0056 - CONSTRUCTION AND PERFORMANCE ANALYSIS OF AN INDUSTRIAL ORIENTED CONCENTRATED SOLAR COLLECTOR BY USING FRESNEL LENS

Ahmet Ersavaş[1] , Yusuf Işıker[2] , Zeynel Abidin Fıratoğlu[2], Bülent Yeşilata[2]
[1]*Mechanical Engineer, Şanlıurfa*
[2]*University of Harran, GAP YENEV Research and Application Center*

Corresponding Author: Ahmet Ersavaş

ABSTRACT

In this study, concentrated solar energy collector prototype has been uniquely designed, produced and the performance has tested according to Şanlıurfa region conditions. 1 m^2 fresnel lens, which can make a linear focusing, has been used in this prototype. Focus line is 1.5 m away from the lens and focus line is 5 cm with and 1 m long. İn order to improve heat transfer a copper pipe is placed to the focus line which has a 7 cm diameter,1.2 m long and 3 mm thickness, also this pipe is placed inside a borosilicate glass, which has a diameter of 15 cm, and isolated from each edges to reduce heat losses. Copper pipe has been connected to the oil tank by heat resistant flexible pipes and a oil pump has connected to the system to make closed circuit. To provide solar tracking in two dimensions, manual controlled mechanism had been developed. K type thermocouple's has been placed to the each edge of the copper pipe, in order to measure temperature difference. Test results showed that Fresnel lenses can be used in concentrated solar energy systems and have technical and economical advantages on energy production.

Key words: Fresnel lens, solar energy, concentrated solar systems.

1. INTRODUCTION

To reduce the impact of conventional energy sources on the environment, much attention should be paid to the development of new energy and renewable energy resources. Solar energy, which is environment friendly, is renewable and can serve as a sustainable energy source. Hence, it will certainly become an important part of the future energy structure with the increasingly drying up of the terrestrial fossil fuel. [1] Regarding to these reasons, global energy need should be provided from, cleaner and renewable sources. At this point, because of sun appears all over the world and energy from sun is unlimited, benefiting from solar energy is critical issue for the world.

IEA(International Energy Agency)'s 2014 World Energy Investment Outlook Special report, state that 1,6 trillion Dollar has been invested to energy sector in 2013. This amount shows that energy investments had doubled with respect to year 2000. In addition to 1,6 trillion dollar 130 billion dollar has been invested on improving energy efficiency, in year 2013. According to this report, until 2035 required annual energy investment is going to reach to 2 trillion dollars and the annual bill of energy efficiency investments will catch 550 billion dollars [2]. Considering this foresee, annual energy efficiency investments in Turkey would be in higher order and these investments should be encouraged to make with own resources. By means of that, Turkey should be exporter in energy generation systems, instead of being importer. In order to reach Turkish Governments year 2023 goals, we should reduce dependency on energy imports and we should develop our own technologies. Turkey should speed energy investments up, especially more efficient usage of renewable sources.

Last years, regarding to the technological developments on energy conversion, solar energy has gained a wide spread of application. Solar energy technologies mainly divided in to two types, with respect to application, photovoltaic (PV) and thermal systems. Electricity production from sun beams and solar thermal systems have various types with respect to their designs, applications and technological levels. Photovoltaic systems are able to produce electricity directly from sunbeams on the other hand thermal systems are able to produce thermal energy (this energy could be converted to electricity) by means of heat [3]. Thermal energy gained from sun could be used either domestically (Hot water systems), or industrially (Steam, Superheated oil and water). Industrial usage needs higher temperatures due to that concentrated solar collectors have been used in these applications.

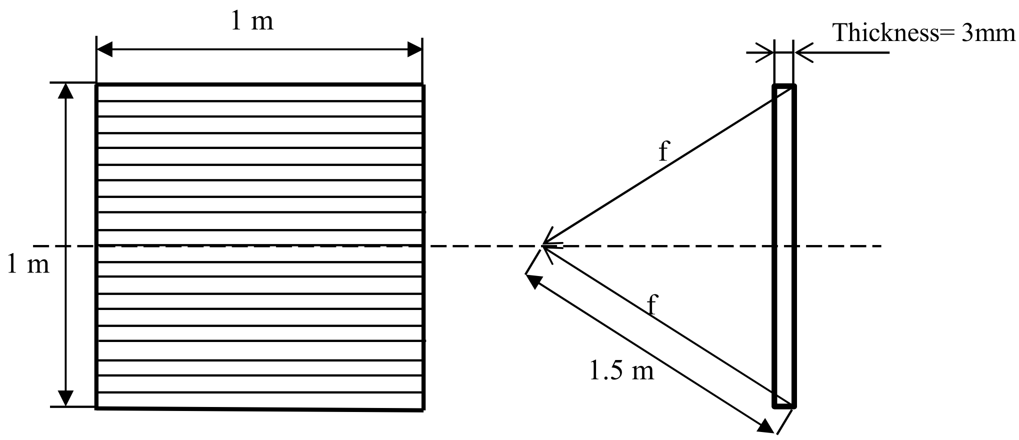
Concentrating collectors use reflectors, lenses or other optical concentrators to change the direction of incident solar radiation and concentrate it to the receiver. The receiver is basically a heat exchanger where the concentrated solar energy is intercepted and transformed into thermal energy. Fresnel lens has become an important choice for solar thermal conversion applications [4,5].

In this respect, production of concentrated solar systems in our country have been targeted and prototype of an industrial oriented concentrated solar Fresnel lens collector has been produced and experimental analysis has been done.

2. MATERIALS AND METHODS

Due to there isn't any decided investment on solar trough technology in Turkey also there aren't any suppliers for the parts of these system. There are no producers and importers of such systems in our country. To avoid the question marks of the investors, concentrated solar systems needs a detailed analysis. The main purpose of this study is to make this analysis and shoving the availability of concentrated solar systems in our region. Concentrated solar energy systems have a simple working mechanism, however focusing the concentrator and selecting the right material for receiver are the most important issues. Regarding to these conditions applying and using of the concentrator is not complicated but for getting high performance, precision is a must. Due to these reasons a linear Fresnel lens had chosen as a concentrator, in this study. Fresnel lens is also considered as a promising solar collector for its flexibility in optical design and less possibility of manufacturing errors when compared to the conventional mirror concentrators [6,7,8,9,10,11,12].

To obtaining the precision in test setup and for supplying concentrator easily, a linear focusing Fresnel lens, has been used. An aluminium frame is produced to place the Fresnel lens, which has 1 m^2 of area (Figure1).



Focal length f=1500 mm line focus is at the groove side material is optical acrylic

Figure 1: Fresnel Lens used in this study

5 mm thick steel sheet plates had been cut on cnc plasma cutting machine with respect to the design (Figure 2.a) and these steel plates placed both sides of the aluminium frame. Steel plates are connected by 5 steel rods, steel rods placed to the steel frames by using the holes, which are pierced during cutting. For moving the system in X-axis, two foots are placed to the system, one of these foots is movable the other is fixed to the ground. For moving in Y axis connections are made by ball bearings. Focus line of the lens is 1.5 m away from the lens top surface and the focusing line is 5 cm thick and 1 m long. Due to these dimensions receiver is chosen as 7 cm thick, 1.2 m long and thickness of 3 mm copper pipe. Copper pipe then placed in the middle of a borosilicate glass pipe, which has a diameter of 15 cm. After that copper pipe is isolated from environment, by using pipe plugs that are placed to each sides of the copper pipe, copper pipe is connected to oil tank and oil pump with high temperature resistant flexible hoses. By means of that a closed system is being formed between tank and receiver copper pipe. For securing the focusing and balancing, a wheeled mechanism with a worm gear is placed to the bottom side of the system. The system is easily controlled manually, however if convenient electric motors located to the movable parts of the system then the system would be controlled automatically (Figure 2.b).

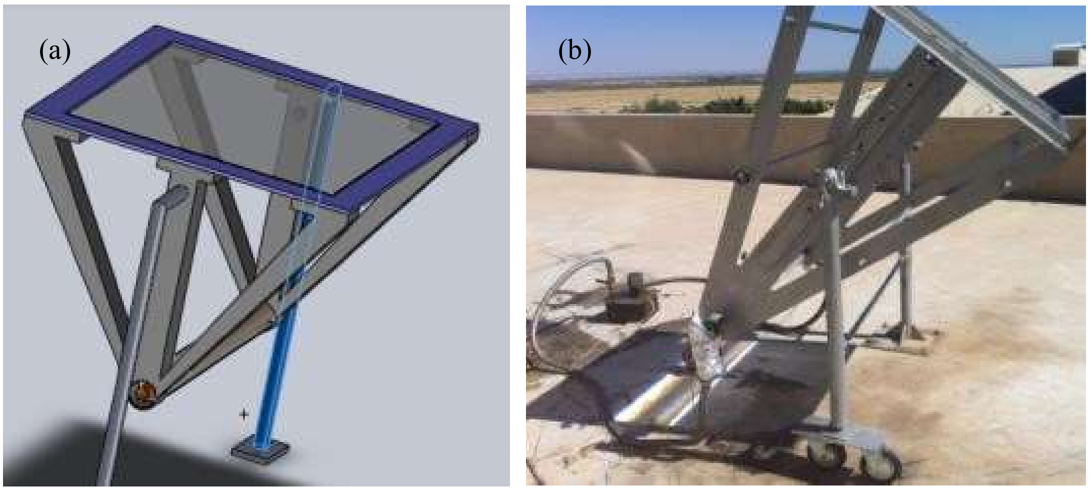


Figure 2 : a. Design of the system b. Finished Fresnel lens solar collector.

To collecting test result data's, K type thermocouples located entrance and exit of the copper pipe. By means of that temperature changes had been transferred to the HIOKI 8422 Data Logger (Figure 3.a) and recorded by this data logger. To collecting instant solar irradiation data Kipp-Zonen (Figure 3.b) brand pyronameter had been used. This data logger is tracking the sun and able to collect, instantly, direct beam radiation, diffuse radiation, total radiation and radiation in horizontal values at the same time [13]. Mobiltherm32 (Heat transfer oil) is used as a working fluid. Mobiltherm32 is industrial oil, which is barely used, in industrial applications. Its heat transfer coefficient is not change too much with respect to temperature changes also flashpoint is 236 °C so it would reduce the fire risk during experiments. Properties of the thermal oil are given in Table 1.

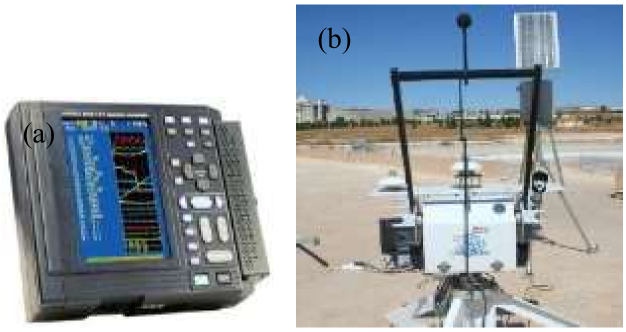


Figure 3 : a. HIOKI 8422 Data Logger. b. Kipp-Zonen data logger.

To calculate the heat transferred to the working fluid equation 1 is used. Mass flow($\dot{m}$) rates are fixed for each experiment, and controlled by a ball valve, which was located just behind the inlet of the copper pipe. Specific heat(c) of the oil had been taken from table 1 with respect to the temperature of the oil.

$$Q = \dot{m}c\,(\Delta T) \qquad (1)$$

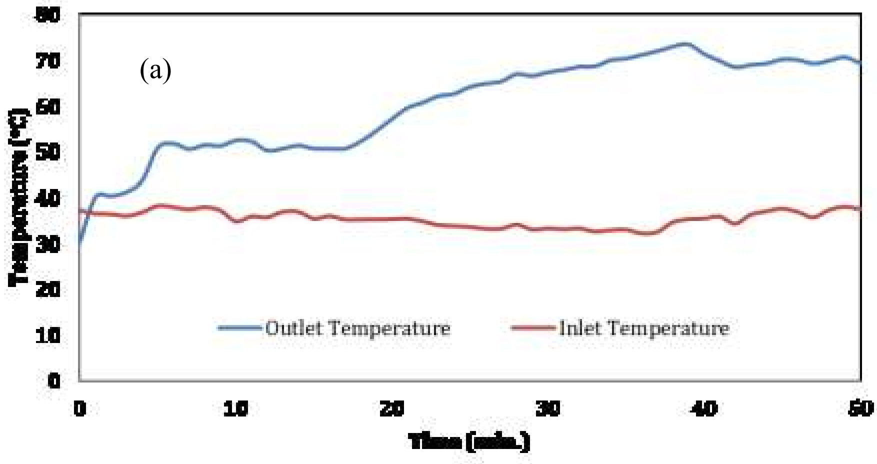
Table 1: Properties of Mobiltherm32

Temperature [°C]	Kinematic Viscosity [cSt]	Density [kg/m3]	Specific Heat Capacity [kJ/(kg.K)]	Heat Transfer Coefficient [W/(m.K)]
0	319.3	879.4	1.805	0.1349
10	154	873.8	1.841	0.1342
20	82.9	868.2	1.877	0.1335
30	48.9	862.7	1.914	0.1327
40	31	857.3	1.95	0.132
50	20.9	851.9	1.987	0.1313
60	14.8	846.6	2.023	0.1306
70	10.9	841.4	2.059	0.1298
80	8.3	836.2	2.096	0.1291
90	6.6	831.1	2.132	0.1284
100	5.3	826.1	2.168	0.1277
110	4.4	821.1	2.205	0.1269

3. RESULTS

To understand the effects of dynamic atmospheric conditions on the produced Fresnel lens collector, experiments are made in different days. Temperature change between inlet and outlet values were collected in every 5 seconds on the other hand direct solar radiation values were taken in every 10 minutes. Two different mass flow rates were used in the experiments.

First experiment had been started at 13:40 June 21, 2012 and took 50 minutes under the mass flow rate of 35 kg/h. Temperature change of the experiment is shown in below Figure 4 a. Regarding to this experiment maximum temperature difference between inlet and outlet had been measured as 39,5 °C. Figure 5 b. is showing the incoming direct solar radiation with respect to transferred energy to the thermal oil. When we compare the heat transferred to the oil and direct solar radiation, heat transfer efficiency was increased by time, as shown in figure 4 b.



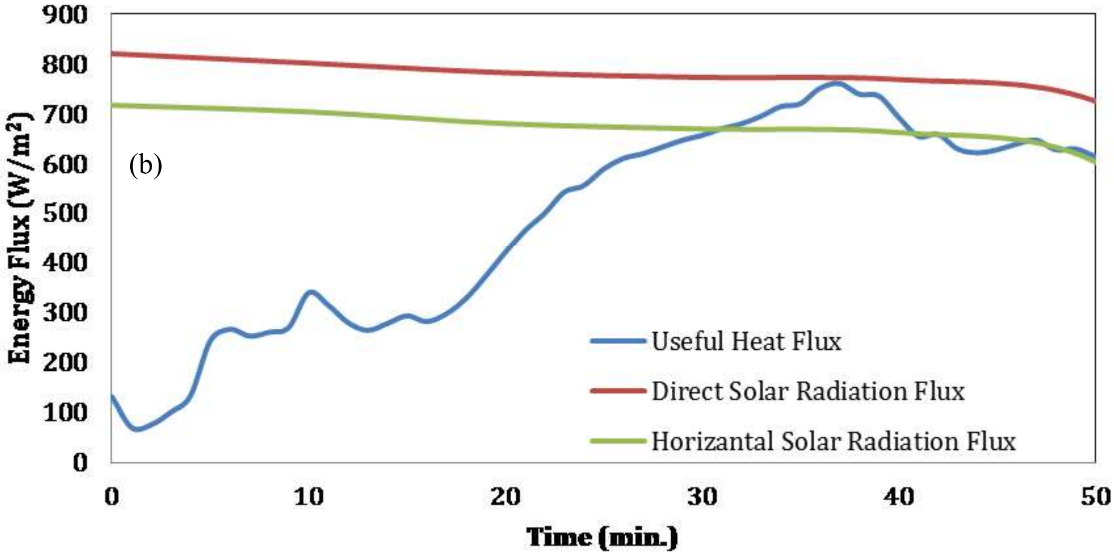
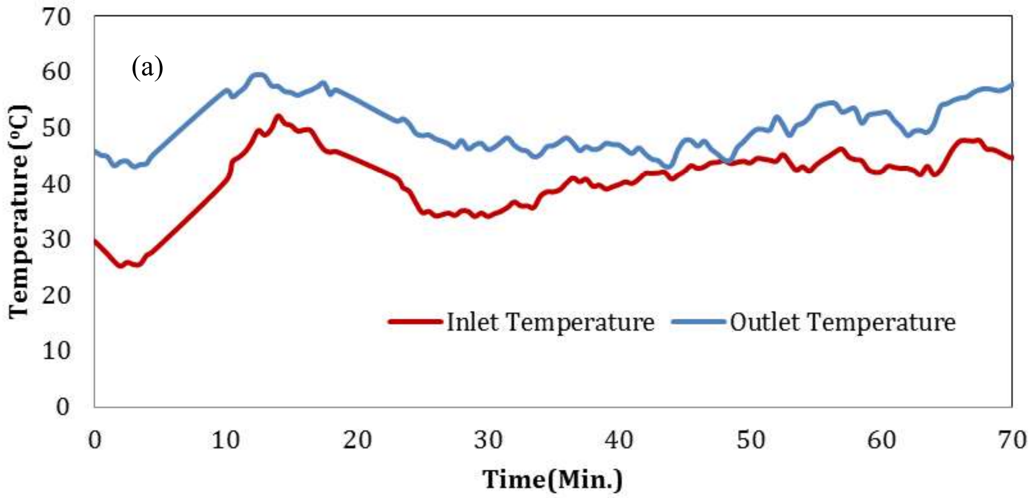


Figure 4: a. Temperature difference. b. Heat transfer and solar radiation values.

Another experiment, had been made on 14:30 July 5, 2012 with the mass flow rate of 82.5 kg/h and took 70 minutes. Temperature changes are shown in figure 5 a. Maximum temperature difference had been measured as 13,8 °C between inlet and outlet. Figure 5 b. is showing the incoming direct solar radiation with respect to transferred energy to the thermal oil. In this experiment the heat transfer efficiency also increased by time, but this increase was not as stable as first experiment. Change in mass flow rate and manually controlled tracking were the reasons of this instability.



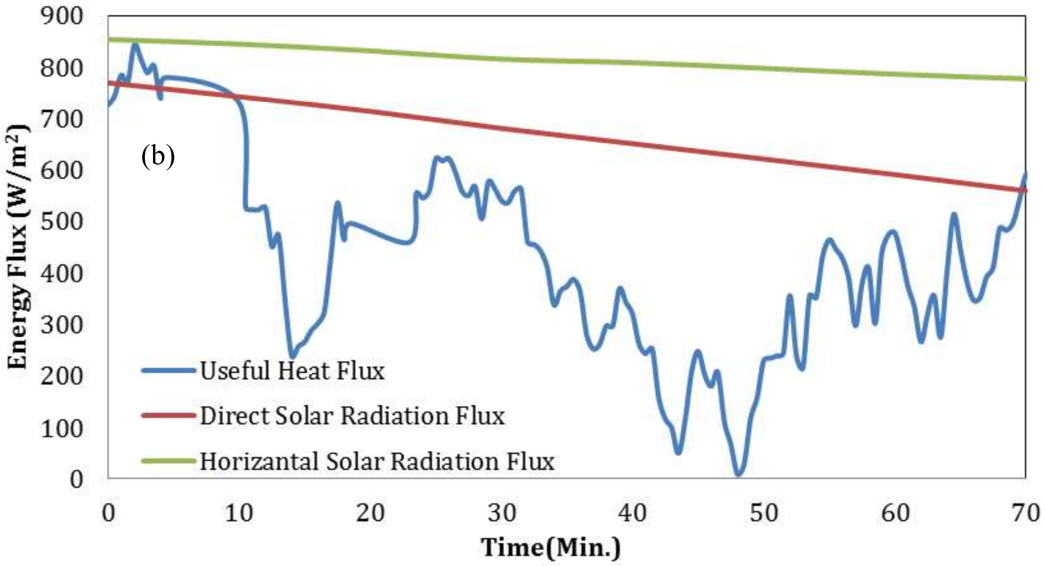


Figure 5: a. Temperature Difference. b. Heat transfer and solar radiation values.

4. DISCUSSION AND CONCLUSION

In this study, uniquely designed Fresnel lens concentrated solar collector had been produced and performance of the collector was measured under Şanlıurfa region conditions. Temperature difference between inlet and outlet of the receiver, direct solar radiation values and horizontal surface solar radiation values was measured. According to findings of the experiments by concentrating direct solar radiation to the receiver, resulted as a considerable temperature difference between inlet and outlet of the receiver. However, mass flow rate increase and manually controlled tracking resulted as decrease in efficiency and instability in experiment results. In low mass flow rates heat transfer efficiency is better than high mass flow rates. Regarding to this, manual tracking is not a major factor on heat transfer efficiency at low mass flow rates.

Second experiment clearly showed that, solar tracking is one of the major variables in concentrated solar systems. Further designs of concentrated solar systems should secure the focusing the solar beams to the receiver. And for achieving to higher energy outputs (for higher energy outputs mass flow rate must be higher), 2-axis solar tracking is inevitable.

In the experiment with manual controlled tracking and constant flow rate pumps, thermal efficiency has been more than 70% in certain instants (Figure 4 b.). As a result for this study, applying concentrated solar systems on Şanlıurfa region would be feasible if modern solar tracking systems and modulating oil pump systems would be used. Also this experiment is shows that parabolic trough systems, which are widely used in USA, Spain, UAE and China, even more feasible in Şanlıurfa region.

REFERENCES

1. W.T. Xie, Y.J. Dai, R.Z. Wang, K. Sumathy. 2011. Concentrated solar energy applications using Fresnel lenses: A review, Renewable and Sustainable Energy Reviews, 2588– 2606
2. World Energy Investment Outlook, Special Report, Internatıonal Energy Agency, 2014
3. Yeşilata, B., H. Bulut, Çetiner, C. Ersavaş, A, 2011. "Termal Güneş Enerjisi Teknolojileri Ve Gap Bölgesine Yönelik Fırsatlar", Mühendis ve Makina, 52/622, 47-56,
4. Xie, W.T., Dai, Y.J., Wang, R.Z., 2011. Numerical and experimental analysis of a point focus solar collector using high concentration imaging PMMA Fresnel lens. Energy Conversion and Management 52 (6), 2417‑2426.
5. W.T. Xie, Y.J. Dai, R.Z. Wang, 2012. Theoretical and experimental analysis on efficiency factors and heat removal factors of Fresnel lens solar collector using different cavity receivers Solar Energy 86, 2458‑2471
6. Leutz, R., Suzuki, A., 2001. Nonimaging Fresnel lenses: design and performance of solar concentrators. Springer, Berlin, New York.
7. Collarespereira, M., 1979. High-temperature solar collector with optimal concentration – non-focusing Fresnel lens with secondary concentra- tor. Sol. Energy 23, 409–420.
8. Kritchman, E.M., Friesem, A.A., Yekutieli, G., 1981. A Fixed Fresnel Lens with Tracking Collector. Sol. Energy 27, 13–17.
9. Vijayaraghavan, S., Ganapathisubbu, S., Kumar, C.S., 2013. Performance analysis of a spectrally selective concentrating direct absorption collector. Sol. Energy 97, 418–425.
10. Al-Jumaily, K.E.J., Al-Kaysi, M.K.A., 1998. The study of the perfor- mance and efficiency of flat linear Fresnel lens collector with sun tracking system in Iraq. Renew. Energy 14, 41–48.
11. Tripanagnostopoulos, Y., Siabekou, C., Tonui, J.K., 2007. The Fresnel lens concept for solar control of buildings. Sol. Energy 81, 661–675.
12. M. Lin, K. Sumathy, Y.J. Dai, X.K. Zhao.2014 Performance investigation on a linear Fresnel lens solar collector using cavity receiver, Solar Energy 107 (2014) 50–6
13. H. Bulut, Işıker, Y., Aktacir M. A., Yeşilata, B, 2010. "Güneş Enerjisi Uygulamalarının Potansiyelini Belirlemek İçin Toplam, Direkt ve Yayılı Güneş Işınım Şiddetlerinin Anlık Ölçümü", UDUSİS 2010-Uluslararası Katılımlı Kamu-Üniversite-Sanayi İşbirliği Sempozyumu ve Mermercilik Şurası Bildiriler Kitabı, 484-490, Diyarbakır.