[1.]Precious EHIOMOGUE, [1.]Prince Nzubechukwu IGWE, [1.]Okechukwu ODUMA, [2.]Unwana Iniobong UDOUMOH, [3.]Stanley Asishana AJAYI, [4.]Alugbe Marcellus BRAI, [1.]Tosin PAUL

PERFORMANCE EVALUATION OF A COMBINED SOLAR WATER HEATER AND WATER DISTILLER FOR DOMESTIC PURPOSES

[1.]Department of Agricultural and Bioresources Engineering, College of Engineering and Engineering Technology, Michael Okpara University of Agriculture, Umudike, NIGERIA
[2.]Department of Agricultural and Food Engineering, Faculty of Engineering, University of Uyo, Uyo, Akwa-Ibom State, NIGERIA
[3.]Department of Agricultural Engineering, College of Engineering Technology and Engineering Technology, Auchi Polytechnic Auchi, Edo State, NIGERIA
[4.]Department of of Sciences, National Institute of Construction Technology (NICT), Uromi, Edo State, NIGERIA

Abstract: The performance of a combined solar water heater and water distiller for domestic purposes was evaluated. Solar energy is a renewable source which can be harnessed in diverse ways to meet the needs and demands of the people. A solar powered system is friendly to the environment and very economical since the energy involved is renewable and can serve for a very long time with little or no maintenance. A solar powered system is a long term investment that can help us save money and energy for many years; while maintaining a hazard free environment. The system having a combination of solar water heater and solar still gave an efficiency of 38.8% and 15%respectively which can be considered satisfactory given the area of the collector and heating rate. Auxiliary heating system can be incorporated to improve the efficiency of the system. This satisfactory efficiency can be attributed to heat losses due to insulation lapses and water leakages during operation. The storage tank should be located at the top of the collector with adequate water volume to allow for easy flow of water at a good pressure.
Keywords: solar energy, water distiller, water heater, solar radiation, temperature

1. INTRODUCTION

The sun is very a good example of renewable energy. The sun has produced energy for thousands of years which undergo a faster replenishment within a relatively short of time than the rate of its consumption. The earth's population currently needs 15 terrawatts of power in total, but the solar radiation that reaches the earth on a continuous basis amount to 120,000 terrawatts; hence a small fraction of the sun reaching the earth will cover the bulk need of the energy's requirement (Krężel and Bradtke, 2012)

Solar energy has always been a capable option for the energy challenges faced by the world. The solar radiation is as a result of the nuclear fusion reactions in the sun. The radiation from the sun can be converted to heat using different equipment of which flat plate collector is the most popular (Hovel, 1975; Patil and Deshmukh, 2015). Radiant energy from the sun has powered life on earth for thousands of years. In the 1830s, the British astronomer, John Herschel, famously used a solar thermal collector box (a device that absorbs sunlight to generate heat) to cook food during an expedition to Africa (Kalogirou, 2004; Nelson, 2003). With the increasing challenges of the earth's ozone layer depletion, health hazards, reduced availability of fossil fuel, global climate change and other air pollution issues resulting from burning of hydrocarbons as a source of energy has led to the drive to use environmentally friendly and renewable alternative sources of energy to eliminate or minimize these negative effects on the environment. Despite this hopeful evaluation of the potential of solar energy, considerable technical and economic problems must be solved before utilization of solar energy can occur (Mohamed et al., 2020; Tian and Zhao, 2013). The solar power development will depend on how a number of serious constraints are dealt with, including scientific and technological problems, marketing, financial limitations and political challenges. In addition, the education of engineers will have to change its focus from non-renewable fossil-fuel technology to renewable power sources. There has been a general agreement that the most significant of the renewable energy sources is solar radiation (Mohamed et al., 2020; Watmuff *et al.*, 1977).

Solar energy collectors are devices used to convert solar radiation to heat. When a dark surface is placed in sunshine, it absorbs solar energy and heats up. A solar energy collector working with sun facing surfaces will transfer energy to the water that flows through it. It usually consists of a surface that efficiently absorbs radiation and converts the incident flux to heat which raises the temperature of the absorbing material.

There are many issues related to water that nations are struggling with in the 21st century. Currently, about one quarter of the world's population, or about 1.2 billion people, lacks access to sufficient water of good quality (Fernández-García *et al.*, 2010; Rijsberman, 2006). This problem is only exacerbated as the world population continues to climb, as it has been shown that water usage increases at twice the rate of population increase (Eltawil *et al.*, 2009; Suman *et al.*, 2015).

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

The solar water heater system consists of mainly two basic parts namely; the storage tank and solar collector. The solar water heating system has proven to be a famous renewable energy technology and has been adopted in many countries of the world likewise the solar water distiller which has the advantage of cost saving when compared to other types of distillation such as reverse osmosis, because solar energy is limitless and easily available.

Nigeria is a country blessed abundance of solar energy from which useful energy can be harnessed for several purposes. This gave rise to the design and fabrication of this project; combined solar water heater and water distiller to meet the demands of domestic users at a lower cost.

With the continuous use of fossil fuels and burning of hydrocarbons in the environment leading to various environmental hazards, it has become a thing of concern that alternative measures that are environmentally friendly be sought in order to curb these effects on these effects on the environment. Hot water is needed in every home for different purposes resulting to high electricity bills using the electrical gadgets to heat up water. Sometimes there is a malfunction of these gadgets (fire outbreaks) which can be detrimental to the household.

Several designs and constructions have been made separately (solar water heater and water distiller) which is very expensive when compared to cost of its combined operation.

Solar energy is a renewable source which can be harnessed in diverse ways to meet the needs and demands of the people. It comes at no cost, can be easily replenished and is environmentally friendly. The system can easily operate 20 years or more without needing any serious maintenance. Very little service or maintenance is required for the life of the system. It is easy to install and there is a high return on investment when compared to all other alternative energy options.

The development of this project will provide one with adequate hot and clean water for domestic use all year round and at a low cost

Table 1: solar water heater materials selected and their properties

s/n	Component	Material
1	Storage tank	Aluminum
2	Collector frame	Plywood
3	Absorber plate	Aluminum
4	Collector tube	Copper pipes
5	Insulator	Foam
6	Support structure	Wood
7	Connecting pipes	Polyvinyl chloride (PVC) pipes

2. MATERIALS AND METHOD

A critical study on the already existing solar water heater and desalination system was made; and choice of materials and design was done bearing in mind its simplicity, installation and cost of maintenance as well as its durability.

3. DESCRIPTION OF THE SYSTEM OPERATION

The system is a combined process of solar water heating and solar water distillation. Cold water flows from the storage tank through the tank's underneath channel to the solar collector where it is heated and sent back to the storage tank through thermosyphon process. The water distillation process follows the same process but with little modification. Here, water flows from the water tank to the solar collected where is preheated and channeled to the basin where it is furthered purified using the evaporation and condensation technique.

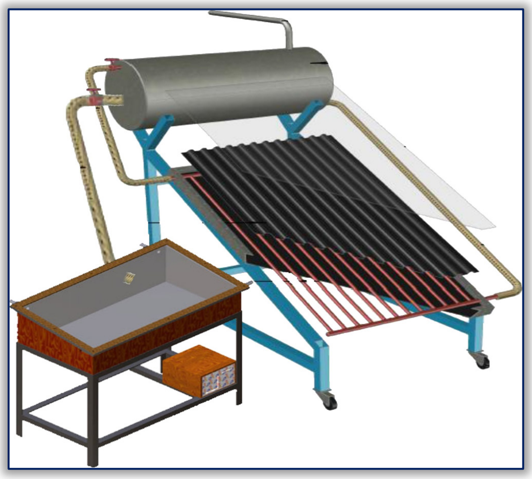

Figure 1: sketch of a combined solar water heater and water distiller

4. RESULTS & DISCUSSIONS

Table 1 shows the hourly temperature and solar radiation variation for each day starting from 2nd December to 7th December 2019. The data obtained showed a gradual increase in both ambient temperature and system fluid output temperature. Maximum increase in temperature occurred between 12pm and 3pm.

Table 2 showed that the average ambient temperature ranged from 25.9 C to 32.7 C. Maximum ambient temperature occurred between 12pm to 3pm with the highest coming at 2pm. Maximum fluid temperature for the system was obtained between 12pm and 4pm with the highest at 3pm. The solar radiation ranged from a low value 548.3W/m^2 at 8am and got to peak between 12pm and 3pm and fell back to a low value between 4pm and 5pm.

Figure 2 gives a graphical representation of the obtained data in table 2. The graphs showed a peak solar radiation value of 1002.6 at 2pm while the maximum ambient temperature and fluid outlet temperature 32.7C and 52.4C respectively occurred at 2pm and 3pm respectively.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

Table 2: hourly system temperature variation and solar radiation

Time	Monday		Tuesday		Wednesday		Thursday		Friday		Saturday	
	temp amb	temp out	temp amb	temp out	temp amb	temp out	temp amb	temp out	temp amb	temp out	temp amb	temp out
8am	26.4	25.2	25.4	26.4	25.4	27	25.7	26	27.6	28.2	24.6	25.8
9am	27.2	26.7	26	27.6	27.8	28.7	26.2	27.1	28.1	30.6	26.2	28.8
10am	29.4	30.6	27.7	30.3	29.1	33.7	28.3	29.8	28.6	35.2	29.4	33.4
11am	30.2	34.4	29.7	34.3	30.1	38.6	30.4	34.5	30.2	37.6	31	37.6
12pm	31	42.5	31.6	40.5	31.7	41.3	32	38.3	31.4	42	32.3	40.8
1pm	32.1	48.3	32.8	44.6	32.6	45.9	32.4	44.3	32	45.7	32.7	46.9
2pm	32.4	50.2	33.6	52.1	32.9	50.6	32.6	51.7	32.3	53	32.5	52.9
3pm	32	53.4	32.7	50.3	31.3	53.8	31.7	52.8	32.6	51.2	32.1	53
4pm	30.6	50.7	32	47.8	29.8	50.6	30	48.7	31.4	48.4	31.8	49.4
5pm	28.7	48.2	30.9	44.2	28.2	46.9	28.8	43.2	29.2	44.5	30	47
daily average	30	41.02	30.24	39.81	29.89	41.71	29.81	39.64	30.34	41.64	30.26	41.56

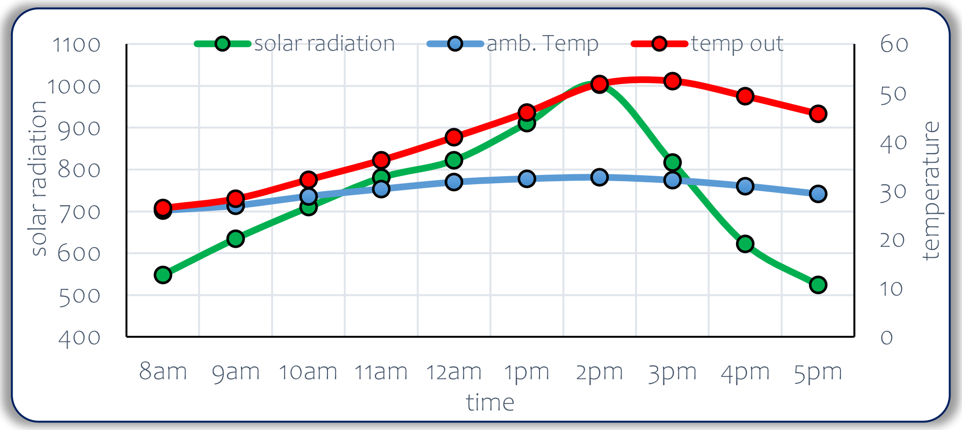

Figure 2: graphical representation of average system temperature and solar radiation variation

The efficiency of the solar water heater was found to be at 38.8% given the average solar radiation and collector area of the system.

$$\eta = Qu/ Ht * Ac$$
$$\eta = 200.6/ 737.35 * 0.7$$
$$\eta = 38.8\%$$

The effectiveness of the system is valued at 2.04l/m²/day as shown in table 4.3. The system operation was carried out at a sun exposure time of 8hrs to determine the mass flowrate per day (8am to 4pm). The average solar radiation for each of the week ranged from 697.80 W/m² to 764.20 W/m² with the highest coming on Wednesday 764.20 W/m².

Table 3: average system temperature and solar radiation variation

Time (h)	Temp amb. (C)	Temp out (C)	Solar radiation (W/m²)
8am	25.9	26.4	548.3
9am	26.9	28.3	634.9
10am	28.8	32.2	710.2
11am	30.3	36.2	780.9
12am	31.7	40.9	822.5
1pm	32.4	46	910.7
2pm	32.7	51.8	1002.6
3pm	32.1	52.4	816.7
4pm	30.9	49.3	622.5
5pm	29.3	45.7	524.2
average	30.09	40.9	737.35

Table 4. System production table

Days	time (4hrs)	purewater collection	al. plate area	m.f rate(4hrs)	m.f rate/day	avg. rad
Monday	4	0.35	0.36	0.97	1.94	710.90
Tuesday	4	0.37	0.36	1.03	2.06	745.90
Wednesday	4	0.4	0.36	1.11	2.22	764.20
Thursday	4	0.36	0.36	1.00	2.00	735.60
Friday	4	0.38	0.36	1.06	2.11	750.77
Saturday	4	0.34	0.36	0.94	1.89	697.80
Average					2.04	734.20

Figure 3 gives a graphical representation of the system production which shows that increase in solar radiation of the system leads to increase in water collection rate. The water collected was found to be odourless, tasteless and colourless with the average collected water temperature at 27.40 C. The system efficiency is valued at 15% which is satisfactory when compared to other solar still designs.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

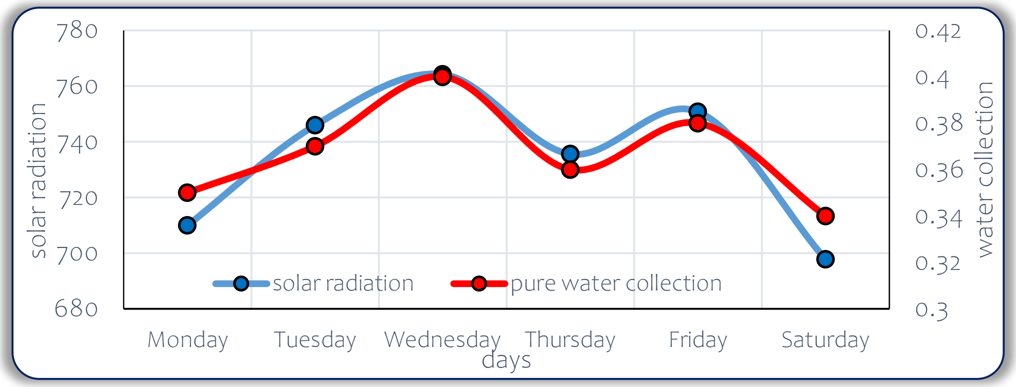

Figure 3: graphical reproduction of system production

5.CONCLUSIONS & RECOMMENDATIONS

A solar powered system is friendly to the environment and very economical since the energy involved is renewable and cab serve for a very long time with little or no maintenance.

The system having a combination of solar water heater and solar still gave an efficiency of 38.8% and 15%respectively which can be considered satisfactory given the area of the collector and heating rate. This satisfactory efficiency can be attributed to heat losses due to insulation lapses and water leakages during operation.

A solar powered system is a long term investment that can help us save money and energy for many years; while maintaining a hazard free environment. The system requires little or no maintenance when properly installed. The solar stills are best technology f or living beings and environment because no electricity is needed and is easy to maintain with high water purity level.

▓ Recommendation to Improve System Design

- The storage tank should be located at the top of the collector with adequate water volume to allow for easy flow of water at a good pressure
- A pump may be installed to allow for effective water return to storage tank. If adopted, it should be solar powered so as to reduce heating loss as compared to when electrically powered.
- Auxiliary heating system can be incorporated to improve the efficiency of the system
- The collector joints should be properly welded to avoid leakages. If fittings are used, it should be properly coated to avoid leakage.

▓ General System Recommendation

- The glass should be regularly cleaned to allow sun rays reaching the collector effectively heat the fluids
- All obstruction and shades around the system should be cleared

References

[1] Eltawil, M. A., Zhengming, Z., & Yuan, L. (2009). A review of renewable energy technologies integrated with desalination systems. Renewable and Sustainable Energy Reviews, 13(9), 2245–2262.
[2] Fernández-García, A., Zarza, E., Valenzuela, L., & Pérez, M. (2010). Parabolic-trough solar collectors and their applications. Renewable and Sustainable Energy Reviews, 14(7), 1695–1721.
[3] Hovel, H. J. (1975). Solar cells. NASA STI/Recon Technical Report A, 76, 20650.
[4] Kalogirou, S. A. (2004). Environmental benefits of domestic solar energy systems. Energy Conversion and Management, 45(18–19), 3075–3092.
[5] Krężel, A., & Bradtke, K. (2012). Estimation of solar energy influx to the sea in the light of fast satellite technique development. Solar Power, Rijeka, InTech, 171–192.
[6] Mohamed, A. S. A., Ahmed, M. S., & Shahdy, A. G. (2020). Theoretical and experimental study of a seawater desalination system based on humidification-dehumidification technique. Renewable Energy, 152, 823–834.
[7] Nelson, J. A. (2003). The physics of solar cells. World Scientific Publishing Company.
[8] Patil, P. P., & Deshmukh, D. S. (2015). Design considerations for flat plate solar water heater system. International Journal of Science, Spirituality Business and Technology (IJSSBT), 3(2).
[9] Rijsberman, F. R. (2006). Water scarcity: Fact or fiction? Agricultural Water Management, 80(1–3), 5–22.
[10] Suman, S., Khan, M. K., & Pathak, M. (2015). Performance enhancement of solar collectors—A review. Renewable and Sustainable Energy Reviews, 49, 192–210.
[11] Tian, Y., & Zhao, C.-Y. (2013). A review of solar collectors and thermal energy storage in solar thermal applications. Applied Energy, 104, 538–553.
[12] Watmuff, J. H., Charters, W. W. S., & Proctor, D. (1977). Solar and wind induced external coefficients-solar collectors. Cooperation Mediterraneenne Pour l'Energie Solaire, 56.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665