Solar Water Heating for Space Heating Purposes

Abdul-Salam H Naser, Khaleel I Abaas

Mechanical Eng. Dept., University of Technology, Baghdad, Iraq

Abstract—*Solar energy is the source of heat and energy on the earth. In this paper, a solar water heating system was proposed for room heating in Baghdad winter weather conditions. The system was mad consisting of a flat plate solar collector, an isolated water storage tank, two pumps, and a radiator inside the room. The study foxed on the performance of the solar collector and the impact of weather conditions (clear or cloudy atmosphere) and water flow rate on its efficiency.*
The results illustrated that the solar collector efficiency increased at clear days compared to cloudy ones. The working fluid (water) flow rates have a significant impact on the collector efficiency. The collector efficiency increased at moderate flow rates and decreased at higher rates. The reduction the water flow rate allows for the heat to transfer longer time to water that increases the collector inlet and outlet temperature differences.

Keywords— Flat plate, solar collector, water storage tank, collector efficiency, heating load.

I. INTRODUCTION

Solar energy is available everywhere in the globe and in most times of the year, giving heat that can be used to produce electricity or water heating and even cooking [1]. Iraq is one of the sunny countries that have up to 340 days of sunshine days per year. Also, the solar radiation intensity arrived for its land ranging from 240 W/m^2 in winter to 980 W/m^2 in summer [2]. These high numbers make the utilization of solar energy efficiently to produce electricity by PV and CPS systems a foregone conclusion [3]. Also, the water solar heating technology is a quite successful and effective in these circumstances [4].

The solar water heating is a technology that has become common today and is used in most countries of the world. Water passes on the solar heater which may be flat (Flat plate water collector) or consists of pipes (Evacuated tube collectors) painted in black color to absorb most of the falling solar radiation. The hot water is stored at the top of the solar collector in a tank to recycle the heat in the water by natural convection and combines hot water at the top of the tank. The heated water can be withdrawn for use in household applications [5]. This hot water can be used also to heat the air-conditioned space to achieve comfort conditions for the occupants through the pass the hot water to heat radiators radiate the heat stored in the water to the space to be heated [6].

Heating homes using electricity or fossil fuels, costing homeowners high amounts each winter to provide comfort for the occupants. While the use of solar energy available for free can reduce these costs, in addition to the systems used require no maintenance during the entire winter season, or it needs maintenance in a very limited conditions, which means little economic cost to the consumer [7]. Solar water heating employing for a space warming has two benefits, the first: reduce the cost of heating, and the second: reduce pollutants resulting from the combustion of fossil fuels used in heating.

However, because Iraq is the one of biggest production and export of oil and gas state of the world, the successive governments on this country have relied on using fossil fuels to produce electricity [8]. Also, Iraqi houses heated either by electric heaters or oil or gas heaters in winter. The excessive use of oil and gas to heat homes in winter has caused a rise of air pollution in these spaces and thus it affects the general health largely [9].

In Iraq, many of the research has investigated new methods to heat the room air without relying on burning fossil fuels and depending entirely on solar energy. In the articles [10 to 14], the researchers studied the air heated by wall Tromp suitable for Iraqi weathers. References [15-16] studied to take advantage of solar salt ponds to heat up the space. Ref. [17] tried to take advantage of the heat stored by paraffin wax as a phase change material (PCM) to increase the heated water period after sunset.

The aim of the present study is to manufacture and evaluate the performance of a solar water heating system used for heating an available space in the winter of Baghdad, Iraq - conditions. The research is part of the continuous efforts of the Energy and Renewable Energies Technology Center in the University of Technology to study and experience the use of green systems in homes, factories, offices, whether for heating, cooling and clean electric power production [18-60].

II. EXPERIMENTAL SETUP

This study was conducted to evaluate the performance of solar collector heat storage water effectiveness when used to warm a room in Baghdad-Iraq winter weather (2015-2016). Baghdadi winter has moderate solar intensity ranged from 240 W/m^2 to 435 W/m^2 during the day, and a temperature ranged from -2°C at night to 20°C at midday. The wind in winter is moderate ranged from 0 to 4 m/s. The tests were conducted in sunny and partial cloudy days to evaluate the collector efficiency when the water flow rate was varied to 1.2, 1.8, 2.5 and 3.0 liter/min. The collector's input and output temperatures were measured and recorded. The tests were conducted three days each and the average was taken as the required reading to confirm the repeatability and reduce the uncertainty in the results.

2.1. Equipment

1. Space selection: A small room has been selected for the space heating procedure. The room dimensions are (2.71x 2.08x 2.51m). The room walls consist of two layers of fiber wood with thickness of 3mm, separated by a layer of 0.6mm of fiber glass.
2. Solar collector: There are many type of solar collectors, but generally they are divided into two types:
   a) Flat plate collector.
   b) Focusing collector.

Flat plate collectors can be designed for applications that require moderate temperatures delivery. When designing a flat plate collector many assumptions are made, as:

1) The collector performance is a steady state.
2) The construction of the sheet and tube.
3) The header covers have a small area of the collector.
4) There is no absorption of solar energy by covers.
5) There is no dimensional heat flow through covers.
6) No loss of heat from the back and the body of the solar collector.
7) The collector properties are independent of temperature.
8) The dust and dirt accumulation are negligible.

Flat plate collectors may be used as an integral part of a wall or roof structure in solar house to be heated, with an angle equal to the altitude of the area where the collector is mounted.

The collector used in the tests was with dimensions of (2mx 0.95m) as Fig. 1 reveals. The collector consists of two galvanized steel plates which were bent to construct paths between them when they were welded together. The collector's bottom served as input, and the top of it as output for the working fluid (water).

The two parallel galvanized plates are fixed on the box-shaped support separated by (4 cm) as a space filled with flexible fiber glass insulation. The upper galvanized steel plate was painted with black color to increase the plate absorptivity. This arrangement was covered with a glass plate to avoid wind effects which might increase the thermal loss to the atmosphere.

3. Storage tank: A cylindrical shaped storage tank was employed to store the hot water that will be supplied to the room. The selected tank's volume was 0.157 m^3 (0.5 m dia. x 0.8m height) as Fig. 2 demonstrates. It was carefully isolated by 10 cm thickness of fiber wool insulation.
4. The flow meter: For flow measurements, one flow meter was placed in the pipeline to measure the flow of the water entering into the collector. For the measuring of the water flow through the radiator, another flow meter was utilized. The flow meter measuring rate was from (0 to 15 liter/ min).

Fig. 1: The Solar Collector Used in the Study

Fig. 2: The Solar Water Heating System Used in the Study

5. Pumps: Two pumps were used to circulate the hot water through the system. One was allocated for the collector while the second was allocated for the radiator. The pumps specifications are: the head =25 m; power consumption= 0.75kW; discharge= 50 liter/min.
6. Radiator: The radiator is the device that transfers heat to the space to warm it. The used radiator has a size of 40x60 cm and has 18 paths for hot water flow.
7. Temperature measurements: Six thermocouples were used to obtain the circulated water

temperatures and distributed in the inlet and outlet for the collector, storage tank and the radiator. The thermocouples were type K.

8. Pipes: Ordinary water pipes (1.27 cm dia.) were used in the system. These pipes were selected as it is commonly used in Iraq and available in the local markets.
9. Solar intensity measurement: The solar radiation intensity was measured using ISM-410 Taiwan made ranged from 0 to 1400 W/m^2.

2.2 Theoretical Calculations

The following equations were used to calculate the heating load for the room:

a) Heat transfer through walls and roof

$$Q_w = A_w U(T_i - T_o) \quad (1)$$

b) The coefficient of heat transfer:

$$\frac{1}{U} = \frac{1}{f_o} + \sum\frac{x}{k} + \frac{1}{f_i} \quad (2)$$

c) Heat transfer by filtration from door and window:

$$Q_{inf} = 0.018 \times q_h \times (T_i - T_o) \quad (3)$$

d) The total heating load for the room:

$$Q_T = Q_n + Q_s + Q_{we} + Q_E + Q_r + Q_g + Q_{inf} \quad (4)$$

Collector efficiency: There are many factors affecting the collector efficiency as: collector temperature, cleaning, glass emissivity, solar intensity, energy absorbed by the black plate, and the wind speed. The collector efficiency represents the amount of useful energy extracted from the collector as a percentage of solar energy incidents on the collector surface during the same period, simply:

$$\eta_0 = \frac{\dot{m} \times cp \times \Delta T}{I_c \times A_c} (5)$$

2.3 Tests Procedure

At the beginning of each test, the water tank was checked to confirm the water level. The collector glass was cleaned every day from dust and dirt. To begin the test, the first water pump located on the pipe entering the collector was started, and some time was left for the system to reach its steady state water circulation at the selected water flow rate by means of flow meter fixed in the water flow line. After confirming the arrival of the system to a steady state, the second to pump was run to supply the room radiator to warm it up. After completing all the former procedure, the temperature reading was recorded.

III. RESULTS AND DISCUSSIONS

The figures from 3 to 6 represent the relation between day time and collector efficiency for the variable studied water flow rates. Weather conditions subjected to considerable changes during the day. Sunny climate may turns into a partly cloudy or totally cloudy. The solar radiation intensity is not constant throughout the day. It starts small and then grows to reach the highest values at 12AM to 2.5PM, and then start to decline as well as the air temperature.

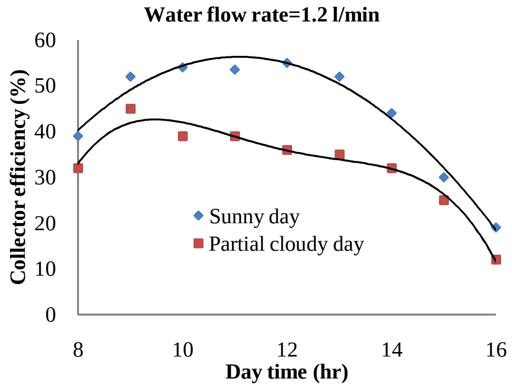

Fig. 3: Collector Efficiency at Water Flow Rate of 1.2 l/min

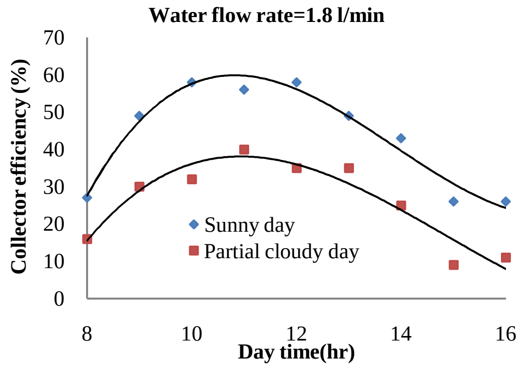

Fig. 4: Collector Efficiency at Water Flow Rate of 1.8 l/min

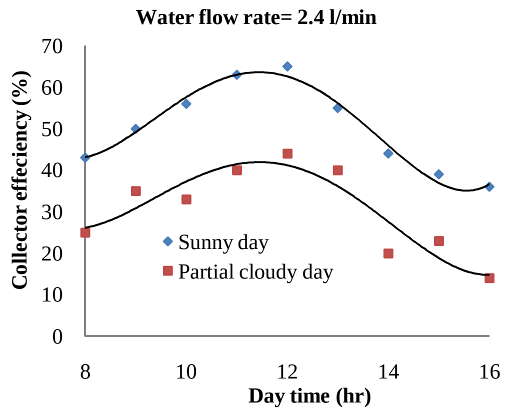

Fig. 5: Collector Efficiency at Water Flow Rate of 2.4 l/min

The collector efficiency means the amount of the solar radiation energy received and heated the collector's water. The water flow was controlled employing a flow meter. In partial cloudy days, the collector can heat the water partially compared to sunny days, but still raising the water temperature. This result indicated that when using this system there is a need for aiding of electrical heater to be used in partially a totally cloudy days. The collector efficiencies for all the flow rates at sunny days were good and acceptable

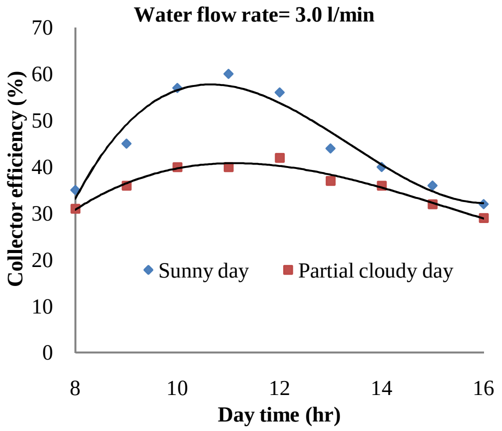

Fig. 6: Collector Efficiency at Water Flow Rate of 3.0 l/min

Fig. 7 shows the effect of variable water flow rates on the collector efficiency. The collector's efficiency increase with mass flow rates increase from 1.2 to 2.4 and then it starts to decline. Increasing the flow rate reduces the time available for heat transfer from the collector metal surface and the water which reduces the temperature differences between the collector's inlet and outlet.

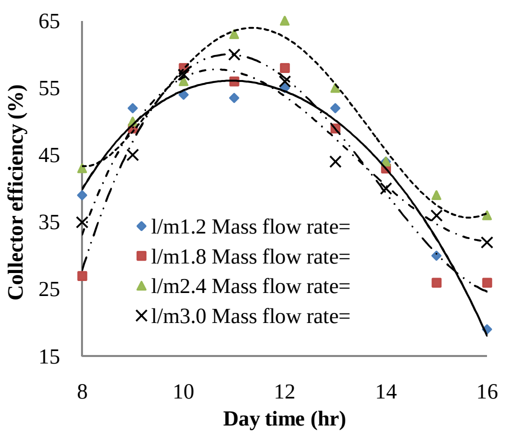

Fig. 7: Collector Efficiency at Variable Water Flow Rates

In general, all the sunny days gave good collector efficiency. As explained previously, the lower water flow rate gave high temperature degrees difference between the collector's inlet and outlet better that the cases when the water flow rates were increased.

Fig. 8 represents the relation between water mass flow rates and the temperature differences between inlet and outlet of the collector. The figure results indicated what was formally mentioned. The heat transfer rate increased with reducing the mass flow rate as the exchanging time increased. Due to this reason, the temperature differences were higher for low mass flow rates.

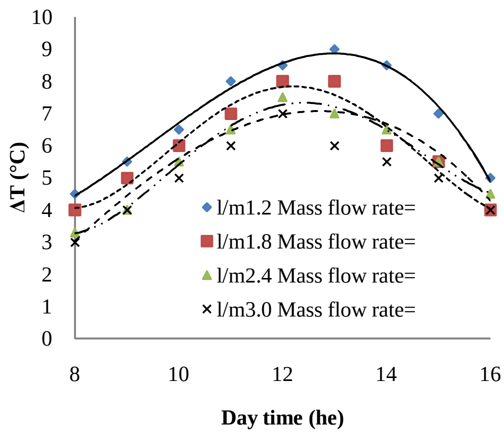

Fig. 8: Collector Temperature Differences at Variable Water Flow Rate of 3.0 l/min

IV. CONCLUSION

A solar water heating system was made and used to heat a room in Baghdad winter weather conditions. The system consisted of a solar collector, a water storage tank, two pumps, and a radiator inside the room. The study foxed on the performance of the solar collector and the impact of water flow rate on its efficiency.

The results indicated that the solar collector performance increased with increasing solar intensity. The water flow rate has a clear effect on the collector efficiency as it increased at moderate flow rates and relatively decreased at higher rates. Also, reducing the water flow rate gives longer time for heat exchanging, which resulted in higher temperature differences between the collector inlet and outlet.

.

REFERENCES

[1] M. T. Chaichan, H. A. Kazem, A. A. Kazem, K. I. Abaas, K. A. H. Al-Asadi, "The effect of environmental conditions on concentrated solar system in desertec weathers,"International Journal of Scientific and Engineering Research, vol. 6, No. 5, pp. 850-856, 2015.

[2] M. T.Chaichanand H. A. Kazem,"Status and future prospects of renewable energy in Iraq,"Renewable and Sustainable Energy Reviews, vol. 16, No. 1, pp. 6007–6012, 2012.

[3] M. T.Chaichanand K. I. Abaas, "Practical investigation for improving concentrating solar power stations efficiency in Iraqi weathers," Anbar J for Engineering Science, vol.5, No. 1, pp. 76-87, 2012.

[4] H. A. Kazem,H. S. Aljibori, F. N. Hasoon and M. T.Chaichan,"Design and testing of solar water heaters with its calculation of energy," Int. J. of Mechanical Computational and Manufacturing Research, vol. 1. No.2, pp. 62-66, 2012.

[5] H. M. Abdlu-Rehman, F. A. Al-Sulaiman, "Optimum selection of solar water heating (SWH) systems based on their comparative techno-economic feasibility study for the domestic sector of Saudi Arabia," Renewable and Sustainable Energy Reviews, vol. 62, pp. 336–349, 2016.

[6] S. Sadhishkumar, T. Balusamy, "Performance improvement in solar water heating systems – a review," Renew Sustain Energy Rev, vol. 37, pp. 191–8, 2014.

[7] M. T.Chaichan,K. I. AbaasandH. A. Kazem,"The effect of variable designs of the central receiver to improve the solar tower efficiency," International J of Engineering and Science, vol. 1, No. 7, pp. 56-61, 2012.

[8] A. A. Kazem, M. T.ChaichanandH. A. Kazem,"Effect of dust on photovoltaic utilization in Iraq: review article,"Renewable and Sustainable Energy Reviews, vol. 37, September, pp. 734-749, 2014.

[9] A. A. Al-Waeely, S. D. Salman, W. K. Abdol-Reza, M. T.Chaichan,H. A. Kazem, and H. S. Al-Jibori, "Evaluation of the spatial distribution of shared electrical generators and their environmental effects at Al-Sader City-Baghdad-Iraq," International Journal of Engineering & Technology IJET-IJENS, vol. 14, No. 2, pp. 16-23, 2014.

[10] K. I. AbaasandM. T.Chaichan,"Experimental study of using solar energy storage wall for heating Iraqi houses purposes,"Wassit Journal for Science & Medicine, vol. 2, No. 2, pp. 212-221, 2009.

[11] S. S.Faris, M. T.Chaichan,M. F. Sachit and J. M. Jaleel, "Simulation and numerical investigation of effect air gap thickness on Trombe wall system," International Journal of Application or Innovation in Engineering & Management (IJAIEM), vol. 3, No. 11, pp. 159-168, 2014.

[12] M. T.Chaichan,K. H. Abaas, "Performance amelioration of a Trombe wall by using phase change material (PCM),"International Advanced Research Journal in Science, Engineering and Technology, vol. 2, No. 4, pp. 1-6, 2015.

[13] M. T. Chaichan,A. H. Al-Hamdani, A. M. Kasem, "Enhancing a Trombe wall charging and discharging processes by adding nano-Al_2O_3 to phase change materials," International Journal of Scientific & Engineering Research, vol. 7, No. 3, pp. 736-741, 2016.

[14] M. T.Chaichan,K. I. Abaas andD. S. M. Al-Zubidi, "A study of a hybrid solar heat storage wall (Trombe wall) utilizing paraffin wax and water," Journal of Research in Mechanical Engineering, vol. 2, No. 11, pp. 1-7, 2016.

[15] M. T.Chaichan,K. I. Abaas andF. F. Hatem, "Experimental study of water heating salt gradient solar pond performance in Iraq," Industrial Applications of Energy Systems (IAES09), Sohar University, Oman, 2009.

[16] M. T.Chaichanand K. I. Abaas,"Productivity amelioration of solar water distillator linked with salt gradient pond,"Tikrit Journal of Engineering Sciences, vol. 19, No. 4, pp. 24-34, 2012.

[17] M. T.Chaichan,K. I. AbaasandH. M. Salih H M, "Practical investigation for water solar thermal storage system enhancement using sensible and latent heats in Baghdad-Iraq weathers," Journal of Al-Rafidain University Collage for Science, Issue 33, pp. 158-182, 2014.

[18] M. T.ChaichanandH. A. Kazem,"Thermal storage comparison for variable basement kinds of a solar chimney prototype in Baghdad - Iraq weathers," International journal of Applied Science (IJAS), vol.2, No. 2, pp. 12-20, 2011.

[19] M. T.Chaichan,"Practical study of basement kind effect on solar chimney air temperature in Baghdad-Iraq weather. Al Khwarizmi Eng. Journal," vol. 7, No. 1, pp. 30-38, 2011.

[20] S. T. Ahmed andM. T.Chaichan,"A study of free convection in a solar chimney sample," Engineering and Technology J, vol. 29, No. 14, pp. 2986-2997, 2011.

[21] M. T.Chaichan,K. I. Abaas, H. A. Kazem,F. Hasoon, H. S. Aljibori, A. A. Alwaeli and A. H. A. Alwaeli, "Effect of design variation on saved energy of concentrating solar power prototype," Proceedings of the World Congress on Engineering (WCE 2012), Vol. III, July 4 - 6, London, UK, 2012.

[22] H. A. Kazem,M. T.Chaichan,I. M. Al-Shezawi, H. S. Al-Saidi, H. S. Al-Rubkhi, J. K. Al-Sinani and A. H. A. Al-Waeli, "Effect of humidity on the PV performance in Oman," Asian Transactions on Engineering , vol.2, Issue 4, pp. 29-32, 2012.

[23] M. T.Chaichan,K. I. Abaas, M. A. Rasheed and H. A. Kazem,"Using paraffin wax as a thermal storage material in a solar air heater," International

Conference for Renewable Energies, UOT, Baghdad, Iraq, 2013.
[24] H. A. Kazem,S. Q. Ali, A. H. A. Alwaeli, K. Mani and M. T.Chaichan,"Life-cycle cost analysis and optimization of health clinic PV system for a rural area in Oman," Proceedings of the World Congress on Engineering 2013, vol. II, WCE 2013, London, U.K., July 3 - 5, 2013.
[25] M. T.Chaichan,K. I. Abaas, H. A. Kazem,H. S. Al JiboriandU. Abdul Hussain, "Novel design of solar receiver in concentrated power system," International J. of Multidispl. Research &Advcs. in Eng. (IJMRAE), vol. 5, No. 1, pp. 211-226, 2013.
[26] Z. A. Darwish, H. A. Kazem,K. Sopian, M. A. Alghoul and M. T.Chaichan,"Impact of some environmental variables with dust on solar photovoltaic (PV) performance: review and research status," International J of Energy and Environment, vol. 7, No. 4, pp. 152-159, 2013.
[27] M. T.Chaichan,"Measurements of laminar burning velocities and Markstein length for LPG–hydrogen–air mixtures,"International Journal of Engineering Research and Development, vol. 9, No. 3, pp. 1-9, 2013.
[28] M. T.Chaichan,"The measurement of laminar burning velocities and Markstein numbers for hydrogen enriched natural gas," International Journal of Mechanical Engineering & Technology (IJMET), vol. 4, No. 6, pp. 110-121, November- December, 2013.
[29] M. T.Chaichanand S. T. Ahmed S T, "Evaluation of performance and emissions characteristics for compression ignition engine operated with disposal yellow grease," International Journal of Engineering and Science, vol.2, No. 2, pp. 111-122, 2013.
[30] M. T.ChaichanandA. M. Saleh, "Experimental measurements of laminar burning velocities and Markstein number of hydrogen–air mixtures," The 3rd Scientific International Conference, Technical College, Najaf, Iraq, 2013.
[31] H. Mazin, H. A. Kazem,H. A. Fadhil, S. Alawi, Q. Mazin and M. T.Chaichan,"Linear and nonlinear modeling for solar energy prediction on the zone, region and global," World Renewable Energy Council/Network (WREC XIII), London, UK, 3-8 August, 2014.
[32] M. T.Chaichan,D. S. M. Al-Zubaidi, "A practical study of using hydrogen in dual – fuel compression ignition engine,"International Journal of Mechanical Engineering (IIJME), vol.2, No. 11, pp. 1-10, 2014.
[33] M. T.ChaichanandH. A. Kazem,"Using aluminum powder with PCM (paraffin wax) to enhance single slope solar water distillator productivity in Baghdad-Iraq winter weathers," International Journal of Renewable Energy Research, vol. 1, No. 5, pp. 151-159, 2015.
[34] M. T.ChaichanandH. A. Kazem,"Water solar distiller productivity enhancement using concentrating solar water heater and phase change material (PCM)," Case Studies in Thermal Engineering, Elsevier, vol. 5, pp. 151-159, 2015.
[35] M. T.Chaichan,B. A. Mohammedand H. A. Kazem,"Effect of pollution and cleaning on photovoltaic performance based on experimental study,"International Journal of Scientific and Engineering Research, vol. 6, No. 4, pp. 594-601, 2015.
[36] M. T.Chaichan,"Performance and emission study of diesel engine using sunflowers oil-based biodiesel fuels," International Journal of Scientific and Engineering Research, vol. 6, No. 4, pp. 260-269, 2015.
[37] M. T. Chaichan,K. I. Abaas,H. A. Kazem,"Design and assessment of solar concentrator distillating system using phase change materials (PCM) suitable for desertec weathers," Desalination and water treatment, pp: 1-11, 2015.DOI: 10.1080/19443994.2015.1069221
[38] M. T.Chaichan,D. S. M. Al-Zubaidi, "Control of hydraulic transients in the water piping system in Badra–pumping station No.5," Al-Nahrain University, College of Engineering Journal (NUCEJ), vol. 18, No. 2, pp: 229-239, 2015.
[39] H. A. Kazem,M. T. Chaichan,S. A. Saif, A. A. Dawood, S. A. Salim, A. A. Rashid, A. A. Alwaeli, "Experimental investigation of dust type effect on photovoltaic systems in north region, Oman," International Journal of Scientific & Engineering Research, vol. 6, No. 7, pp. 293-298, 2015.
[40] H. A. Kazem,M. T.Chaichan,A. H. Alwaeli, and K. Mani, "Effect of Shadow on the Performance of Solar Photovoltaic,"WREN/WREC World Renewable Energy Congress, Rome, Italy, 2015.
[41] M. T. Chaichan and K. A. H. Al-Asadi, "Environmental Impact Assessment of traffic in Oman,"International Journal of Scientific & Engineering Research, vol. 6, No. 7, pp. 493-496, 2015.
[42] M. T.Chaichan,S. H. KamelandA. N. M. Al-Ajeely, "Thermal conductivity enhancement by using nano-material in phase change material for latent heat thermal energy storage Systems," SAUSSUREA, vol. 5, No. 6, pp: 48-55, 2015.
[43] H. Mazin, H. A. Kazem,H. A. Fadhil, S. Alawi and M. T.Chaichan,"Global linear, nonlinear and ANN-based modeling of monthly diffuse solar

energy,"WREC XIV Proceedings, University POLITEHNICA of Bucharest, Romania, June 8 – 12, 2015

[44] H. A. Kazem and M. T.Chaichan,"Effect of humidity on photovoltaic performance based on experimental study," International Journal of Applied Engineering Research (IJAER), vol. 10, No. 23, pp. 43572-43577, 2015.

[45] H. A. Kazem,A. H. A. Al-Waeli, A. S. A. Al-Mamari, A. H. K. Al-Kabi, M. T.Chaichan,"A photovoltaic application in car parking lights with recycled batteries: A techno-economic study," Australian Journal of Basic and Applied Science, vol. 9, No. 36, pp. 43-49, 2015.

[46] H. M. S. Al-Maamary, H. A. Kazem andM. T.Chaichan,"Changing the energy profile of the GCC States: A review," International Journal of Applied Engineering Research (IJAER), vol. 11, No. 3, pp. 1980-1988, 2016.

[47] H. A. Kazem,,M. T.Chaichan,"Experimental analysis of the performance characteristics of PEM Fuel Cells,"International Journal of Scientific & Engineering Research, vol. 7, No. 2, pp. 49-56, 2016.

[48] H. A. Kazem,, A. H. A. Al-Waeli, M. T.Chaichan, A. S. Al-Mamari, A. H. Al-Kabi, "Design, measurement and evaluation of photovoltaic pumping system for rural areas in Oman," Environ Dev Sustain, 2016. DOI 10.1007/s10668-016-9773-z.

[49] M. T.Chaichan,H. A. Kazem,"Experimental analysis of solar intensity on photovoltaic in hot and humid weather conditions," International Journal of Scientific & Engineering Research, vol. 7, No. 3, pp. 91-96, 2016.

[50] M. T.Chaichan,"EGR effects on hydrogen engines performance and emissions," International Journal of Scientific & Engineering Research, vol. 7, No. 3, pp: 80-90, 2016.

[51] M. T.Chaichan,H. A. Kazem,A. M. J. MahdyandA. A. Al-Waeely, "Optimal sizing of a hybrid system of renewable energy for lighting street in Salalah-Oman using Homer software," International Journal of Scientific Engineering and Applied Science (IJSEAS), vol.2, No. 5, pp. 157-164, 2016.

[52] M. T.Chaichan,"Enhancing productivity of concentrating solar distillating system accompanied with PCM at hot climate," Wulevina, vol. 23, No. 5, pp. 1-18, 2016.

[53] M. T.Chaichan,H. A. Kazem,A. M. J. MahdyandA. A. Al-Waeely A A, "Optimization of hybrid solar PV/ diesel system for powering telecommunication tower, "IJESET, vol. 8, No. 6, pp. 1-10, 2016.

[54] M. T.Chaichan,H. A. Kazem,K. I. Abaas, A. A. Al-Waeli, "Homemade solar desalination system for Omani families,"International Journal of Scientific & Engineering Research, vol. 7, No. 5, pp.1499-1504, 2016.

[55] H. A. Kazem,H. A. S. Al-Badi,A. S. Al BusaidiandM. T.Chaichan,"Optimum design and evaluation of hybrid solar/wind/diesel power system for Masirah Island," Environment, Development and Sustainability, 2016. DOI: 10.1007/s10668-016-9828-1

[56] M. T.Chaichan,K. I. Abass, D. S. M. Al-Zubidi, H. A. Kazem,"Practical investigation of effectiveness of direct solar-powered air heater," International Journal of Advanced Engineering, Management and Science (IJAEMS), vol. 2, No. 7, pp.1047-1053, 2016.

[57] H. A. Kazem,A. H. A. Al-Waeli, M. T.Chaichan,A. S. Al-Mamari, A. H. Al-Kabi, "Design, measurement and evaluation of photovoltaic pumping system for rural areas in Omanenvironment," Development and Sustainability, DOI: 10.1007/s10668-016-9773-z, 2016.

[58] H. A. Kazem, and M. T.Chaichan,"The impact of using solar colored filters to cover the PV panel on its outcomes," Bulletin Journal, vol. 2, No. 7, 464-469, 2016. DOI: 10.21276/sb.2016.2.7.5.

[59] A. H. A. Al-Waeli, A. S. A. Al-Mamari, A. H. K. Al-Kabi, M. T.Chaichan,H. A. Kazem,"Evaluation of the economic and environmental aspects of using photovoltaic water pumping system," 9th International Conference on Robotic, Vision, Signal Processing & Power Applications, Malaysia, 2016.

[60] A. H. Al-Waeli, H. A.Kazem and M. T. Chaichan, "Review and design of a standalone PV system performance," International Journal of Computation and Applied Sciences IJOCAAS, vol. 1, No. 1, pp. 1-6, 2016.