Isı Bilimi ve Tekniği Dergisi, 32, 1, 51-58, 2012
J. of Thermal Science and Technology
©2012 TIBTD Printed in Turkey
ISSN 1300-3615

AN EXPERIMENTAL INVESTIGATION OF THE EFFECT OF PERIPHERY HEIGHT AND GROUND TEMPERATURE CHANGES ON THE SOLAR CHIMNEY SYSTEM

Abdulcelil BUĞUTEKİN
Adiyaman University Vocational High School Adıyaman– Turkey, Tel.0416-2212325–26-27 Fax: 0416-2232129 abugutekin@posta.adiyaman.edu.tr

(Geliş Tarihi: 21. 09. 2010, Kabul Tarihi: 07. 12. 2010)

Abstract: A solar chimney system was established in Adıyaman University campus area designing a special layered soil (27 m diameter and 0.5 m deep drop-circular hole, while the aluminum foil, glass wool, sand, gravel, broken glass trotters windscreen and its top surface, asphalt) on the 0.004 m thick glass laying the panels, 17 m height of 0.8 m in diameter chimney and a height adjustable air inlet collector (periphery) from 0.05 to 0.35 m to investigate the effect of environmental temperature, chimney height, the collector diameter, the value of solar radiation etc on the performance or effectiveness of Solar Chimney (SCS). In this study, on July 22 on 13:00, temperature, air velocity and temperature under collector at point C_2 for different heights (0.05 – 0.35 m) for air inlet portion of collector (periphery) and of special prepared ground floor according to weather conditions (solar radiation, ambient temperature, air velocity) is investigated. Moreover, temperature of ambient, under collector, glass surface and ground under collector along the day with two hours interval and ambient air velocity, temperature and air velocity at point C_2 where turbine is assembled is investigated. Measurements made in the collector air inlet height is now long solar chimney performance dropped the most ideal height 0.05 m, the specific configuration of the ground daily solar radiation and ambient temperature proportional to a heat store and heat it to the night collector environment by giving the system performance increase was observed. Solar chimney 'of the ground under the collector of solar radiation absorption rates to the performance of the system efficiency can be considered as a parameter. It is observed in the measurements that as long as the collector air inlet height increases, solar chimney performance dropped and the most ideal height becomes 0.05 m. Also, the specific configuration of the ground daily solar radiation and ambient temperature proportional store heat and it increases the performance of the system by giving this heat to the collector environment in evening. Solar radiation absorption rate of ground under the collector in solar chimney should be considered as a parameter that affects efficiency performance of the system.

Keywords: Solar chimney power plant, Special ground, Ground temperature, Performance.

DIŞ KENAR YÜKSEKLİĞİ VE ZEMİN SICAKLIK DEĞİŞİMİNİN GÜNEŞ BACASI SİSTEMİ ÜZERİNDE ETKİSİNİN DENEYSEL OLARAK İNCELENMESİ

Özet: Güneş bacası performansını veya verimini etkileyen çevre sıcaklığı, bacanın yüksekliği, kolektör çapı, bölgenin güneş ışınım değeri vb. Adıyaman üniversitesi yerleşke alanı içine özel katmanlı zemin (27 m çapında 0,5 m derinliğinde açılan dairesel çukura sırası ile alüminyum folyolu cam yünü, çakıl, kum, kırık cam paçacıkları ve en üst yüzeye asfalt) üzerine 0,004 m kalınlığında cam döşenen kolektör, 17 m yüksekliğinde 0,8 m çapında baca ve 0.05 – 0.35 m yüksekliklere ayarlanabilen kolektör hava girişi dizayn edilerek güneş bacası sistemi kurulmuştur. Bu çalışmada 22 Temmuz saat 13:00 de kolektör hava giriş kısmının, farklı yüksekliklerde (0.05 – 0.35 m) iken (C2) noktasında sıcaklık, hava hızı ve kolektör altındaki sıcaklık ile özel imal edilen zeminin Adıyaman hava şartlarına (güneş ışınım değeri, çevre sıcaklığı, rüzgâr hızı) göre, 2 saat aralıklarla gün boyunca kolektörün altındaki zeminin, cam yüzeyin, kolektör altındaki ve çevre sıcaklıkları, çevre rüzgar hızı, bacanın içine montajı yapılacak olan türbinin konulacağı noktanın (C2) sıcaklık ve hava hızları incelenmiştir. Yapılan ölçümlerde kolektör hava giriş yüksekliği artıkça güneş bacasının performansının düştüğü en ideal yüksekliğin 0,05 m olduğu, özel yapılan zeminin günlük güneş ışınımı ve çevre sıcaklığı ile orantılı bir şekilde ısı depoladığı ve bu ısıyı gece kolektör ortamına vererek sistemin performansını artırdığı görülmüştür. Güneş bacasında kolektörün altındaki zeminin güneş ışınım emilim oranı sistemin verimlilik performansını etkileyen bir parametre olarak düşünülebilir.

Anahtar kelimeler: Güneş baca santrali, Özel zemin, Zemin sıcaklığı, Performans.

INTRODUCTION

While global warming and global climate change increase the need for clean energy sources day to day, the energy crisis leads scientists to find new environment-friendly alternative energy resources (Oztas vd., 2011; Demirbas, 2010; Saidur, 2010; Keskin and Emiroglu, 2010; Yumurtaci and Kecebas, 2011;

Sahin, 2011; Kecebas and Alkan, 2009; Demirbas, 2009; Kirtay, 2009; Balo, 2011; Ucar, 2009). One of these energy resources is the sun. Electricity is produced from solar nergy in various ways (Rajamohan vd., 2010; Ralegaonkar and Gupta, 2010). However, in the recent years, many studies have been conducted on solar power plants chimney. Solar tower is a solar power plant proposed to generate electricity in large scale by transforming solar energy into mechanical energy or micro for experimental. In other words, it is an artificial wind generator, albeit a hot one. Solar radiation strikes the transparent roof surface, heating the air underneath as a result of the greenhouse effect. Due to buoyancy effect, the heated air flows up the tower and induces a continuous flow from the perimeter towards the middle of the roof where the tower is located. Shaft energy can be extracted from the thermal and kinetic energies of the flowing air to turn an electrical generator (Koonsrisuk and Chitsomboon, 2006). Since then, more and more researchers have shown strong interest in and studied such solar thermal power generating technology for its huge potential of application all over the world. Haaf et al and schlaich described the operation and presented results for a prototype solar chimney power plant built in Manzanares, Spain, in 1982 (Haaf vd., 1983; Haaf, 1984; Schlaich, 1994). A courtyard solar chimney thermal power generating facility with an power output of 10 W built in America Its collector had a diameter of 6 m and the chimney was 10 m tall (Krisst, 1983). A solar chimney thermal power generating demonstration model was built and modified twice on the campus of the University of Florida, and both theoretical and experimental investigation on their performances was carried out (Pasurmarthi and Sherif, 1997). A case study of SC power plants in Northwestern regions of China, concluded that a SC power plant is able to produce 110–190 kW of electric power with a chimney height of 200 m and diameter of 10 m, and with a collector cover of 196 m^2. Through use of a mathematical model and code for sloped collector fields in MATLAB (Dai vd., 2003). Bernardes et al. developed an analysis for the solar chimneys, aimed particularly at a comprehensive analytical and numerical model to estimate power output of solar chimneys as well as to examine the effect of various ambient conditions and structural dimensions on the power output. This study shows that the height of chimney, the factor of pressure drop at the turbine, the diameter and the optical properties of the collector are important parameters for the design of solar chimneys (Bernardes, 2003). This study developed a numerical model simulating the performance of a large-scale reference solar chimney power plant, indicating that greater power production is possible by optimizing the collector roof shape and height (Pretorius vd., 2004). A good overview the technology has been provided by Schlaich et al. including the theoretical principles governing its design. The main parts of the plant are the collector roof, solar chimney and machinery space, which includes turbines and generators for electric power production (Schlaich vd., 2005). The power source is the working potential of heated air, which has been defined and analyzed, in this study, the dependence of the work potential on the air flowing into the air collector from the heat gained inside the collector, air humidity and atmospheric pressure as a function of elevation are determined (Ninic, 2006). The potential of SC power plant applications in rural areas was studied and considered the appropriateness of a solar chimney to rural villages and highlight some features of such a power generating plant. The calculations the temperature ratio of the difference between the collector surface temperature and the temperature at the turbine, difference between the air mass temperature under the roof and the collector surface temperature (Frederick and Reccab, 2006). Pretorius and Kröger evaluates the influence of a recently developed convective heat transfer equation, more accurate turbine inlet loss coefficient, quality collector roof glass and various types of soil on the performance of a large scale solar chimney power plant (Pretorius and Kroger, 2006). A simulation study was carried out to investigate the performance of the power generating system based on a developed mathematical model. The simulated power outputs in steady state were obtained for different global solar radiation intensity, collector area and chimney height (Xinping vd., 2007). Compares the methods used to calculate the heat fluxes in the collector, and their effects on solar chimney performance. Reasons for the discrepancies between the predictions of the two models are given (Bernardes vd., 2009). 10 m diameter and 8 m tall chimney built for temperature distribution in the solar chimney was measured. They find that temperature different between the collector outlet and the ambient usually 24.1 ^{0}C, which generates the driving force of airflow in setup (Xinping vd., 2007). A study aimed to maintain dynamic similarity for a prototype and its models while using the same solar heat flux (Atit and Tawit, 2009). A study is to investigate the effect of the collector diameters on air flow rate and temperature in the chimney by using mathematical theories. For this purpose at certain times of the day, air flow rate and temperature in the chimney, ambient temperature, ambient air velocity, surface temperature of collector and solar radiation values of Adiyaman are measured and evaluated for collectors having different diameters. As a result, collector having large diameter means more solar energy. As the collector area grows, the ground temperature increases %35-55 compared to ambient temperature and at further studies, it is observed that temperature and air flow rate at the point turbine placed (C_2) increase quickly as diameter of collector increases (Bugutekin, 2011). Figure 1 shows the solar chimney system established in Adiyaman University campus area. Measurements are made for different solar radiation of Adiyaman, ambient temperature and air velocity values on 30 July along the day with 2 hours interval (temperature of ground and air under collector and ambient, temperature and air velocity at point C_2 turbine is assembled in chimney, temperature and air velocity at C_2 for different heights (0.05-0.35 m) of air inlet portion of system (periphery, Ps))

SC System description and experimental work procedure

A chimney, made from 0.07 m thick sheet metal, 15 m high, 0.80 m in diameter, in the sun at all hours of day and open areas, is manufactured in Adiyaman University campus area. A 0.05 m thick aluminum foil, covered with glass wool, is placed in the center of the collector to keep the temperature inside of the chimney lower.

Collector is produced as having an air inlet (Ps), adjustable to different heights (0.05-0.35 m), and having 6° degree slope (greenhouse) (according to solar inclination angle of Adiyaman), as made from 0.04 x 0.04, 0.04 x 0.08 ve 0.02 x 0.02 metal square or rectangle profiles to resist the wind and to carry the weight (Figure 1). Insulation is performed for metal profiles not to absorb heat at ground. The top of collector is coated with 0.004 m thick glass. 10 thermometers range of -50 °C - 150 °C in the measurement accuracy of ± 0.01 (Xinping vd., 2007) are used to measure the air and atmosphere inside the chimney and 5 infrared thermometers are used to measure the temperature of ground floor.10 Homis anemometers, ± 0.01 m / s accuracy, rotor diameter 50 mm, with eight blades, and CMP21 model pyranometer, measures solar radiation values, daily and 10 minutes and records these values with data collecting system, are used for measuring air velocity in the chimney and ambient air velocity with collector. The main parameters of solar chimney power setup as shown in Figure 1 (a) are listed in Table 1.

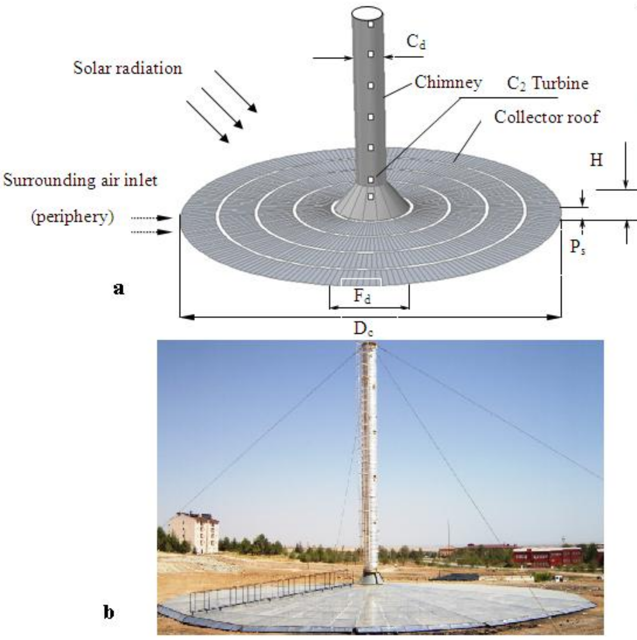

Figure 1. a. Schematic overview of the Solar Chimney principle. **b.** Picture of the system

Table 1. Main parameters of the Solar Chimney plant Power Plant

Parameter	**Symbol**	**Value/m**
Collector Diameter	D_c	27
Height from collector outlet to ground level	H	1.35
periphery (Surrounding air inlet)	Ps	0.05
Chimney diameter	C_d	0.8
Chimney height	H_c	17.15
Funnel diameter	F_d	1.6
Hight of turbine from ground	C_2	2.15

Surrounding air inlet (periphery) description

The collector is one the most important parts in solar chimney system. There are many parameters affecting the efficiency of the collector. For example, the materials used in the construction of collectors and the type of materials that will be laid on top of the collector were previously determined in previous studies. However, due to not obtaining adequate information on the collector entrance area (periphery) of the height on the system performance, measurements are performed using air intake portion of collector with adjustable panels (0.05-0.35 m heights), as shown in Figure 2, to investigate the effect of air velocity and temperature at the point, where turbine will be assembled, on the temperature under collector.

Ground description and measurement

There are many parameters (collector diameter, height and diameter of chimney, solar radiation, ambient temperature and materials used in the system) that affects efficiency in Solar Chimney systems. Daytime performance of solar chimney is in the maximum value because of solar radiation and ambient temperature. Due to the falling of the temperature and hot air under the collector quickly at night, the performance drops rapidly. Therefore, when it is needed a basis that can absorb solar radiation daytime as heat to make solar chimney continued its performance at night, the following special ground is prepared shown with manufacturing drawings and information. It is interpreted by taking the average of measurements on the system performance and cooling curves, with two hours intervals, taken from several points of the ground at intervals. The special ground floor is designed as follows. 27 m diameter and 0.5 m deep pit is covered with the aluminum foil with 0.05 m thick glass wool to prevent heat stored daytime pass through ground. 0.1 m thick gravel, 0.05 m sand , 0.05 m (15 tons) glass and 0.25 m asphalt pave (top surface) was compressed onto glass wool (Figure 3,4).

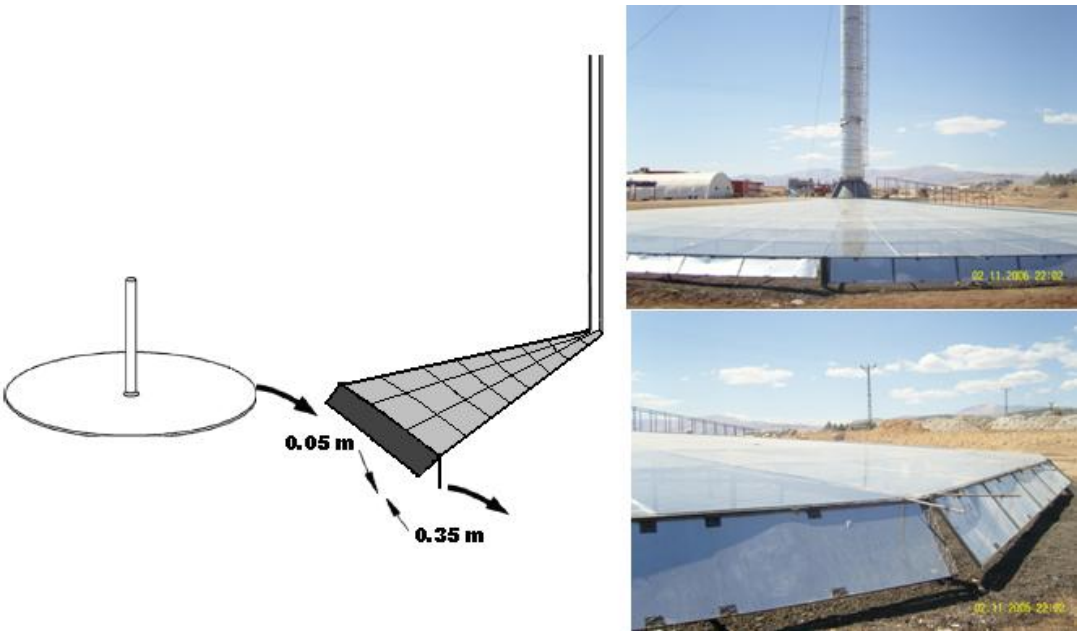

Figure 2. Surrounding air inlet to system (periphery)

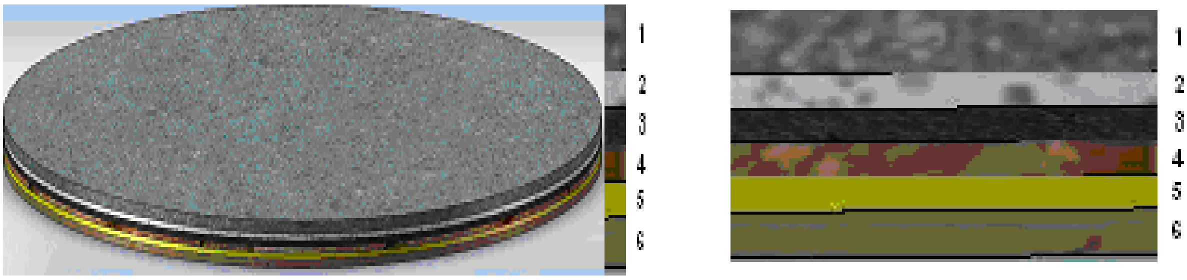

Figure 3. Ground (1. Asphalt, 2.Glass, 3. Thick sand 4. Gravel 5. Aluminum foil with glass wool 6. Ground floor

Figure 4. Pictures showing the construction steps of ground of solar tower system A ground floor, B Aluminum folio with glass wool, C Gravel laying, D Sand, E Glass laying, F Asphalt paved.

RESULTS AND DISCUSSION

While collector air inlet height (periphery) from 0.05 to 0.35 m, the air temperature between panel cover and the collector has gradually increased throughout measurements. Therefore, collector air inlet height (periphery) increases as long as the hot air in the collector escapes outside from air inlet portion of collector. Temperature at C_2 and the point under collector rapidly decreases due thermal balance between chimney and collector is interrupted. As conversion amount of hot air to kinetic energy decreases, air velocity at C_2 decreases and affect the system negatively as shown in Figure 5.

The ground is heated quickly with the sun rise in the morning. The measurements performed with 2 hours interval (started from 08.00 am in the 30th of July until 06:00 pm in the 31st of July) show that ground temperature reaches 92 °C (the ambient temperature of 42.5 °C) as noon. At the following hours along the day while temperature is rapidly falling, continuity in the performance of solar chimney has been provided by giving a part of its conserved heat to the system as shown in Figure 6.

The measurements performed with 2 hours interval (started from 08.00 am in the 30th of July until 06:00 pm in the 31st of July) variation of ground, glass temperature under and on the collector, show that ground temperature reaches 92 °C, collector temperature reaches 67 °C and glass temperature reaches 48 °C as noon. At the following hours along the day while temperature is rapidly falling, continuity in the performance of solar chimney has been provided by giving a part of its conserved heat to the system. as shown in Figure 7.

Measurements carried out during the day between 10:00 to 15:00 hours with little increase in ambient velocity, while the ground temperature, temperature C2 and C2 velocity values shows a marked increase. These values remain constant, then decreased during the night. These are volues Shown in Figure 8.

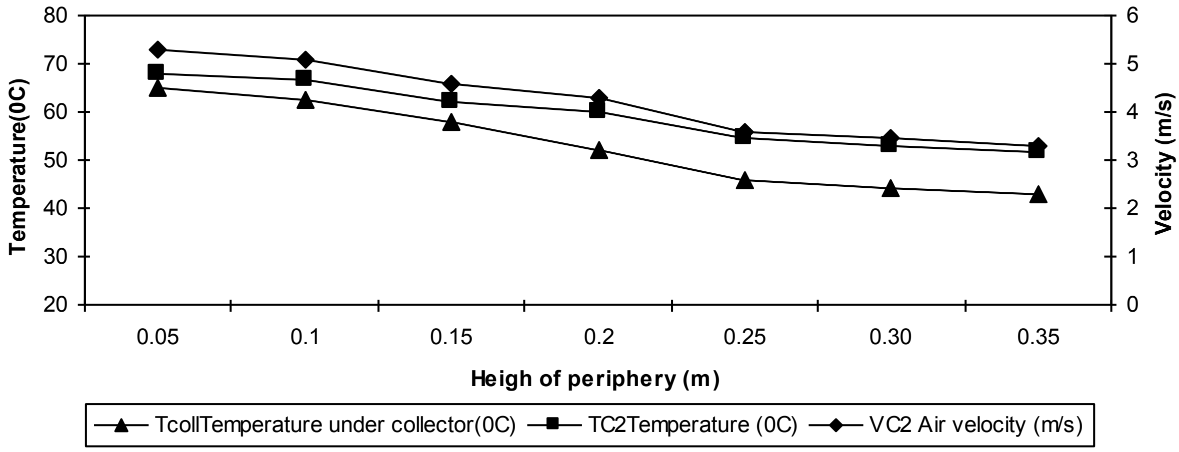

Figure 5. Heat variation under temperature, air speed and collector at C_2 point according to periphery height, ambient temperature (40 °C), Time: 22th July - 13:00 , solar irradiation 841 W/m^2

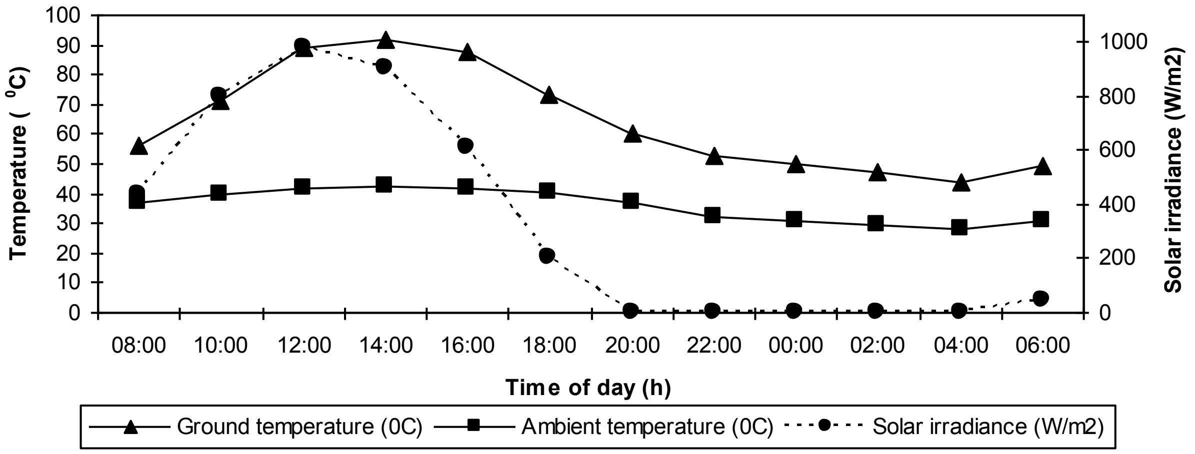

Figure 6. Change of ground temperature daytime according to environmental atmosphere and values of sun rise.

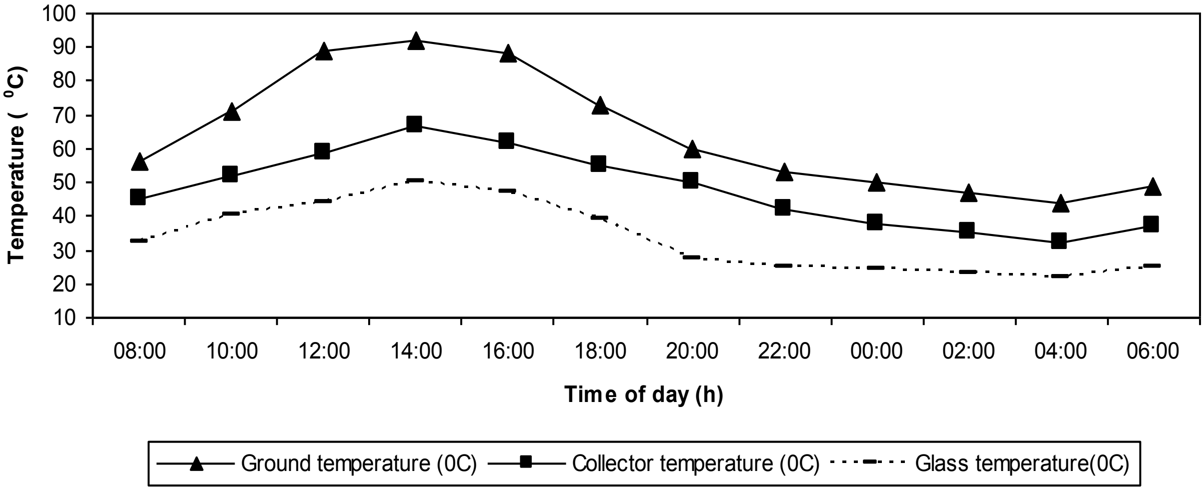

Figure 7. Change (Variation) of ground, glass temperature under and on the collector daytime.

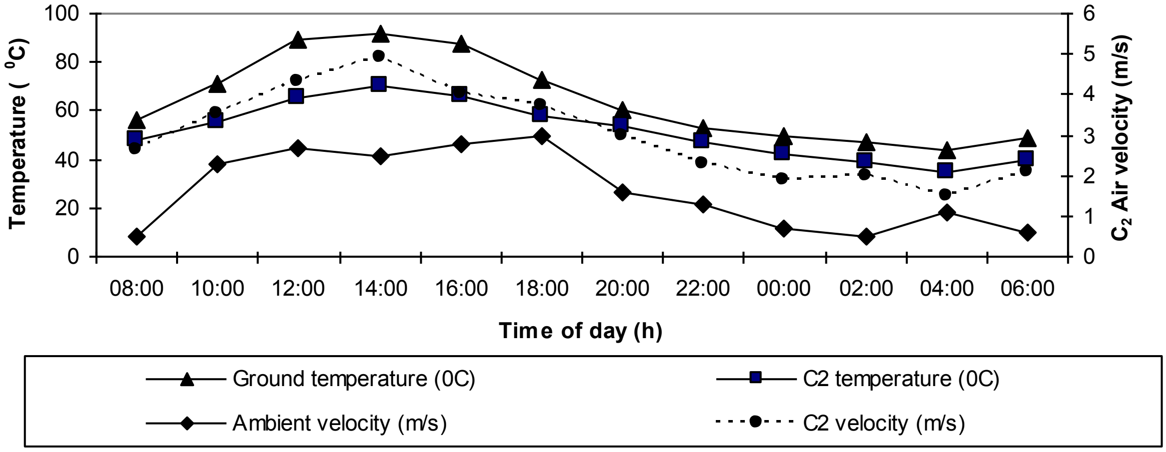

Figure 8. Enviromental wind speed, ground and air temperature at C_2 point.

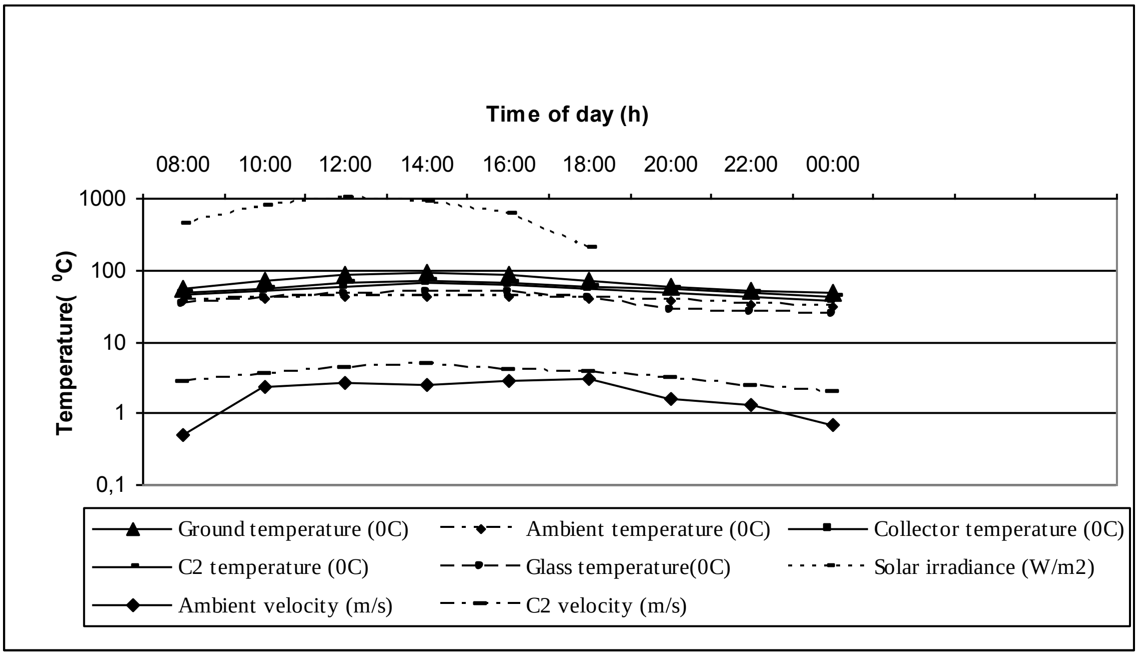

Figure 9. Change of parameters, determine the performance of solar chimney daytime of according to ground temperature.

CONCLUSION

In conclusion, it is determined that due to the height of collector air inlet is minimum, performance of the system increases positively. Also, it is found that solar chimney system performance is negatively affected, since air inlet portion collector is high, it breaks the heat and air flow balance between collector. The ground under collector at the hours, solar radiation and environmental temperature is maximum, absorbs a portion of the heat, conversion of solar radiation pass through glass. And it makes the system working by spreading the heat under collector till morning from the late hours of night where the environmental temperature is minimized. Also, few affect of environmental wind speed on system and ground is observed.

ACKNOWLEDGEMENTS

This research project is supported by both the Adıyaman University Scientific Research Projects (ADYÜBAP) No. AMYOBAP 2010/0004 and Turkey Petroleum Corporation (TPAO) regional offices of Adiyaman.

REFERENCES

Atit K. and Tawit C., Partial geometric similarity for solar chimney power plant modeling, *Solar Energy* 83, 1611–1618, 2009.

Balo F., Energy and economic analyses of insulated exterior walls for four different city in Turkey, *Energy Educ Sci Technol Part A*, 26,175–188, 2011.

Bernardes M.A.S., Von Backström T.W. and Kröger D.G., Analysis of some available heat transfer coefficients applicable to solar chimney power plant collectors, *Solar Energy,* 83, 264–275, 2009.

Bernardes M.A.S., Symmetric sink flow and heat transfer between two parallel disks. ASME Summer Heat Transfer Conference – *Heat Transfer, ASME,* Las Vegas, Nevada, USA, 2003.

Bugutekin A., Effect of the collector diameter on solar chimney power plants, *Energy Education Science and Technology Part A* 27, 155-168, 2011.

Dai Y.J., Huang H.B., and Wang N.R.Z., Case study of solar chimney power plants in North-western regions of China, *Renew Energy,* 28, 1295–304, 2003.

Demirbas A., Social, economic, environmental and policy aspects of biofuels, *Energy Educ Sci Technol Part B* 2,75–109, 2010.

Demirbas A., Concept of energy conversion in engineering education. *Energy Educ Sci Technol Part B* 1,183–197, 2009.

Frederick N.O., Reccab M.O.J., The potential of solar chimney for application in rural areas of developing countries, *Fuel,* 85, 2561–6, 2006.

Haaf W., Solar Chimneys, Part II: Preliminary Test Results From the Manzanares Pilot Plant, *Int. J. Sol. Energy,* 2, pp. 141–161, 1984.

Haaf W., Friedrich K., Mayr G. and Schlaich J., Solar Chimneys,Part I: Principle and Construction of the Pilot Plant in Manzanares, *Int. J. Sol.Energy*, 2, pp. 3–20, 1983.

Kecebas A. and Alkan M.A., Educational and consciousness-raising movements for renewable energy in Turkey, *Energy Educ Sci Technol Part B* 1,157–170, 2009.

Keskin A. and Emiroglu A.O., Catalytic reduction techniques for post-combustion diesel engine exhaust emissions, *Energy Educ Sci Technol Part A,* 25,87–103, 2010.

Kirtay E., The role of renewable energy sources in meeting Turkey's electrical energy demand. *Energy Educ Sci Thecnol Part A* 23,15-30, 2009.

Koonsrisuk A. and Chitsomboon T., Partial Similarity in Solar Tower Modeling, *The 20th Conference of Mechanical Engineering Network of Thailand* 18-20, Nakhon Ratchasima, Thailand. October 2006.

Krisst R.J.K., Energy transfer system, *Alternative Sources of Energy*, 63, 8–11, 1983.

Ninic N., Available energy of the air in solar chimneys and the possibility of its ground-level concentration. *Solar Energy,* 80, 804–811, 2006.

Oztas F., Kalıpcı E. and Bozkurt E., How do biology teacher candidates perceive global climatic change? *Energy Educ Sci Technol Part B,* 3,99–107, 2011.

Pasurmarthi N. and Sherif S.A., Performance of a demonstration solar chimney model for power generation, *Proceeding of the 35th heat transfer and fluid, Sacrmento,* CA, USA, 203–40, 1997.

Pretorius J.P. and Kröger D.G., Critical evaluation of solar chimney power plant performance, *Solar Energy* 80, 535–544, 2006.

Pretorius J.P., Kröger D.G., Buys J.D. and Von Backström T.W., Solar tower power plant performance characteristics, *Proceedings of the ISES EuroSun International Sonnenforum* 1, Freiburg, Germany, 870–879, 2004.

Rajamohan P., Rajasekhar R.V.J. and Shanmugan S. and Ramanathan K., Energy and economic evaluation of fixed focus type solar parabolic concentrator for community cooking applications, *Energy Educ Sci Technol Part A*, 26,49–59, 2010.

Ralegaonkar R.V. and Gupta R., Application of passive solar architecture for intelligent building construction: A review. *Energy Educ Sci Technol Part A* 26,75–85, 2010.

Sahin Y., Environmental impacts of biofuels. *Energy Educ Sci Technol Part A*, 26,129–142, 2011.

Saidur R., Energy, economics and environmental analysis for chillers in office buildings. *Energy Educ Sci Technol Part A*, 25,1–16, 2010.

Schlaich J., Bergermann R., Schiel W. and Weinrebe G., Design of Commercial Solar Updraft Tower System – Utilization of Solar Induced Convective Flows for Power Generation, *ASME J. Solar Energy Eng*., 127, 1, 117-124, 2005.

Schlaich J., *The Solar Chimney: Electricity From the Sun*, Deutsche Verlags-Anstalt, Stuttgart, 1994.

Ucar A., The environmental impact of optimum insulation thickness for external walls and flat roofs of building in Turkey’s different degree-day regions, *Energy Educ Sci Technol Part A*, 24,49–69, 2009.

Haaf W., Friedrich K., Mayr G. and Schlaich. J., Solar Chimneys,Part I: Principle and Construction of the Pilot Plant in Manzanares, *Int. J. Sol.Energy*, 2, 3–20, 1983.

Xinping Z., Jiakuan Y., Xiao B. and Guoxiang H., Simulation of a pilot solar chimney thermal power generating equipment. *Renewable Energy*, 32, 1637–1644. 2007.

Xinping Z., Jiakuan Y., Xiao B. and Guoxiang H., Experimental study of temperature field in a solar chimney power setup, *Applied Thermal Engineering*, 27, 2044-2050, 2007.