet parabolic collector can be estimated. All of these values have been collected in table (4.9) for different day and time.

Table 4.9, Inlet collector temperature and outlet parabolic collector temperature

Time (hour)	**First day T(˚k)**		**Fifth day T(˚k)**		**Tenth day T(˚k)**		**Fifteenth day T(˚k)**		**Twentieth day T(˚k)**		**Twentieth-fifth day T(˚k)**		**Thirtieth day T(˚k)**	
	T_i	T_o	T_i	T_o	T_i	T_o	T_i	T_o	T_i	T_o	T_i	T_o	T_i	T_o
7	600	405	595	410	589	418	581	418	581	438	561	450	550	465
8	615	445	605	450	598	458	591	458	591	478	570	488	561	499
9	629	456	624	461	618	469	609	469	609	489	594	505	584	515
10	640	467	635	472	628	480	619	480	619	500	633	514	623	534
11	655	477	650	483	648	491	639	491	639	511	656	527	630	540
12	690	500	685	505	678	513	669	513	669	533	677	553	655	570
13	655	485	650	490	648	498	639	498	639	518	652	568	644	555
14	640	467	635	485	628	493	620	493	620	513	620	555	608	533
15	675	405	624	480	618	488	610	488	610	508	588	528	577	511
16	671	495	665	410	618	418	600	418	600	538	570	498	555	480
17	615	475	605	480	600	418	600	418	600	538	565	480	544	477
18	600	465	595	470	589	410	589	410	589	530	550	430	533	420

The value of energy received by collector and energy absorbed in parabolic collector system are estimated by equations (7) and (8). The thermal efficiency for parabolic system is calculated by equation (9). Exergy received and exergy absorbed in collector system will be estimated by using equation (10) and (11). The value of second law efficiency is estimated by equation (12). All of results have been sorted from table (5.10) to (5.16) for different days and time. The value thermal efficiency that has been estimated by thermal received in collector system is 31.32%.

Table 4.10, The value of exergy and efficiency for collector system in first of Sep

First of September						
Time	**Q_i**	**$Q_{i(tot)}$**	**Q_s**	**X_s**	**X_c**	**η**
9	1.99	94.85	29.71	85.37	8.17	9.57
10	6.29	299.65	93.85	269.68	25.37	9.41
11	9.11	433.99	135.93	390.59	36.94	9.46
12	10.66	507.78	159.03	457.00	43.79	9.58
13	9.94	473.10	148.17	425.79	38.46	9.03
14	7.69	366.31	114.73	329.68	31.01	9.41
15	3.71	176.88	55.40	159.19	22.16	9.22

Table 4.11, The value of exergy and efficiency for collector system in 5th of Sep

5th of September						
Time	**Q_i**	**$Q_{i(tot)}$**	**Q_s**	**X_s**	**X_c**	**η**
9	2.01	95.69	29.97	86.13	7.83	9.09
10	6.42	305.72	95.75	275.15	24.58	8.93
11	9.30	443.03	138.76	398.73	35.65	8.94
12	10.90	518.84	162.50	466.95	42.70	9.14
13	10.16	483.65	151.48	435.29	37.29	8.57
14	7.88	375.07	117.47	337.56	27.75	8.22
15	3.82	181.70	56.91	163.53	13.13	8.03

Table 4.12, The value of exergy and efficiency for collector system in 10th of Sep

10th of September						
Time	**Q_i**	**$Q_{i(tot)}$**	**Q_s**	**X_s**	**X_c**	**η**
9	2.03	96.78	30.31	87.10	7.31	8.39
10	6.59	313.64	98.23	282.27	23.15	8.20
11	9.55	454.81	142.45	409.33	34.51	8.43
12	11.20	533.26	167.02	479.94	40.65	8.47
13	10.45	497.41	155.79	447.67	36.06	8.06
14	8.12	386.51	121.05	347.86	26.02	7.48
15	3.95	188.01	58.88	169.21	12.39	7.32

Table 4.13, The value of exergy and efficiency for collector system in 15th of Sep

15th of September						
Time	**Q_i**	**$Q_{i(tot)}$**	**Q_s**	**X_s**	**X_c**	**η**
9	2.06	97.89	30.66	88.10	7.05	8.00
10	6.76	321.88	100.81	289.69	22.64	7.81
11	9.81	467.08	146.29	420.37	33.88	8.06
12	11.51	548.28	171.72	493.45	40.04	8.11
13	10.75	511.74	160.27	460.56	35.37	7.68
14	8.37	398.43	124.79	358.59	25.56	7.13
15	4.09	194.59	60.94	175.13	12.19	6.96

Table 4.14, The value of exergy and efficiency for collector system in 20th of Sep

20th of September						
Time	**Q_i**	**$Q_{i(tot)}$**	**Q_s**	**X_s**	**X_c**	**η**
9	2.08	99.02	31.01	89.11	6.11	6.86
10	6.94	330.42	103.49	297.38	19.90	6.69
11	10.08	479.79	150.27	431.81	30.10	6.97
12	11.84	563.84	176.59	507.46	35.90	7.07
13	11.06	526.59	164.93	473.93	31.23	6.59
14	8.63	410.81	128.66	369.73	22.20	6.01
15	4.23	201.43	63.09	181.29	10.55	5.82

Table 4.15, The value of exergy and efficiency for collector system in 25th of Sep

25th of September						
Time	**Q_i**	**$Q_{i(tot)}$**	**Q_s**	**X_s**	**X_c**	**η**
9	2.10	99.80	31.26	89.82	4.68	5.21
10	7.07	336.45	105.37	302.80	19.81	6.54
11	10.26	488.75	153.08	439.88	30.10	6.37
12	12.07	574.83	180.03	517.35	32.98	6.84
13	11.28	537.08	168.21	483.37	21.67	4.48
14	8.81	419.54	131.40	377.59	13.78	3.65
15	4.33	206.27	64.60	185.64	6.59	3.55

Table 4.16, The value of exergy and efficiency for collector system in 30th of Sep

30th of September						
Time	**Q_i**	**$Q_{i(tot)}$**	**Q_s**	**X_s**	**X_c**	**η**
9	2.13	101.28	31.72	91.15	3.75	4.11
10	7.31	348.23	109.06	313.41	15.58	4.97
11	10.63	506.31	158.57	455.68	22.65	4.97
12	12.52	596.34	186.77	536.70	24.24	5.02
13	11.71	557.61	174.64	501.85	24.14	4.81
14	9.17	436.66	136.76	393.00	16.87	4.29
15	4.53	215.75	67.57	194.17	7.73	3.98

4.3 Thermodynamics result for receiver system

For finding exergy and thermal efficiency in reciver system, accuracy values of inlet and outlet temperature are necessary. They have been recorded by short wavelength pyrometer gauge and solar temperature gauge. Also the value of mass flow rate is measured by Mass follow controller monitoring. The value of exergy received and exergy absorbed in receiver are estimated by equations (15),(16) and (17). The results have been shown by table 4.17 to 4.23 by different days and times.

Table 4.17, The value of exergy and efficiency for receiver system in first of Sep

First of September						
Time	**T_{fo}**	**T_{fi}**	**C_p**	**X_c**	**X_u**	**η**
9	523	490	3.42	23.77	12.50	52.58
10	528	495	3.47	75.08	39.99	53.27
11	533	500	3.52	108.74	58.65	53.94
12	538	504	3.57	127.23	69.47	54.60
13	535	501	3.54	118.54	64.26	54.21
14	529	496	3.48	91.78	49.01	53.40
15	519	489	3.38	44.32	23.06	52.02

Table 4.18, The value of exergy and efficiency for receiver system in 5th of Sep

5th of September						
Time	**T_{fo}**	**T_{fi}**	**C_p**	**X_c**	**X_u**	**η**
9	516	494	3.36	23.98	12.37	51.60
10	521	499	3.40	76.60	40.06	52.30
11	528	504	3.47	111.00	59.13	53.27
12	531	508	3.50	130.00	69.77	53.67
13	527	505	3.46	121.18	64.39	53.13
14	522	501	3.41	93.98	49.28	52.44
15	512	492	3.32	45.53	23.23	51.03

Table 4.19, The value of exergy and efficiency for receiver system in 10th of Sep

10th of September						
Time	**T_{fo}**	**T_{fi}**	**C_p**	**X_c**	**X_u**	**η**
9	508	500	3.29	24.25	12.23	50.44
10	513	506	3.33	78.58	40.21	51.17
11	523	512	3.42	113.96	59.92	52.58
12	523	508	3.42	133.61	70.26	52.58
13	519	507	3.38	124.63	64.84	52.02
14	514	500	3.34	96.84	49.69	51.31
15	504	491	3.25	47.11	23.48	49.85

Table 4.20, The value of exergy and efficiency for receiver system in 15th of Sep

15th of September						
Time	T_{fo}	T_{fi}	C_p	X_c	X_u	η
9	503	496	3.25	24.53	12.19	49.70
10	508	501	3.29	80.65	40.68	50.44
11	514	507	3.34	117.03	60.05	51.31
12	519	511	3.38	137.38	71.47	52.02
13	515	507	3.35	128.22	65.98	51.46
14	507	501	3.28	99.83	50.21	50.30
15	502	493	3.24	48.76	24.16	49.55

Table 4.21, The value of exergy and efficiency for receiver system in 20th of Sep

20th of September						
Time	T_{fo}	T_{fi}	C_p	X_c	X_u	η
9	499	488	3.21	24.81	12.18	49.10
10	504	493	3.25	82.79	41.27	49.85
11	508	499	3.29	120.21	60.64	50.44
12	515	503	3.35	141.28	72.70	51.46
13	511	502	3.31	131.94	67.13	50.88
14	503	493	3.25	102.93	51.16	49.70
15	498	488	3.20	50.47	24.70	48.95

Table 4.22, The value of exergy and efficiency for receiver system in 25th of Sep

25th of September						
Time	T_{fo}	T_{fi}	C_p	X_c	X_u	η
9	495	483	3.18	25.00	12.12	48.48
10	500	487	3.22	84.30	41.52	49.25
11	504	493	3.25	122.46	61.05	49.85
12	511	497	3.31	144.03	73.28	50.88
13	507	496	3.28	134.57	67.68	50.30
14	499	493	3.21	105.12	51.61	49.10
15	494	490	3.17	51.68	24.98	48.33

Table 4.23, The value of exergy and efficiency for receiver system in 30th of Sep

30th of September						
Time	T_{fo}	T_{fi}	C_p	X_c	X_u	η
9	490	481	3.14	25.38	12.11	47.70
10	495	485	3.18	87.25	42.30	48.48
11	499	490	3.21	126.86	62.29	49.10
12	507	493	3.28	149.42	75.15	50.30
13	502	496	3.24	139.71	69.23	49.55
14	494	490	3.17	109.41	52.88	48.33
15	489	484	3.14	54.06	25.70	47.55

The highest value of second law efficiency for each day is taken at 12 noon. Also, on the first of September second law efficiency has the highest value. As far as first law efficiency is considered, that value is estimated by equation (14) and the results have been sorted by Figure 4.2 for different days at 12 noon. The first law efficiency for receiver system is arond54%. But, it was decreased when days are closed to end of September. It reaches to below 20% in 30th of September.

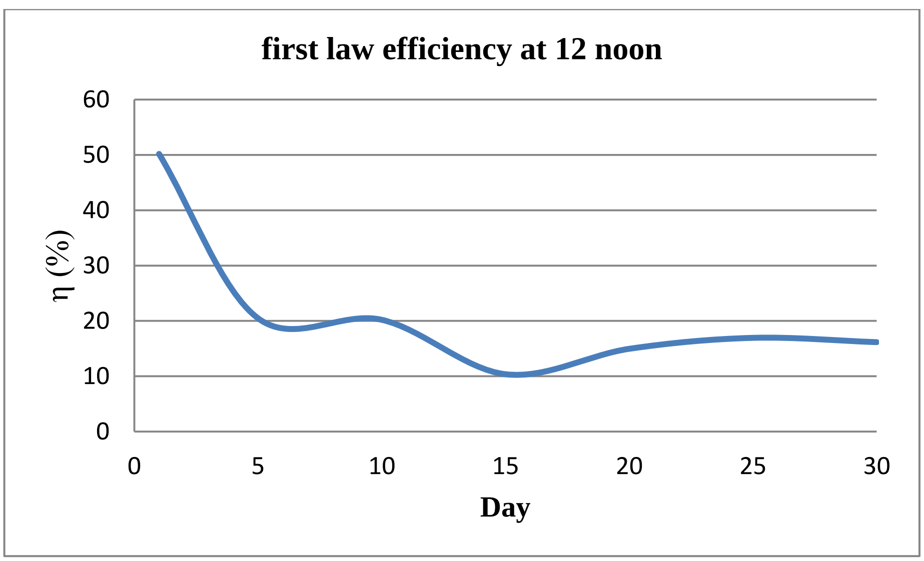

Figure 4.2, The value of first law efficiency for collector system at 12 noon

Value of first law efficiency can be changed at the same time in different place of receiver system. However, this changing value is not considered. Since, there were no slope through the receiver pipe, pressure drop is very small and the range of tolerance temperature is neglected. When it comes to finite element analysis, a graph can be drawn that shows relationship between tolerance efficiency and different segment of receiver at the same time. Figure 4.3 shows tolerance efficiency receiver system at 20 segments at 12 noon on the 1st of September.

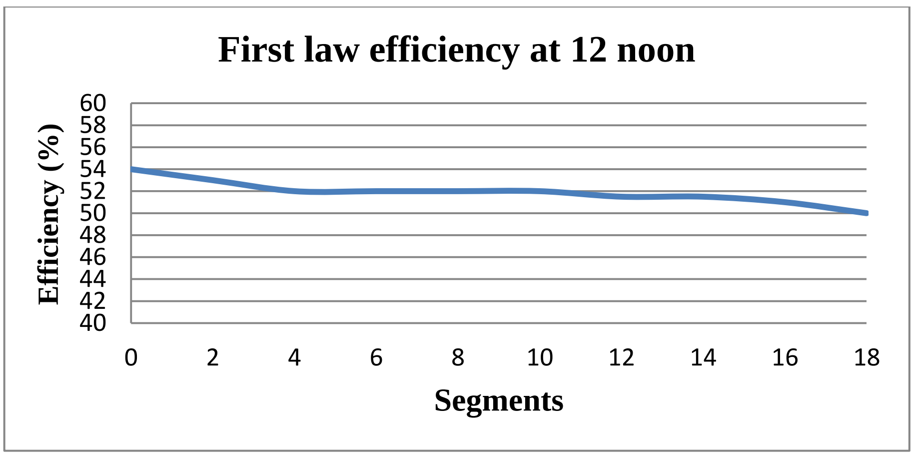

Figure 4.3, The percentage of receiver efficiency in the 20 segments

As it can be seen, the range of efficiency at the same time is not high. In the first segment of receiver efficiency value is around 54%. But, it was decreased when it went forward to end of segments. It reached to 51%. Although this range of tolerance is not high, it can be considered when heat transfer losses value is calculated through of receiver.

4.4 Rankine system

According to thermodynamic formula, the value of work and heat transfer for turbine and two pumps are calculated by equations (19) to (22) and their results have been shown by table 4.24.

Table 4.24, Thermodynamics results for Rankine system

Turbine	Pump (Rankine Cycle)	Pump(Oil Cycle)
W_T=534.82Kw	W_{p2}=839Kw	W_{p1}=49.14Kw
X_T=760.24Kw	X_{p2}=250.57Kw	X_{p2}=8.16Kw
η=70%	η=29.9%	η=17.5%

The value of turbine efficiency is around 70% in the September while the thermal efficiency in solar cycle is below 50%. The most important factor for reduce solar efficiency is design of parabolic collector. Since, aperture area in parabolic system is not one piece and it is made by four pieces of mirror, the collector efficiency is reduced. But, turbine efficiency is high for rankine in power system. Also, the value of thermal pump efficiency is higher than the value of oil cycle efficiency. It can be said that, the exergy value in rankine cycle is more proper than another cycle.

4.5 Heat transfer result

According to heat transfer methodology in this research, the value heat losses in different part of receiver have been shown by table 4.25. Since, heat transfer occurs into the receiver part, all of heat transfer equation that was mentioned in methodology is related to this section of solar device. Besides that, the hot oil temperature has been measured 250ºC by solar gauge. It was between 11:30 to 2:00 in September month.

Table 4.25, Heat transfer results for different part of receiver

Heat transfer	Heat transfer parameter	No. Eq	Heat transfer symbol	Value of heat transfer
Convection heat transfer between the heat transfer fluid and the receiver pipe	ν= 3.32*10^{-7} m^2/s Re= 1.32*10^5	(29) (27)	$Q_{f-pi,conv}$ (23)	15.46kW

	f_{pi}= 0.0169	(26)		
	c_p= 1.9 W/kg˚k			
	k_{oil}= 0.105 W/m^2k			
	ρ_{oil}= 868.1 m^3/kg			
	Pr_f= 5.19	(28)		
	Pr_{pi}=5.45			
	Nu_{Dpi}=665.762	(25)		
	h_f= 1.05 W/m˚k	(24)		
Conduction heat transfer through the receiver pipe wall	K_{pipe}=0.617 W/m^2k		$Q_{pi-po,cond}$(30)	10.04kW
Heat transfer from the receiver pipe to the glass envelope (vacuum in annulus)	δ= 3.55*10^{-8}cm		$Q_{po-gi,conv}$(31)	0.058kW
	P= 0.01 Pa			
	λ= 0.89cm	(34)		
	γ= 1.39			
	k_{std}= 0.025 W/m^2k			
	a=0			
	b=1.57	(33)		
	h_{po-gi}=0.0038 W/m˚k	(32)		
Heat transfer from the receiver pipe to the glass envelope (pressure in annulus)	L_c=1.25cm	(38)	$Q_{po-gi,conv}$(35)	58.11W
	f_{cyl}= 0.041	(37)		
	β= 0.002 1/˚k	(44)		
	Ra= 23152.06	(43)		
	k_{eff}= 0.0526 W/m^2k	(36)		
Radiation Heat Transfer	ε_g= 0.9		$Q_{po-gi,rad}$(39)	282.34W
	ε_s= 0.75			
	σ=5.67*10^{-8} W/m^2k^4			
Heat transfer from the glass envelope to atmosphere(Convection heat transfer) no wind	Nu_{Dgo}=6.36	(42)	$Q_{go-a,conv}$ (40)	110.3W
	k_{air}= 0.0251 W/m^2k			
	h_{go}=3.8 W/m˚k	(41)		
Heat transfer from the glass envelope to atmosphere (Convection heat transfer)	C=0.26		$Q_{go-a,conv}$ (wind) (40)	4.72kW
	m=0.6			
	n=0.37			
	Nu_{Dgo}=163.12	(45)		
	h_{go}= 97.5 W/m˚k	(41)		

Table 4.25 shows all of heat losses values that occur in different part of receiver. There are seven different heat losses that among of them the Convection heat transfer between the heat transfer fluid and the receiver pipe was the highest. Since, there is no vacuum between glass envelop and receiver tube, the Nusselt number value was increased dramatically. Therefore, coefficient convection is going up. In this research, heat convection equation has been exported by equation (23) and its value in 250ºC for oil is around 15.46kW.

Heat transfer from the glass envelope to atmosphere is known as heat convection and it is divided to windy and no windy status. Obviously, the Nusselt number in the case of windy is more than another case. Therefore, the heat convection value in this section is around 4.72 kW for windy case that is frothy times as much as when there is no wind.

As long as Heat transfer from the receiver pipe to the glass envelope (vacuum in annulus) is considered, its value is the lowest. Since, the accommodation coefficient value is assumed zero, the value of convection coefficient is decreased. Finally, heat losses value in this section was below 1kW.

It can be said, the higher efficiencies are obtained when the annuals is under vacuum, but in both cases at the high temperatures the collector efficiency drops gradually, which is more notable for the black chrome coating. It can be found that, two different cases can be considered. First case is air flow between glass envelop and receiver system. Another case is defined when vacuum is installed between them. Obviously, thermal efficiency is higher for different temperature when it comes to vacuum installation in receiver part. Figure 4.4 shows thermal efficiency values for vacuum and air installation in different temperature.

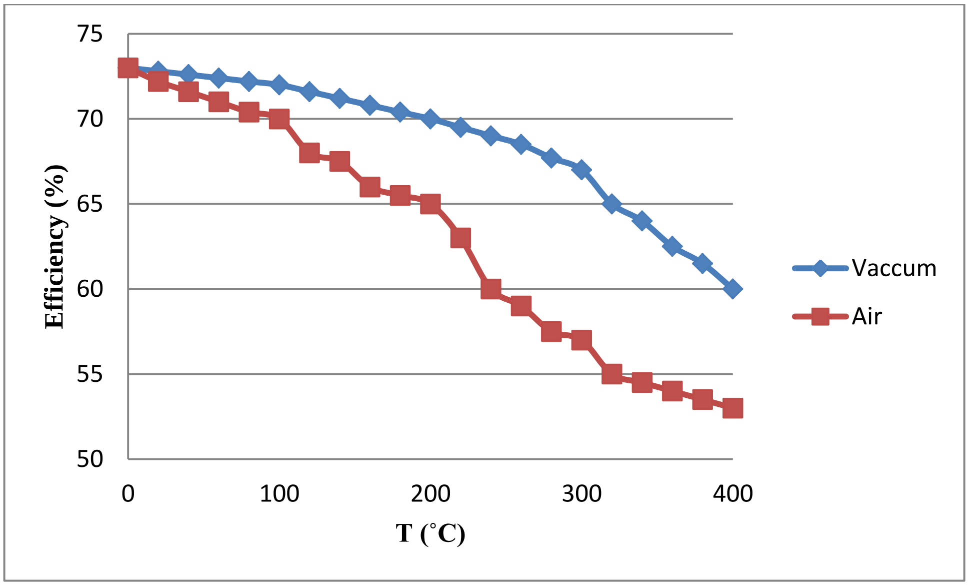

Figure 4.4, The percentage of collector efficiency in the different temperature

As it can be seen thermal efficiency value for vacuum case is higher although this case can be considered as an ideal case. It can be found that, the heat losses values for vacuum installation is lower than another case. It has been shown by Figure 4.5 as sun is appear and Figure 4.6 as the cloudy case or sun disappear.

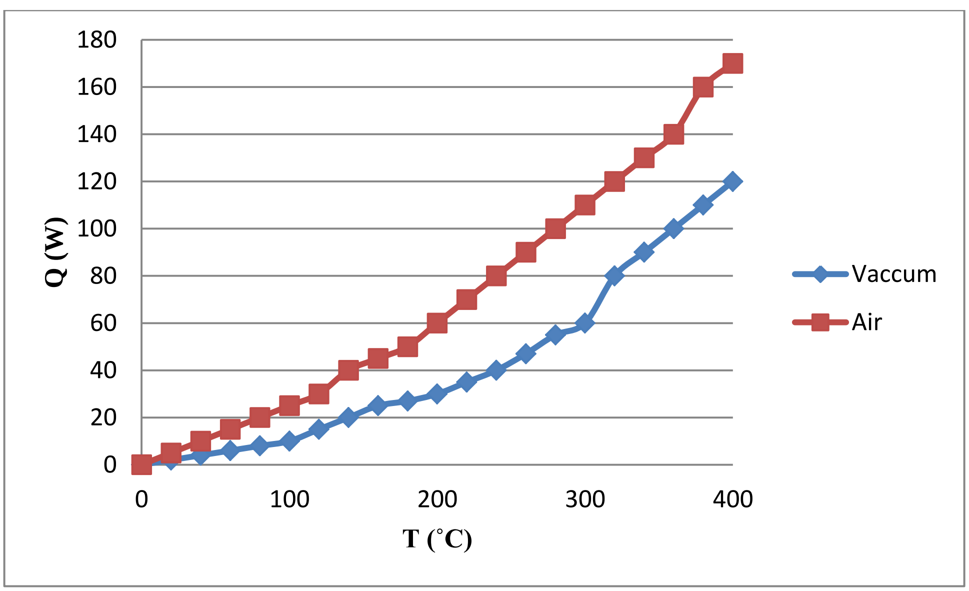

Figure 4.5, Comparison of thermal losses in receiver part when sun is appear

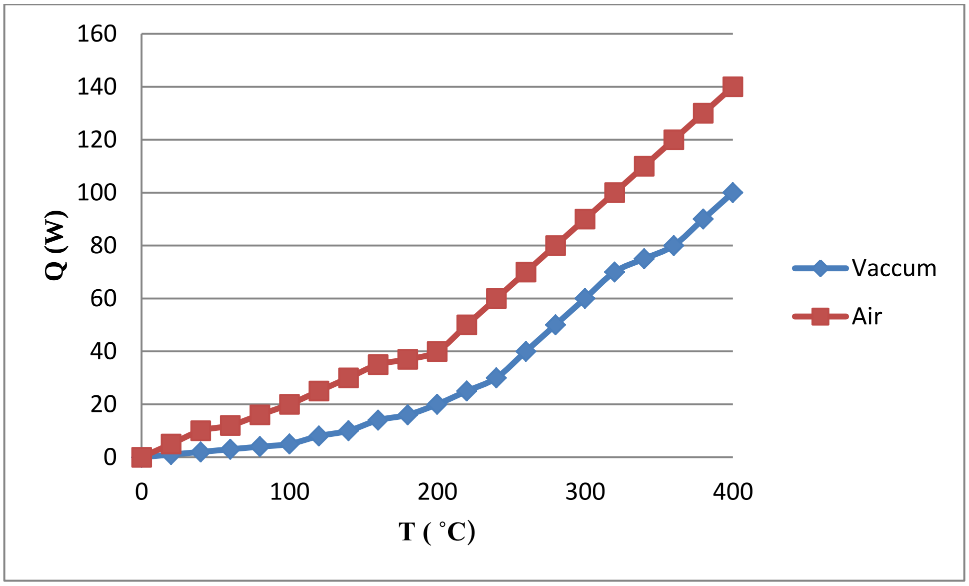

Figure 4.6, Comparison of thermal losses value in receiver when sun is not appear

As it can be seen, the heat losses values for sun appear case is higher than when sun is disappear or cloudy factor might be concerned. In September cloudy factor is so less when it is referred to Table 3.3.

4.6 Ways to improve the performance

Having seen the thermodynamic analysis performed for the solar power plant in the study, one might ask if there are any ways to further improve the efficiency of a solar power plant with a parabolic trough collector. In this section two suggestions will be made concerning this issue. One is the use of Phase Change Materials (PCM) and the other is the heat transfer enhancement in the system by replacing the fluid in the collector with a nanofluid which is defined as Nano sized particles (1-100nm) suspended in a base fluid.

Recently there has been a major interest in the use of thermal storage devices. By the use of these types of material a significant amount of energy may be conserved and the efficiency of energy consuming mechanisms may be enhanced. Phase Change Material (PCM) is one tool that can contribute to the achievement of this goal. These materials are capable of store the energy in a phase and then release it when needed by changing their phase.

Nanofluid which is a colloidal mixture of a base fluid like water and solid nano particles has showed some favorable behavior regarding this issue. During the recent years a significant number of researches have been performed to disclose the unknown facts about this new class of fluids.

Since, there are no mirror reflectors technology in Iran, all of aperture area has been covered by three or four pieces of mirror. Therefore, there is no specific focal point for each parabolic system. It can be found as the main factor to reduce thermal efficiency for solar power plant system.

5 Conclusion

As conclusion, parabolic trough solar power plant system in Iran was considered. By using some of the useful physical parameters and physical properties of receiver oil, thermodynamics parameters were estimated and heat transfer could be analyzed. First, fifth, tenth, fifteenth, twentieth, twentieth-fifth and thirtieth of September were calculation days, the value of exergy and thermal efficiency were the highest value when it comes to first of September.

Also, the value of exergy and thermal efficiency at 12 noon was the most. The exergy received value was around 460kJ/kg at 12 noon of first September and the value of exergy absorbed by collector was approximately 45kJ/kg. The energy efficiency of parabolic trough collector system was calculated to be around 10%. It can be said that type of mirror used is effective on the amount of efficiency. If one-piece mirror were used the efficiency would be higher. On the other hand the second law efficiency for receiver system was around 55% that by comparison of fossil power plant was low. Some technologies could be utilized to improve the efficiency. Phase Change Material can be used to store thermal energy. Nanofluid can also increase the performance since they can increase the heat transfer to the receiver fluid.

As far as heat transfer is considered, the value of Convection heat transfer between the heat transfer fluid and the receiver pipe was high in 250˚C. It was around 15.5kW. Also, the value of heat transfer from the glass envelope to atmosphere with wind was higher than the value of Heat transfer from the glass envelope to atmosphere without wind. It can be found that coefficient of heat convection in case of wind is bigger than another one.

Various recirculation regions can be found on the leeward and forward sides of the parabolic collector when the collector orientation changes with respect to wind direction. The flow field and pressure field around the collector are affected by the small gap between the two sections of collector's sides and the distance between collector and the ground, and less affected by the receiver tube.

Last but not least the value of thermal loss when it comes to on-sun case is more than when the off-sun case. It is approximately two times more than ones. The resultant force on the collector structure is maximum when wind blows normal to the opening and minimum when the collector is oriented parallel with wind direction.

6 Recommendation

The following recommendations should be considered for further research in this area:

Since in a solar power plant the heat absorbed by the solar collector is to be transferred in a suitable time and be used later in the power generating cycle such as a Rankine cycle, PCM might be useful to store the energy resulting from radiation. To the best of authors' knowledge very few studies have investigated the effect of latent heat storage by PCM incorporated with a solar power plant. A model for energy and exergy analysis of latent heat thermal storage usage is in a solar system. Their system included an air flow heated by a solar collector entering a tank filled with PCM afterwards. Calculations done in this work are used to perform a comprehensive second law analysis for the PCM used.

Enhancing the thermal performance of the solar collector is another way that could play a remarkable role in the improvement of solar power plant efficiency. One of the ways is to use a fluid with higher thermal performance so that more heat gain could be obtained from the solar radiation. Nanofluid is known a new technique for reducing of heat losses value and enhancement of thermal efficiency.

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