
Effects of Tilt Angles on the Thermal Performance of a Solar Parabolic Trough Collector System

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Abstract: This paper studied the effects of tilt angles on the thermal performance of a solar parabolic collector system. This is the angle at which the beam solar radiation arriving from the sun will fall perpendicular to the solar collector surface. The quantitative assessments of radiation incident on a tilted plane are very important for designing solar collecting devices. The idea was to evaluate the thermal performance of the solar collector at the monthly optimal tilt angles in Bauchi (latitude 10°30' North and 10°00' East). Monthly mean daily global and diffuse components of the solar radiation for 10 years (January, 2009-December, 2019) were collected and used for the simulation using MATLAB software. Also used for the simulation are the developed energy balance equations for evaluation of thermal performances of solar collector. It was observed that, as the tilt angles decreases, both absorber tube and fluid temperatures together with the thermal efficiencies of the collector increased. Higher tilt angles were witnessed during January-February and September-December (20°-33°) and these months were having low temperatures of the absorber tube and the fluid (169°C-228°C and 130°C-117°C respectively). Low tilt angles between March to August (7°-16°) and with temperatures of the absorber tube and fluid between 220°C-235°C and 128°C-142°C respectively. Maximum thermal efficiency of 73% was obtained at the least optimal tilt angles (7°-8°). Thus, for efficient solar radiation collections, solar parabolic trough collector system should be maintained at optimal tilt angles between 7°-33° in Bauchi depending upon the seasonal variations.

Keywords: Tilt Angle, Parabolic Collector, Thermal Performance, Solar Collector, Solar Radiation and Incidence Angle

1. Introduction

A nation's economic development is, more often than not, measured by the ability to effectively and efficiently converting available energy resources into useful energy and the level of utilization of the energy in the economy. Thus, humanity is faced with a critical challenge of expanding the energy services in a sustainable way and at the same time mitigate the environmental impacts usually associated with energy usage. This call for strong campaign for more reliance on energy systems that is environmentally benign, such as solar and wind energy which are renewable energy sources as a way of providing solution to the World energy demands. For countries such as Nigeria which are closer to the equator, where solar energy is an abundant available natural resource, it will play a vital role in addressing the energy crisis of the country.

According to Abdul Qayoom *et al.* [1] any effort that is tailored towards the improvement of the performance of solar energy system via research and development efforts is highly reassuring particularly for accurately predicting the output from the available climatic and environmental conditions of the area under review. Thus, to design a solar device with better efficiency it is most important to determine the amount of energy actually available at various orientations of a collector [2]. Solar radiation data provide the best source of information for proper estimation of the amount of average solar incidence radiation necessary for design and assessment of conversion systems for solar energy.

There are numerous meteorological stations that are available across the globe but, they provide, in most cases facilities for measuring insolation arriving on horizontal surfaces. However, on incline surfaces it is much less common, solar conversion systems are mostly tilted towards the sun

central rays for maximum capturing of the amount of solar radiations incident on the collector or module surface [1]. Therefore, the calculation of the amount of global tilted surface irradiation is achieved by means of empirical models. These quantitative assessments of radiation incident on a tilted plane are very important to engineers for designing solar collecting devices. In order to maximize the amount of solar radiation incident on a collector or module surface, computation of tilt angle is one of the simplest and appropriate ways to pursue this problem. Kallioğlu [3] reported that collector tilt angle (0° - 90°) if properly located and positioned will yield maximum productivity from solar energy.

The term tilt angle, β according to Ekadewi *et al.* [4] is defined as the angle at which the beam solar radiation arriving from the sun will fall perpendicular to the solar collector surface as shown in Figure 1. Thus, to increase the efficiency of any collecting device it should be mounted at an optimum tilt angle depending on the location. Hence, it becomes necessary to determine the radiation flux which falls on a tilted surface. This flux according to Mark and Vijaysinh [5] is the sum of the beam and diffuse radiation falling directly on the tilted surface of the collector.

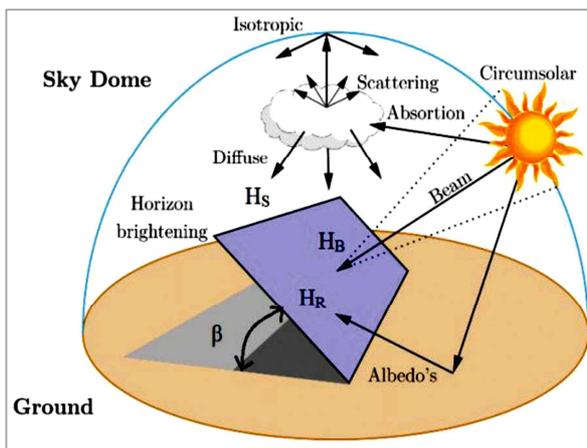


Figure 1. Components of solar irradiance on a tilted surface [3].

The efficiency of a solar parabolic collector can be increased by mounting the collector at the monthly average tilt angle and the slope adjusted every month [4]. Various researchers reported that high tilt angles are observed from September to February and low tilt angle between March to August [2, 3] and [6]. This is as a result of the seasonal variations in sun positions; during later months (March to August) the sun comes overhead and maximum radiation is attainable on a horizontal surface.

The orientation of the solar parabolic trough collector (SPTC) is set such that its axis is either horizontally in the East-West or North-South direction. On the other hand, SPTC may be positioned such that its axis makes an angle β with the south direction in the Northern hemisphere or north direction in Southern hemisphere [4]. This angle is referred to as tilt angle and the solar radiation falling on this surface depends on the radiation falling on this tilt surface and the latitude of the location. The ratio of the beam radiation flux

incident on tilted surface to that incident on a horizontal surface is termed the tilt factor. Thus, the performance of this type of solar collector can be improved by obtaining accurately the tilt angle of the collector relative to the direction of the solar rays. This is to ensure that the concentrated flux is precisely directed to the thermal conversion device, which is at the focal length of the reflector. Therefore, this study is aimed at investigating the effects of this tilt angle on the thermal performance of solar parabolic trough collector system in Bauchi which is at latitude $10^{\circ}30'$ North and $10^{\circ}00'$ East.

Many research activities on finding optimum tilt angle have been carried out in different locations across the globe. The main idea of such researches according to Kallioğlu *et al.* [3] was to optimize the tilt angle so as to obtain maximum radiation. Approaches usually adopted for the determination of optimal tilt angles of solar collectors are both theoretical and experimental in nature. A research conducted by Moghadam *et al.* [7] in Iran to evaluate the optimal tilt angle for two different locations Zahedan (27.18° N- 56.26° E) and Bandar Abbas (29.49° N- 60.88° E) and found out that solar panel tilt angle is from 9.9° - 59.2° . Benghanem [8] carried out an optimization of tilt angle for solar panel in Medina (24.5° N- 39.61° E), Saudi Arabia and the result shows that, the optimal tilt angles were 17° (spring), 12° (summer), 28° (autumn), 37° (winter) and 23.5° as annual average. Mark and Vijaysinh [5] estimated the World photovoltaic optimal tilt angles and ratios of solar radiation incident on tilted and tracked solar panels in relation to horizontal panels. In their study, data obtained from Northern and Southern Hemispheres were used to develop a 3rd order polynomial to fit the optimal tilt angle, they however, suggested that for higher accuracy the optimal tilt angle for each specific location should be calculated by the solar installers.

An investigation on the optimal tilt angle in Hannover (52.37° N- 9.73° E) Germany was carried out by Beringer *et al.* [9] and they found out that solar collector are efficient between 0° - 30° during summer season and 50° - 70° during winter season. Rahman *et al.* [2] was of the view that optimal tilt angle is dependent on the location's latitude and is usually close to the latitude of the respective location. Equations for the computation of tilt angles were developed by Ekadewi *et al.* [4] and were able to compute the tilt angles for Surabaya, Indonesia. From March 12-September 30 the optimal tilt angle varied between 0° - 40° (face to the North) and from October 1-March 11 the optimal tilt angle varied between 0° - 30° (face to the South). Nabila *et al.* [10] also conducted a research on a best tilt angle of fixed solar conversion systems at M'sila region in Algeria using Reindl model and found that it is preferable to change the tilt angle of the solar conversion systems monthly. Manoj *et al.* [17] also carried a similar research in India using real time data acquisition and it was observed that the performance of the collector increases by 7-8% and also the tilt angles for winter period gives the best output results. In the work of Theophilus *et al.* [18] which was conducted in Kumasi Ghana using RETScreen 4, the optimal tilt angle was achieved at 10° . A study aimed at

determining the optimal tilt angle for solar photovoltaic panel in Ilorin was conducted by Ajao *et al* [11] and from the results obtained it was shown that maximum power performance could be achieved when the average optimal tilt angle of a solar panel mounted at fixed position in Ilorin is 22°.

2. Methods

2.1. Mathematical Procedure for the Calculation of Optimal Tilt Angle

According to Peter *et al.* [12] solar incidence angle θ is the angle between the sun's rays and the normal on a surface. For maximum solar radiation collection on a tilted surface, the angle of incidence of beam radiation on a surface must be at maximum. This can only be achieved when the tilt angle β is at optimal level. This implies that, optimal tilt angle of a surface is associated with the value of β that maximizes $\cos\theta$. According to Ekadewi *et al.* [4] such value can be obtained from the requirement that $d \cos\theta / d\beta = 0$. Taking the derivation it is found that:

$$\tan\beta = \frac{(-\sin\delta\cos\phi\cos\gamma + \cos\delta\sin\phi\cos\gamma\cos\omega + \cos\delta\sin\gamma\sin\omega)}{\sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega} \quad (1)$$

The tilt angle β will make $\cos\theta$ maximum when $d^2\cos\theta / d\beta^2 < 0$. The second derivative:

$$\frac{d^2\cos\theta}{d\beta^2} = -A\cos\beta - B\sin\beta \quad (2)$$

Where $A = \sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega$ and $B = (-\sin\delta\cos\phi\cos\gamma + \cos\delta\sin\phi\cos\gamma\cos\omega + \cos\delta\sin\gamma\sin\omega)$

From Equation (1), the tilt angle can be easily estimated provided that the day in a year n , the orientation of the surface (surface azimuth angle γ), latitude ϕ , declination angle δ and time of the day ω (hour angle) are available [4]. The monthly average optimal tilt angles were computed using equation 2.

2.2. Experimentation

Monthly mean daily global and diffuse components of the solar radiations for 10 years (January, 2009-December, 2019) were collected from the National Meteorological weather station at the Bauchi International Airport and the beam radiation were obtained by subtracting the diffuse from the global radiation. These radiations were used for the simulation of the thermal performances of a tilted SPTC (TE38) as depicted in Figure 2.

2.3. Simulation

MATLAB software was employed for the simulation. The energy balance equations developed by Sintali *et al.* [13] was

$$2\alpha_g RL[(I_{beam} * R_b) + I_{diff}] + \rho_c \alpha_g \left[\frac{(W - D)L}{\pi} \right] (I_{beam} * R_b) + \frac{A_t \sigma (T_t^4 - T_g^4)}{\frac{1}{\epsilon_t} + \frac{A_t}{A_g} \left[\frac{1}{\epsilon_g} - 1 \right]} - \sigma \epsilon_g A_g (T_g^4 - T_{sky}^4) - A_g h_c (T_g - T_{sur})$$

adapted and used for the calculation of thermal performances of the SPTC. The developed model equations considered longitude (γ) and latitude (ϕ) of the location in radian, as well as the geocentric global coordinates, the local topocentric coordinates of the sun and the heliocentric longitude (H). The equation for the computation of the thermal efficiency (η_{th}) of the collector also take into consideration the direct (E_{gd}) and reflected (E_{gr}) solar radiations incident on the tilted surface of the parabolic trough collector and reflected on receiver at the focal line of the collector. The tilt factor (R_b) was considered in computing the energy balance of the receiver assembly. The thermal properties of the collector materials as well as the total energy losses (Q_{losses}) in the system were all considered. The SPTC used for the simulation has the following specifications:

- 1) Inclination and azimuth-Adjustable
- 2) Parabolic reflector-Stainless Steel
- 3) Aperture width (w)-800mm (0.8m)
- 4) Collector length (L)-300mm (0.3m)
- 5) Focal length(f)-487mm (0.487)
- 6) Aperture area (A_a)-0.24m²
- 7) Rim angle (ψ_{rim})-45°



Figure 2. Solar Parabolic-Trough Collector (TE38).

2.3.1. Energy Balance Equations

The design of solar concentrator required that the data of beam radiation on a horizontal surface be converted into that of radiation on a tilt surface using the conversion ratio R_b (tilt factor). This depends solely on the solar topocentric angles and is given by equation 3 [13].

$$R_b = \frac{\cos(\phi - \rho_t)\cos\delta_t\cosh_t + \sin(\phi - \rho_t)\sin\delta_t}{\cos\phi\cos\delta_t\cosh_t + \sin\phi\sin\delta_t} \quad (3)$$

where ϕ local observer latitude angle ρ_t is the tracking angle, δ_t topocentric declination, and h_t topocentric hour angle. Thus, the beam radiation incident on the aperture of the collector becomes $I_{beam} * R_b$. Thus, the enveloping glass cover's energy balance equation is given by equation 4.

$$= m_g c_{p_g} dT_g/dt \quad (4)$$

where α_g represents the glass-cover material absorptance, R represents the outer radius of the enveloping glass-cover, D is the outer diameter of the enveloping glass-cover, L represents the length of the concentrator, R_b is the tilt factor and is defined in equation 2, I_{beam} is the beam radiation on a horizontal surface, I_{diff} is the diffuse radiation, p_c is the reflectance of the concentrator, W is the width of the concentrator aperture, A_g is the surface area of the enveloping glass-cover, m_g stands for the mass of the enveloping-glass-cover material, the specific heat capacity of the enveloping-glass-cover material is represented by C_{p_g} , A_t

is the surface area of the absorber-tube, σ is the Stefan-Boltzmann's constant of radiation, T_t stands for the temperature of the absorber-tube, T_g is the temperature of the enveloping glass-cover, ε_g stands for the emittance of the enveloping glass-cover material, ε_t stands for the emittance of the coating material on the absorber-tube, T_{sky} is the sky temperature, T_{surr} is the ambient temperature, h is the convective heat transfer coefficient, and $\left(\frac{dT_g}{dt}\right)$ stands for the temperature gradient of the enveloping-glass-cover. The absorber-tube energy balance is as shown in equation 5:

$$2RL\alpha_t\tau_g[(I_{beam} * R_b) + I_{diff}] + \alpha_t\tau_g\rho_c\left[\frac{(W-D)L}{\pi}\right][I_{beam} * R_b] - \frac{A_t\sigma(T_t^4 - T_g^4)}{\frac{1}{\varepsilon_t} + \frac{A_t}{A_g}\left[\frac{1}{\varepsilon_g} - 1\right]} - \frac{A_{in}(T_t - T_f)}{\left[\frac{1}{h_f} + \frac{A_{in}\ln\left(\frac{r}{r_i}\right)}{2\pi KL}\right]} = m_t c_{p_t} dT_t/dt \quad (5)$$

where α_t is the absorptance of the absorber-tube material, τ_g represents the transmittance of the enveloping glass-cover material, A_{in} is the surface area of the tube based on internal diameter of absorber-tube and T_f stands for the temperature of the air fluid, h_f is the convective heat transfer coefficient of the air fluid, r_1 stands for the inner radius of the absorber-tube and r stands for the outer radius of the absorber-tube, m_t is the mass of the absorber-tube material, C_{p_t} stands for the specific heat capacity of the enveloping-glass-cover material and $\frac{dT_g}{dt}$ stands for the temperature gradient of the absorber-tube.

The energy balance equation for the working fluid developed is given by equation 6 as follows;

$$\frac{A_{in}(T_t - T_f)}{\left[\frac{1}{h_f} + \frac{A_{in}\ln\left(\frac{r}{r_i}\right)}{2\pi KL}\right]} - \frac{2A_c(T_f - T_{surr})}{\frac{1}{h_c} + \frac{1}{h_f}} = m_f c_{p_f} dT_f/dt \quad (6)$$

where: convective heat transfer coefficient of the surrounding air (h_c), mass of the air fluid, (m_f), specific heat capacity of the working fluid (C_{p_f}) and temperature gradient of the working fluid, $\left(\frac{dT_g}{dt}\right)$.

2.3.2. The Thermal Efficiency of the Parabolic-Trough Collector (η_{th})

According to Sintali *et al.* [13] the Parabolic-trough thermal efficiency is given by:

$$\eta_{th} = 1 - \frac{Q_{losses}}{Q_{input}} \quad (7)$$

where Q_{losses} stands for the total heat losses and Q_{input} stands for the total heat supplied to the receiver.

The hourly Q_{input} to the receiver and total heat losses in the system can be computed by equations (8) and (9) as follows:

$$Q_{input} = [(I_{beam} * R_b) + I_{diff}][WL] \quad (8)$$

The Q_{losses} in the system is taken as the sum of the radiative heat-loss from the surface of the enveloping glass-

cover to the surroundings (q_2), the convective heat loss from the surface of the enveloping glass-cover to the surroundings (q_c) and the convective heat loss from the fluid to the surroundings (q_1). This can be expressed as follows;

$$Q_{losses} = q_{r_2} + q_c + q_1 \quad (9)$$

Where

$$q_{r_2} = \sigma\varepsilon_g A_g (T_g^4 - T_{sky}^4) \quad (10)$$

T_{sky} is the temperature of the sky given by the relation.

$$T_{sky} \approx T_{surr} - 6 \quad (11)$$

T_{surr} = Ambient temperature

$$q_c = A_g h_c (T_g - T_{surr}) \quad (12)$$

where, h_c is the convection heat transfer coefficient of the surrounding air. This coefficient may be correlated as in equation 13:

$$h_c = 3.8V_{wind} + 5.7 \quad (13)$$

V_{wind} = wind velocity.

And

$$q_1 = \frac{2A_c(T_f - T_{surr})}{\frac{1}{h_c} + \frac{1}{h_f}} \quad (14)$$

3. Results and Discussions

3.1. Monthly Mean Global, Beam and Diffuse Radiations

The average monthly mean global, beam and diffuse components of the solar radiations for 10 years (2009-2019) under review is presented in Table 1. MATLAB software employed for the predictions the glass-cover temperature, absorber-tube and the fluid with change in time. This was aimed at ascertaining the effects of tilt angles on the thermal performance of SPTC (TE 38).

3.2. Monthly Average Tilt Angles, Thermal Efficiencies, Glass-Cover, Absorber-Tube and Working Fluid Temperatures

Table 2 presents the monthly average predicted tilt angles, glass-cover temperatures, absorber-tube, the working fluid and the computed average monthly thermal efficiencies of the collector.

Table 1. Monthly Average Global, Beam and Diffuse Solar Radiations in Bauchi for 10 years.

Month	Global Radiation (W/m ²)	Beam Radiation (W/m ²)	Diffuse Radiation (W/m ²)
January	657	403	254
February	712	440	272
March	854	579	275
April	809	574	235
May	753	485	268
June	689	421	268
July	484	293	191
August	399	225	174
September	426	231	195
October	416	247	169
November	453	219	234
December	576	291	285

Table 2. Predicted Monthly Average Tilt Angle, Glass Cover, Absorber Tube, Fluid in °C and Thermal Efficiency for 10 years.

Month	Tilt Angle (°)	Glass Cover Tempt (°C)	Absorber Tube Tempt. (°C)	Fluid Tempt. (°C)	Thermal Efficiency (%)
Jan.	30	49	206	126	61
Feb.	26	57	228	130	63
Mar.	15	58	232	137	65
April	10	58	232	139	68
May	7	59	235	140	73
Jun.	8	57	231	142	73
Jul.	10	50	228	135	70
Aug.	16	48	220	128	68
Sept.	20	49	197	125	64
Oct.	25	48	184	123	62
Nov.	30	48	170	117	60
Dec.	33	47	169	117	60

Figure 3 presents the monthly averages of the absorber tube and fluid temperatures against tilt angles. The graph shows increased in temperatures in both absorber tube and the fluid temperatures as the tilt angle decreased. This is as a result of the seasonal variations in sun positions across the two tropics (tropic of Cancer and Capricorn).

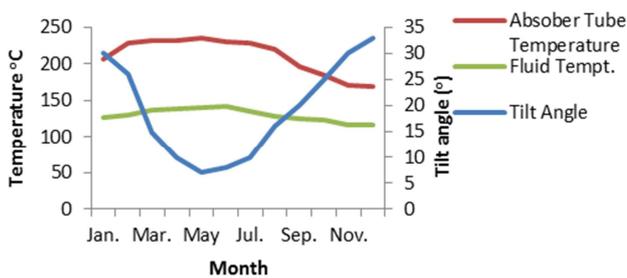


Figure 3. Average monthly Temperatures of the absorber Tube, fluid and Tilt Angle against Month.

During later months (March to August) the sun comes overhead and maximum radiation is attainable on a horizontal surface, which is in accordance with Rahman *et al.*, [2], Ekadewi *et al.* [4] and Skeiker [14]. Also Tian [15] and, Tang and Wu [16] reported that when values of optimal tilt angles are low or even negative which may be happening around April, May, June and July sun is nearer to the equator,

more solar radiation would be received and. Just like in the cases of Rahman *et al.* [2], Kallioğlu *et al* [3] and Can *et al.*, [6], it was also observed in this work that high tilt angles are witnessed during January-February and then in September to December (20°-33°) and these months are having low temperatures of the absorber tube and the fluid (169°C-228°C and 130°C-117°C respectively). Low tilt angle between March to August (7°-16°) and with temperatures of the absorber tube and fluid between 220°C-235°C and 128°C-142°C respectively. The solar radiation intensity is mostly a function of the angle of incidence, at which the Sun's rays strike the Earth's surface or collector aperture area. The incoming insolation from Sun positioned directly overhead or at 90° from horizontal normally strikes the surface of the Earth or the collector at right angles intensely. This period is experienced when the sun is close to the equator and such scenario happens when the optimal tilt angle is close to the latitude of the location. However, for Sun positioned at 45° above the horizon, the incoming insolation strikes the Earth's surface at an angle. This implies that more adjustment of the tilt angle is require for aligning the solar beam radiation to be at right angle to the collector aperture area.

Other parameters that improve the performance of the collector are as a results of high transmissivity of the glass cover, which permits direct solar radiation to pass through it,

the high thermal conductivity of copper coupled with small tube thickness that offer low thermal resistance. The copper tube was coated with emulsion black paint that has low emittance high absorption ability of the incident solar irradiance and low reflectivity. The absorber tube was covered concentrically with an enveloping glass cover made of Pyrex glass tube of equal length and the annular gap of the receiver being evacuated; thus, reduced the convective heat losses between the absorber tube and the glass cover, thereby making the tube temperature to build up progressively.

The thermal efficiency of the parabolic trough collector was observed to increase as the tilt angles of the collector decreases i.e. between March-August as shown in Figure 4. The variations of the thermal efficiencies and tilt angles against months indicated that the tilt angle is inversely proportional to the thermal efficiency of the collector. This was as a result of increase in the incidence angles due to changing the positions of the tilt angles to focus the collector aperture area towards the beam radiations at all times. Maximum thermal efficiency of 73% was obtained at the least optimal tilt angles (7° - 8°). It was also observed that the thermal efficiency decreases around August-December, due to changes in the meteorological conditions of Bauchi which increases during these periods. Can [6]. reported that optimal tilt angle depend not only on the latitude but also on the weather conditions, which implies that with increase in these weather conditions (i.e. clouds concentrations, aerosol and wind speed) the optimal tilt angle will be difficult to obtain thereby decreasing the performance of the collector

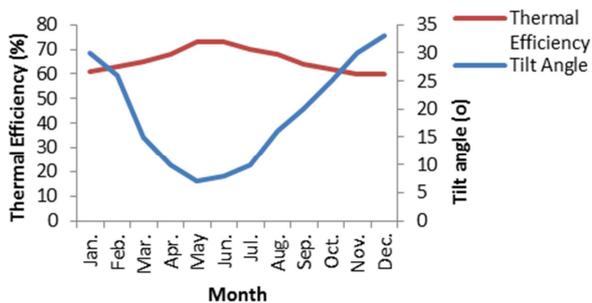


Figure 4. Monthly Thermal Efficiency and Tilt angle against Month.

4. Conclusions

The effects of optimal tilt angles on the thermal performances of a solar parabolic trough collector system was investigated and it was found that as the tilt angles decreases the thermal performances of the collector increases. The least tilt angle that produced the highest temperatures of the absorber tube and the fluid (235°C and 142°C respectively) was 7° in the month of May and the highest value of tilt angle obtained was 33° which produced the list temperatures of both the absorber tube and the fluid (169°C - 117°C respectively). The maximum thermal efficiency attained was 73% at tilt angle range of 7° - 8° . Thus, for efficient solar radiation collections in Bauchi at latitude

$10^{\circ}30'$ North and $10^{\circ}00'$ East, solar parabolic trough collector system should be maintained at optimal tilt angle between 7° - 33° depending upon the seasonal variations.

References

- [1] Abdul Qayoom, J., Al-Khalid, O., Andrew, R. H. R., Saleem, R. S. and Shakeel A. K. (2012): Estimation of Incident Solar Radiation on Tilted Surface by Different Empirical Model, *International Journal of Scientific and Research Publications*, 2 (12).
- [2] Rahman, M. M., Shareef, S., Rahman, R. and Choudhury, M. G. M. (2000): Computation of Solar Radiation Tilt Factor and Optimum Tilt Angle for Bangladesh: *India Journal of Radio and Space Physics*, 29 (37-40).
- [3] Kallioğlu, M. A., Durmuş, A., Karakaya, H. and Yılmaz, A. (2019): Empirical calculation of the optimal tilt angle for solar collectors in northern hemisphere, *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*. <https://doi.org/10.1080/15567036.2019.1663315>.
- [4] Ekdewi, A. H., Ichsanía, D. and Prabowoa (2013): *The optimal tilt angle of a solar collector*: International Conference on Sustainable Energy Engineering and Application, *Energy Procedia Elsevier* (32) 166-175.
- [5] Mark, Z. J. and Vijaysinh, J. (2018): World estimates of PV optimal tilt angles and ratios of sunlight incident upon tilted and tracked PV panels relative to horizontal panels; *Solar Energy* 169 (55-66).
- [6] Can, E., Evrendilek, F. and Kulcu, R. (2008): Modeling Station-Temporal Dynamics of Optimum Tilt Angles for Solar Collectors in Turkey. *Sensors*; (8): 2913-2931.
- [7] Moghadam, H., Tabrizi, F. F. and Sharak, A. Z. (2011): Optimization of solar flat collector inclination. *Desalination* 265 (1-3): 107-11. doi: 10.1016/j.desal.2010.07.039.
- [8] Benghanem, M. (2011): Optimization of tilt angle for solar panel: Case study for Madinah, Saudi Arabia. *Applied Energy* 88 (4) 1427-1433. doi: 10.1016/j.apenergy.2010.10.001.
- [9] Beringer, S., Schilke, H., Lohse, I. and Seckmeyer, G. (2011): Case study showing that the tilt angle of photovoltaic plants is nearly irrelevant. *Solar Energy*, 85 (3) 470-76 doi: 10.1016/j.solener.2010.12.014.
- [10] Nabila I., Razika I. and Abdeldjabbar C. (2017): Best Tilt angle of fixed solar Conversion Systems at M'sila Region (Algeria), *Science Direct Elsevier, Energy Procedia* (118) 63-71.
- [11] Ajao, K. R., Ambali, R. M. and Mahmoud, M. O. (2013): Determination of the Optimal Tilt Angle for Solar Photovoltaic Panel in Ilorin, Nigeria, *Journal of Engineering Science and Technology Review* 6 (1) 87-90.
- [12] Peter, V., Palacka, M., Ďurčanský, P. and Jandačka, J. (2017): *Determination of optimal position of solar trough collector*: TRANSCOM 2017: International scientific conference on sustainable, modern and safe transport Procedia Engineering, Žilina, Slovakia (192) 941-946.
- [13] Sintali, I. S., Egbo, G. and Dandakouta, H. (2004): Energy Equations for Computation of Parabolic-Trough Collector Efficiency Using Solar Position Coordinates; *American Journal of Engineering Research*. 3 (10) 25-33.

- [14] Skeiker, K. (2009): Optimum tilt angle and orientation for solar collectors in Syria. *Energy Conversion and Management* 50 (9) 2439–2448. doi: 10.1016/j.enconman.2009.05.031.
- [15] Tian, P. C. (2008): Study on the Optimal Tilt Angle of Solar Collector According to Different Radiation Types. *International Journal of Applied Science and Engineering*; (6) 151-161.
- [16] Tang, R. and Wu, T. (2004): Optimal Tilt-Angles for Solar Collectors Used in China. *Applied Energy*, (79) 239-248.
- [17] Manoj K. S., Deepak K., Sandeep D. S., Dipesh G. and Yajvender P. V. (2020): Optimal Tilt Angle Determination for PV Panels Using Real time Data Acquisition. *Global Challenge*, Wiley Online Library 4 (8). doi.org/10.1002/gch2.201900109.
- [18] Theophilus F. A., Emmanuel K. A., Emmanuel R. and Lena D. M. (2020): The Optimal Tilt Angle of Solar Collector Using RETScreen 4 in Kumasi Ghana. *International Journal of Energy and Environmental Science* 5 (1) 7-13. doi: 10:11648/j.ijees.2020050112.