Transmissivity of the Glazing Surface of a Solar Flat Plate Collector Based on the Metrological Parameters of Yola, Nigeria

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Abstract: A glazing surface is one of the most vital components of a solar flat plate collector which is meant to admit maximum possible radiation and minimizes upward loss of heat. The most commonly used glazing surface is transparent glass. The performance of the glazing surface depends on the magnitude of its transmissivity. For a given material, this optical property is a function of solar geometry that varies with geographic location. In this work, the monthly mean value of transmissivity of the most commonly used glazing surface, 3mm transparent glass was determined for 12 months of the year with respect to the solar geometry of Yola town. A peak value of 0.8823 was recorded in the month of September while a minimum value of 0.8775 was recorded in the month of January. An annual mean value of 0.8807 was recorded with a standard deviation of 0.0015. The results imply that plane glass as a glazing surface admits about 88% of the solar radiation incident on it to the absorbing surface. The slight variation all year round is an indication of its consistent performance all times of the year at the locality.

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Key words: transmissivity, plane glass, glazing cover, flat plate collector, solar energy

1. Introduction

The current trends in global energy demand and the environmental impact of excessive exploitation of conventional energy sources necessitate the need for diversification of energy sources. Owing to the ever growing global population and economic growth of developing countries, the global energy demand increases at the rate of 1.2% per year and it is projected to be 35% more that the current demand by the year 2030 (Exxolmobil, 2010). This comes at a time when about 90% of the world's primary energy supply comes from the non renewable fossil fuel (International Energy Agency, 2010). The resources are therefore fast deflating due to excessive exploitation in an attempt to meet the ever increasing demand. Consequently the price continuously rise over the years thereby causing hardship in addition to increased greenhouse gas emission which leads to an irreversible damage to natural habitat.

Significant population of many developing countries of Asia, Africa and the Caribbean depends on the fossil fuel as a conventional energy sources for domestic use. In Nigeria, the conventional sources of energy for domestic cooking like liquefied petroleum gas (natural gas), kerosene and electricity are characterized by irregular availability, increased in cost and mostly not environmentally friendly (Bello, Makinde & Sulu, 2010). This necessitates the need for intensive effort toward harnessing non renewable and environmentally friendly energy sources.

The applicability and popularity of solar technology is therefore widening in Nigeria as it is in both developed and developing countries due to its simplicity and environmental friendliness as people are battling with the challenge of meeting their energy demands. The effective performance of any solar system however requires favourable weather conditions and good insolation. Tropical regions of the world have greater potential application of solar technology due to their relatively large solar insolation, minimal variation of daily sunshine hours and large sky clearness index (Mzad, 2008).

The town of Yola, the capital of Adamawa state in North-Eastern Nigeria, lies within Latitude: 09^{o}.14'N and Longitude: 012^{o}.28'E at a mean altitude of 174 m above sea level within the upper Benue trough of North-Eastern Nigeria. The town receives abundant daily sunshine and has maximum annual ambient temperature ranging between 32^{0}C to 43^{0}C (Adebayo and Tukur, 1999). Thus the town lies within a high sunshine belt of the country and solar radiation across it is fairly distributed. According to metrological data, the town receives an average of about 2.18 X10^{7}Jm^{-2}

per day from the sun; equivalent to 774.84Wm^2. This is significantly higher than the country's annual mean of about 1.89X10^{7}Jm^{-2}-day (Sambo and Taylor, 1990). The intensity however varies fairly with time from about 1.58X10^{7}J/m^2-day in August to about 2.58X10^{7}J/m^2-day in the month of March. The current electricity demand of the entire Adamawa state is about 4000MW. This could have been provided with this mean intensity of 774.84Wm^2 falling in an area of 0.4km^2 (40 hectares) of land if a conversion device of only 10% efficiency is use. This enormous potentiality raises the need for intense research in the field with a view of maximizing its benefit.

One of the most effective methods of converting solar energy to useful form is heliothermal, the process of converting solar radiation to useful thermal energy. It is the principle of operation of many solar devices such as solar cooker, solar still, solar water disinfection, solar power desalination etc. The most important component of heliothermal system is the flat plate collector. Both liquid and gas flat plate collectors as well as photovoltaic cell consist among other things, a glazing which may be one or more sheets of glass or any other radiation transmission material. Glass is the most commonly used material as it can transmit up to about 90% of the incident short wave radiation while its transmittance to the long wave heat radiation (5 to 50 μm) emitted by the absorber plate is very negligible (Tiwari 2002). In this work, the effectiveness of 3mm transparent glass as a glazing surface is tested with respect to the metrological parameters of Yola town. The aim of this work is to determine the transmissivity for the most commonly used glazing surfaces: 3mm transparent glass. This is with a view of assessing its performance under the solar geometrical condition of Yola town. The work therefore provides a useful data in analysing the thermal performance of a prototype solar collector. It also serves as an appraisal of the impact of geographic location and seasonal variation of metrological parameters to the performance of glass as a glazing cover.

2. Parametric definition and computation

The intensity of solar radiation striking the absorber plate of a flat plate collector depends on the transmission properties of the glazing cover. The rate at which energy is absorbed by a plate per unit area $\dot{q}_{ab}$ is related to the solar intensity $I(t)$ by the equation (Tiwari , 2002)

$$\dot{q}_{ab} = (\tau\alpha)I(t) \qquad 1$$

where τ is the transmittance or transmissivity of the glazing cover. Transmissivity of the cover is therefore very important in designing and evaluating the performance of solar energy conversion systems. It varies with geographic location due to the variation of solar geometry with location (Sukhatme 1984). The parameter depends on solar geometry and can be obtained using the following solar geometrical factors:

Declination δ **.** This is the angle between the lines joining the centres of the sun and the earth with its projection on the equatorial plane. It is given by Cooper's equation (Mzad, 2008) as

$$\delta = 23.45\sin\left[\frac{360}{365}(284+n)\right] \qquad 2$$

where n is the day of the year. For this work, n is taken as the last day of each month.

Hour angle ω . Is the angular measure of time, equivalent to 15^0 per hour. It is measured in the noon based on local apparent time (LAT).

Local Apparent Time (LAT) is defined by Sukhatme (1984) as

LAT = Standard time ∓ *(standard time longitude) - (longitude of location) + (equation of time correction).* 3

The negative sign in the first term is applicable to eastern hemisphere while the positive sign is applicable to western hemisphere.

Slope β is the angle made by the collector plane surface and the horizontal (Fig. 1). The equation of time correction, which is a correction due to the fact that the earth's orbit and rate of rotation are subject to small perturbation, is based on experimental observation. A correction chart was given by Sukhatme (1984) from where correction for the last day of each month of the year, taken as the days of the experiment, was obtained (table 1).

In Nigeria, standard time is based on longitude 15^{o}E. For 13:00hours (1:00pm) of the experimental day at Yola (Long. 12^o 28'E), LAT is calculated for the 12 months of a year from the expression:

LAT=1300hrs-4(15^o-12^o.28')min + (equation of time correction for the month). 4

The incident angle of the beam radiation θ_i is given by Tiwari (2002) as

$$\sin\theta_i = \sin\delta\sin(\phi-\beta) + \cos\delta\cos\omega\cos(\phi-\beta)$$

where ϕ is the latitude of the location. In this work, the collector is tilted at latitude angle. Thus $\phi = \beta$ and therefore

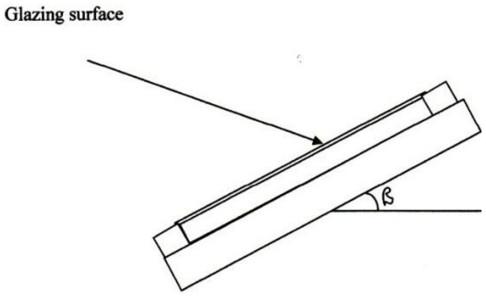

Fig. 1. Plane glass glazing cover

$$\sin\theta_i = \cos\delta\cos\omega . \tag{5}$$

The refracted angles are given by Snell's law as

$$\theta_r = \sin^{-1}\left[\frac{\sin\theta_i}{n}\right] \tag{6}$$

The reflectivities for both the beam and diffused components of radiation are respectively given by the equations (Tiwari, 2002)

$$\rho_1 = \frac{\sin^2(\theta_r - \theta_i)}{\sin^2(\theta_r - \theta_i)} \tag{7a}$$

$$\rho_2 = \frac{\tan^2(\theta_r - \theta_i)}{\tan^2(\theta_r + \theta_i)} \tag{7b}$$

The transmissivity based on the reflection τ_r is given by the equation (Garg and Prakash, 1997)

$$\tau_r = \frac{(\tau_{r1} + \tau_{r2})}{2} \tag{8}$$

Where

$$\tau_{r1} = \frac{1-\rho_1}{1+\rho_1} \quad \text{and}$$

$$\tau_{r2} = \frac{1-\rho_2}{1+\rho_2}$$

The transmissivity of the cover τ is given by

$$\tau = \tau_r \tau_o \tag{9}$$

Where τ_o is the transmissivity based on absorption given by Bouger law (Sukhatume, 1984) as

$$\tau_o = e^{-\frac{k\delta}{\cos\theta_r}} \tag{10}$$

k is the property of the glass cover known as its extinction coefficient. Its value for a plane glass varies from about 5 to 25m^{-1} depending on the glass quality. Assuming the glass cover is of average quality, k=15m^{-1}. The glass cover used for this work is plane of thickness δ =3mm. Thus τ_o and τ are computed for the 12 months as shown in table 1.

3 Result and discussion

The computed results based on the above definations and inputs are summarized in table 1. Fig. 2 is the plot of the variation of transmittvity τ with time of the year. With a mean value of 0.8807 and a standard deviation of just 0.0015, the variation over a year is insignificant. It however follows the trend of the variation of solar intensity with time. The results as illustrated in Fig. 2 reveals that monthly values of transmissivity fluctuates around an average value of 0.8807 each season. It is however noted that with a standard variation of just 0.0015, the variation is less significant. A peak value of 0.8823 is recorded in the month of September while a minimum value of 0.8775 is recorded in the month of January. The plot shows two peak regions within the months of February-March and August-October. The implication is that solar flat plate collectors constructed with this plane glass as a glazing cover performs at a relatively higher efficiency within these periods when compared to the minimum periods of November-January. It worth nothing however that with a mean value of 0.8807, about 88.07% of the solar intensity falling on a 3mm transparent glass glazing cover under the condition of Yola solar geometry is transferred and transmitted to the absorber plate. This amount is nearly constant with a slight variation over the year. The slight variation over the year is an indication of a year–round reliability and good consistency of a plate glass as a glazing cover in the locality

4. Conclusion

The efficient and effective performance of the glass glazing surface within the town is yet another indicator to the fact that Yola town is endowed with abundant solar energy potentials. Regrettably like the remaining part of the country however, the population almost entirely depends on the non renewable conventional energy sources mostly fossil fuels and biomass for domestic use. With an annual mean transmissivity value of 0.8807, the glazing surface is capable of all year round performance and therefore consistently reliable within the locality. It therefore provides an opportunity for the most efficient means of converting solar energy to thermal and electrical energies if used as glazing cover on a solar flat plate collector or photovoltaic cell. If placed in a convenient location say the roof of buildings, the devices will provide domestic heating, purification and electricity for domestic use cost effectively and will therefore supplement the deflated conventional source.

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Appendix

Table .1, transmissivity computation table

Month	***n***	δ (°)	***Eqn of time corr'n (min)***	***LAT***	$\omega/^{o}$	θ_I	θ_r	ρ_1	ρ_2	τ_{r1}	τ_{r2}	τ_r	τ_0	τ	$(\tau\alpha)$
1	31	-17.78	-3	12.47	-7.05	19.08	12.59	0.0507	0.0340	0.9035	0.9342	0.9189	0.9549	0.8775	0.8512
2	59	-8.67	-16	12.34	-5.10	10.05	6.68	0.0417	0.0384	0.9199	0.9260	0.9230	0.9557	0.8821	0.8556
3	90	3.62	-17	12.33	-4.95	6.13	4.08	0.0407	0.0395	0.9218	0.9240	0.9229	0.9559	0.8822	0.8557
4	120	14.59	-4	12.46	-6.90	16.11	10.66	0.0445	0.0358	0.9148	0.9309	0.9229	0.9552	0.8816	0.8552
5	151	21.90	3	12.53	-7.80	23.18	15.21	0.0498	0.0312	0.9051	0.9395	0.9223	0.9544	0.8803	0.8539
6	181	23.18	2.5	12.52	-7.80	24.39	15.98	0.0510	0.0302	0.9029	0.9414	0.9222	0.9543	0.8800	0.8536
7	212	18.17	-3	12.47	-7.05	19.45	12.83	0.0466	0.0338	0.9109	0.9346	0.9228	0.9549	0.8812	0.8548
8	243	8.10	-6	12.44	-6.60	10.43	6.93	0.0419	0.0383	0.9196	0.9262	0.9229	0.9557	0.8820	0.8555
9	273	-3.82	0	12.47	-7.35	8.28	5.51	0.0411	0.0389	0.9210	0.9251	0.9231	0.9558	0.8823	0.8558
10	304	-15.06	8	12.58	-8.70	17.34	11.46	0.0452	0.0351	0.9135	0.9322	0.9229	0.9551	0.8815	0.8551
11	334	-21.97	16	13.06	-15.90	26.89	17.55	0.0537	0.0281	0.8981	0.9453	0.9217	0.9539	0.8792	0.8528
12	365	-23.09	11	13.01	-15.15	27.39	17.86	0.0543	0.0277	0.8970	0.9461	0.9216	0.9538	0.8790	0.8526

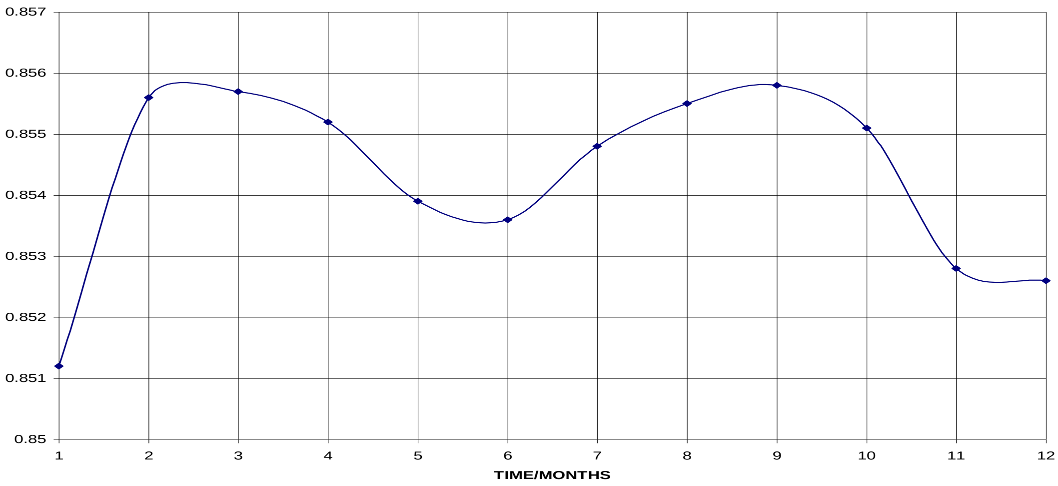

Fig. 2, variation of transmissivity with months of the year

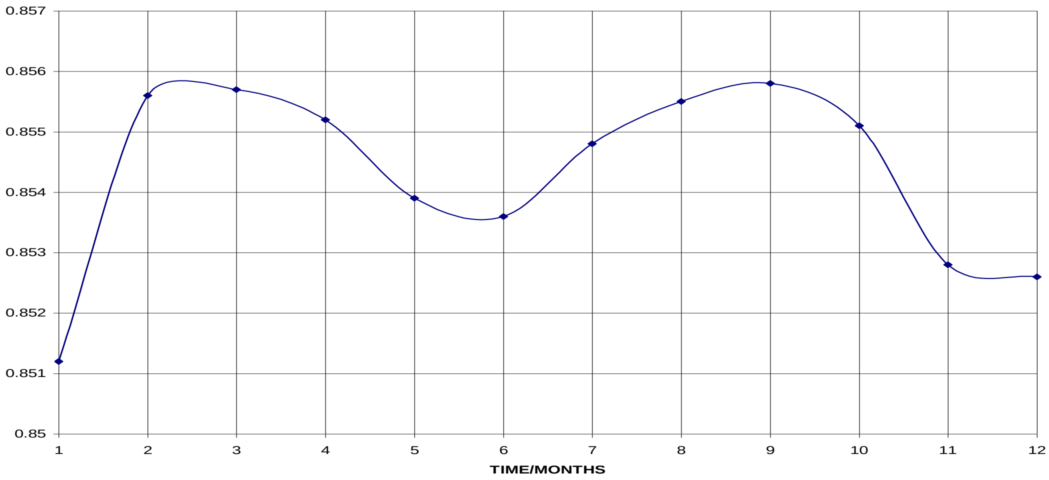

Fig. 3. variation of $(\tau\alpha)$ for a dull black surface

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