Idowu et al. International Journal of Energy and Environmental Engineering 2013, 4:29
http://www.journal-ijeee.com/content/4/1/29

International Journal of
Energy and Environmental Engineering
a SpringerOpen Journal

ORIGINAL RESEARCH **Open Access**

Determination of optimum tilt angles for solar collectors in low-latitude tropical region

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Abstract

This work optimises the collection of solar energy within the period of its availability in order to increase its utilisation and also to enhance performance of heating systems that depend on it through appropriate determination of optimum solar collector tilt angles. Buoyancy-induced flow equation in solar collector pipe was established by continuity, energy and Navier–Stokes equations in cylindrical coordinates. Fundamental solar radiation equations were programmed to determine optimum tilt angles in locations within latitudes 1° and 14°. A set of data recorded from a pryanometer located on latitude 6.45° north of the equator was used to generate average monthly radiation over the latitudes. Graphs obtained from latitude 6° and 13° data were analysed to investigate solar radiation on some tilt angles. The optimum tilt angles for solar heating for periodic tracking of the sun in the region within latitudes 1° and 14° were predicted as $\varnothing + 25°$ for November, December and January; $\varnothing + 15°$ for February, September and October; $\varnothing - 15°$ for August; $\varnothing - 25°$ for May, June and July; and $\varnothing$ for March and April. The results of this work confirmed that solar radiation on tilted surface increases with latitude.

Keywords: Solar energy; Optimization; Buoyancy; Pryanometer; Tilt angle; Tracking; Latitude

Background

Renewable energy obtained from the sun is very important because of the fact that it is free and environment-friendly [1]. The importance of detailed knowledge of solar radiation received from the sun at a site in the design and selection of solar devices cannot be overstated [2]. In order to optimise solar isolation on solar collectors, appropriate method to determine solar tilt angles at any given time is essential to increase the efficiencies of the collectors and that of the devices connected to them [3,4]. The position of the earth relative to the sun changes with time; the change must be monitored adequately in order to increase the amount of energy being received by solar devices [5].

Solar radiation in low-latitude tropical region is not as intensified as that in high latitude tropical region due to cloudiness and high humidity in the former region [2]. For example, Nigeria is located between longitude 3° and 14° east of Greenwich and latitude 4° and 14° north of equator. Ojosu's [6] study on the iso-radiation map of Nigeria showed that the annual average solar radiation along the coastal areas is 3.7 kW/m^2/day, while that in the semi-arid zone is 7.0 kW/m^2/day. Interestingly, Abubakar [7] in an independent study showed that the mean annual average of total solar radiation varies from 3.5 kW/m^2/day in the coastal latitudes to about 7.0 kW/m^2/day along the semi-arid areas in the far north. The emerging conclusion from the past studies was that solar energy must be managed effectively in the southern region of Nigeria.

The magnitude of solar radiation received by a collector is a function of many factors such as location latitude, the declination angle (the angular position of the sun at solar noon with respect to the plane of the equator), tilt angle, the sunrise hour angle and the azimuth angle [8]. According to Benghanem [9], both the orientation and tilt angles have significant effects on the magnitude of the solar radiation reaching the surface of a collector. Many investigations have been carried out to determine the optimum tilt angle for solar collector. Honsberg [10] suggested the following tilt angles: $\varnothing + 15°$ for optimum, $\varnothing - 15°$ for maximum and $\varnothing$ for uniform power production. Some other research works suggested two values for optimum tilt angle, one for summer (rainy season in tropical region) and the other for winter (dry season in tropical region): $\varnothing \pm 8°$ [11,12] and $\varnothing \pm 5°$

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[11,13] ('+' is for winter or dry season, while '–' is for summer or rainy season).

In a solar system where thermal fluid is to be heated, mathematical simulation shows that for maximum flow rate, the solar collector tilt angle is 90° [14]. This specification is not suitable for solar collector, either in low or high latitude region for maximum solar energy collection. Therefore, the required optimum tilt angle of the solar collector should be less than 90°.

A lot of awareness is ongoing worldwide on solar energy utilisation. This research study determines appropriate periodic optimum tilt angles for solar collectors in different locations at different days of the year using Nigeria as a case study.

Fundamentals of solar radiation on earth surface

When solar rays hit a flat surface at an oblique angle, the rays are more spread out [5]. This means, the power of the beam is being spread out over a larger area. Figure 1 shows the relationship between radiation on horizontal surface and that on tilted surface. The ratio of normal radiation on tilted surface (H_T) to that on horizontal surface (H) is given in terms of θ_z (the angle between the beam from the sun and vertical), θ_T and H_n as shown below [15]:

$$R_b = \frac{H_T}{H} = \frac{H_n \cos\theta_T}{H_n \cos\theta_Z} \tag{1}$$

$$\frac{\cos\theta_T}{\cos\theta_Z} = \frac{\cos(\phi - s)\cos(\delta)\cos(\omega) + \sin(\phi - s)\sin(\delta)}{\sin(\delta)\sin(\phi) + \cos(\delta)\cos(\phi)\cos(\omega)} \tag{2}$$

$$\delta = 23.45 \sin\left(\frac{360}{365}(284 + d)\right). \tag{3}$$

Maximum power into the solar collector occurs when the surface is normal to the incident solar radiation; however, it is not always possible with fixed solar collector since the relative position of the earth to the sun varies [10]. Outside the earth's atmosphere, at any given point in space, the energy given off by the sun (insolation) is nearly constant. On earth, however, that situation changes as a result of earth rotation about its axis, change in earth position in space as indicated in Figure 2 and the earth atmosphere which includes gases, clouds and dust [5].

Fundamentals of induced thermo-siphoned flow through circular pipes

For simplicity without compromising the usefulness of the results, steady flow analysis can be adopted to determine the fluid flow regimes [20]. The three fundamental steady flow equations that govern the flow of thermal fluid in solar collector pipes are continuity, momentum and energy equations.

The continuity equation is

$$\frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} = 0. \tag{4}$$

Navier–Stokes equation (momentum equation) for steady flow is

$$\rho \frac{D}{Dt} v = -\nabla p + \mu \nabla^2 + \rho g. \tag{5}$$

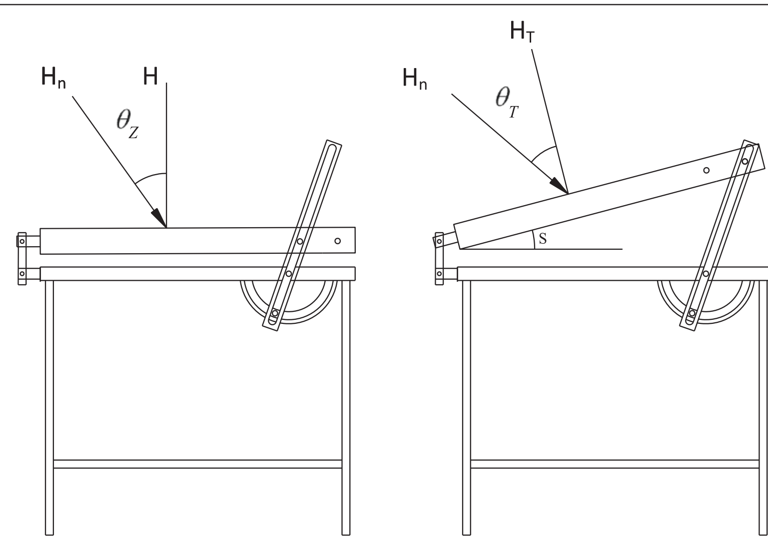

Figure 1 Radiation on horizontal and tilted surfaces.

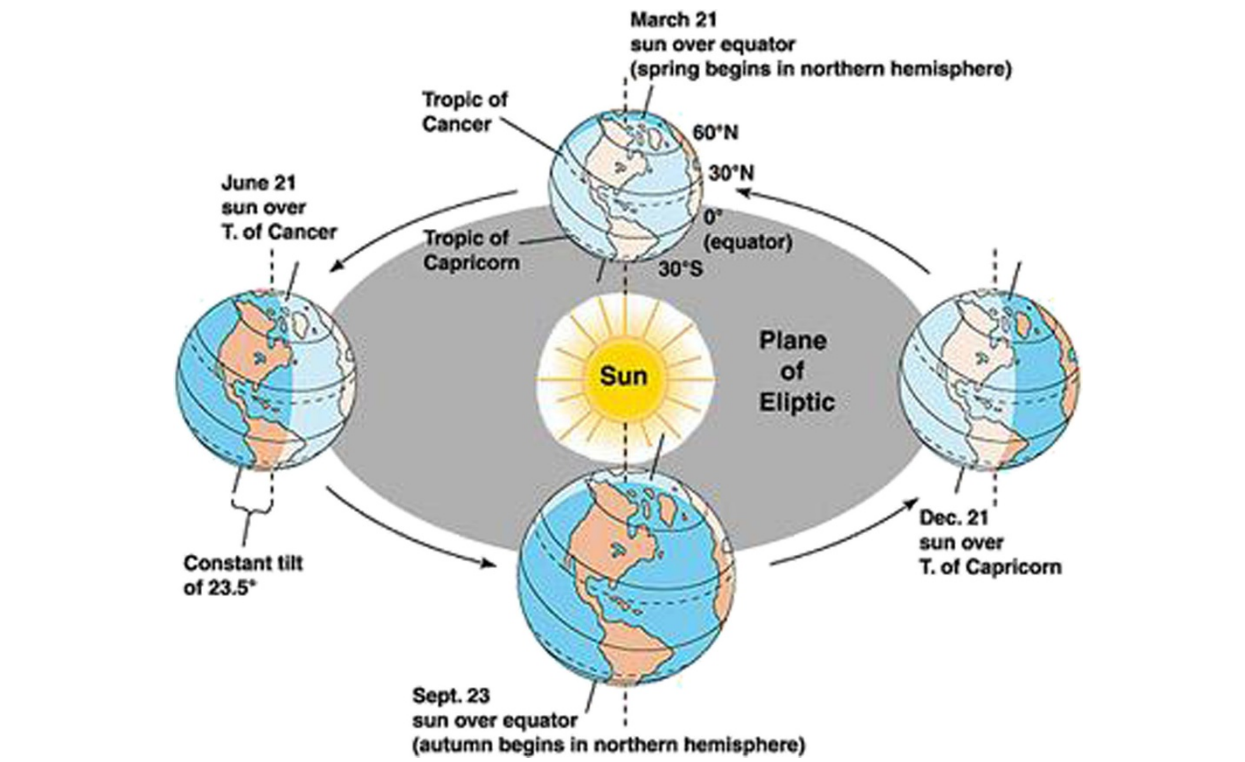

Figure 2 The positions of the earth at different seasons of the year [16].

Below is the modified Navier–Stokes equation in cylindrical coordinate:

$$\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial v}\right)\rho=-\frac{\partial p}{\partial x}+\frac{1}{r}\frac{\partial}{\partial r}\left(\mu r\frac{\partial u}{\partial r}\right)-\rho g. \qquad (6)$$

Energy equation for temperature distribution analysis is presented below:

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial r}=\frac{k}{\rho c_p}\left(\frac{\partial^2 T}{\partial r^2}+\left(\frac{1}{r}\frac{\partial T}{\partial r}\right)+\left(\frac{\partial^2 T}{\partial x^2}\right)\right). \qquad (7)$$

The following assumptions prevailed [14]:

1. Fluid properties are independent of temperature, i.e. μ, c_p, β and k are constants.
2. The Boussinesq approximation characterizes the buoyancy effects.
3. The flow is fully developed, $\frac{\partial u}{\partial x}=0$.

The momentum equation model for inclined pipe flow is shown in Figure 3.

$$\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial v}\right)\rho=-\frac{\partial p}{\partial x}+\frac{1}{r}\frac{\partial}{\partial r}\left(\mu r\frac{\partial u}{\partial r}\right)-\rho g\sin\theta. \qquad (8)$$

Equation (8) can be simplified using Boussinesq approximation for free convection. By putting the assumption (3) above into consideration and by assuming that radial flow equals zero (v = 0)

$$-\frac{\partial p}{\partial x}+\frac{1}{r}\frac{\partial}{\partial r}\left(\mu r\frac{\partial u}{\partial r}\right)-\rho g\sin\theta=0. \qquad (9)$$

Volumetric coefficient of thermal expansion is expressed through this equation: $\beta=-\frac{1}{\rho}\left(\frac{\partial p}{\partial T}\right)_p$

$$\rho_\infty-\ \rho=\rho\beta(T-T_\infty) \qquad (10)$$

For incompressible liquids, the term $\rho\beta$ is nearly constant. This approximation is good for gravity-induced flow over vertical surfaces with negligible temperature variation of T_∞ with x. It should be noted that Equation

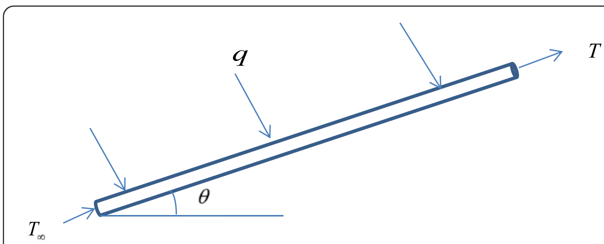

Figure 3 Inclined pipe showing thermal fluid and energy flows.

(10) should not be applied if the dependence between density and temperature is nonlinear in the temperature range of interest [17].

Momentum (9) was integrated to generate

$$u(r) = -\frac{R^2}{4\mu}\left(\frac{dp}{dx} + \rho g \sin\theta\right)\left(1 - \frac{r^2}{R^2}\right) \tag{11}$$

$$\bar{u} = \frac{2}{R}\int_0^R u(r) r dr \tag{12}$$

$$\bar{u} = \frac{(\Delta p - \rho g L \sin\theta) D^2}{32\mu L}. \tag{13}$$

By finding the average velocity of the flow in the pipe based on Equation (12), hence, Equation (13) is produced. The pressure-gradient term in the momentum equation is due to the hydrostatic pressure field outside the boundary layer [17], with

$$\frac{\Delta p}{L} = \rho_\infty g \sin\theta \tag{14}$$

By substituting, Equation (14) in (13),

$$\bar{u} = \frac{(\rho_\infty - \rho) g \sin\theta D^2}{32\mu}. \tag{15}$$

Furthermore, by substituting Equation (10) in Equation (15),

$$\bar{u} = \frac{(T - T_\infty)\beta\rho g \sin\theta D^2}{32\mu}. \tag{16}$$

Simplifying the energy balance equation for the pipe line under steady state condition yields

$$\frac{q\pi DL}{\dot{m}} = c_p(T - T_\infty) \tag{17}$$

$$\mathrm{Pr} = \frac{\mu c_p}{k}. \tag{18}$$

By eliminating $T - T_\infty$ in Equation (16) using Equation (17) and by rational mathematical manipulation using Equation (18),

$$\bar{u} = \frac{q\pi\beta\rho g \sin\theta D^3}{32\, \dot{m}\cdot \mathrm{Pr} k\cdot}, \tag{19}$$

given that modified Grashof number is $\mathrm{Gr}^* = \frac{q\beta g D^4}{k\nu^2}$ [14] and $\dot{m} = \frac{\pi}{4}\rho\bar{u}D^2$.

Equations (20) and (21) are produced from Equation (19) by substituting the relevant dimensionless parameters:

$$\mathrm{Re} = 0.354\left(\frac{\mathrm{Gr}^* H_\mathrm{p}}{\mathrm{Pr} D}\right)^{0.5}, \tag{20}$$

where $H_p = L\sin\theta$

$$\dot{m} = 0.28\left(\frac{\mu^2 \mathrm{Gr}^* D H_\mathrm{p}}{\mathrm{Pr}}\right)^{0.5}. \tag{21}$$

From Equation (21), it can be deduced that the fluid mass flow rate increases as the collector tilt angle increases; the maximum mass flow rate occurs at θ = 90° for any given length of the pipe. It is obvious from Equation (21) that Prandlt number $\left(\mathrm{Pr} = \frac{\mu c_p}{k}\right)$ plays an important role in the determination of magnitude of thermal fluid flow rate induced by buoyancy. The following deductions about thermal fluid used in solar collector are valid:

1. Highly viscous thermal fluid will reduce heat transfer in the solar collector.
2. Thermal fluid with low specific heat capacity is required for effective heat transfer from the solar collector.
3. Thermal fluid with relatively high thermal conductivity is required for effective heat transfer from the solar collector.

Methods

A computer program was written to investigate suitability of water or methanol as thermal fluid for heat transfer in solar collector using Equations (20) and (21) above. The pipe length used for the simulation was 700 mm, while the pipes nominal diameters used were 12 and 20 mm, respectively. The simulation was carried out with solar radiation ranging between 0 and 1,000 W/m^2, while the tilt angle of the collector was 30°. Methanol and water at average temperature (70°C) were used as thermal fluids in succession. The graphs in Figure 3 obtained from the simulation showed that the induced

Table 1 Measured solar radiation intensity for the simulation of collector tilt angle at different latitudes

Time	Solar radiation intensity (H/W/m^2)
7:00 am	62
8:00 am	105
9:00 am	200
10:00 am	450
11:00 am	330
12:00 noon	600
1:00 pm	800
2:00pm	960
3:00 pm	575
4:00 pm	422
5:00 pm	205

Table 2 Simulated solar radiation intensity with collector tilt angle equals to location latitude plus 25° (∅ + 25)

Latitude	January	February	March	April	May	June	July	August	September	October	November	December	Tilt angle
1	478.5873	443.5266	398.442	349.9231	311.0312	291.8618	301.7392	336.0522	382.0572	430.7677	469.9777	489.2786	26
2	482.7909	446.0119	398.9691	348.8276	308.9313	289.3829	299.4431	334.559	381.9966	432.6307	473.7505	494.0414	27
3	487.2193	448.664	399.6209	347.8456	306.9529	287.3026	297.2718	333.1809	382.0538	434.6443	477.7315	499.0516	28
4	491.8814	451.4872	400.3985	346.9755	305.0926	284.8063	295.2213	331.9158	382.2286	436.8119	481.929	504.3197	29
5	496.787	454.4868	401.303	346.2159	303.3468	282.6998	293.2879	330.7615	382.5215	439.1371	486.3511	509.8574	30
6	501.9465	457.668	402.336	345.5657	301.7129	280.7093	291.4682	329.716	382.9329	441.6239	491.0069	515.677	31
7	507.3711	461.0368	403.499	345.0237	300.1877	278.8309	289.7589	328.7779	383.4633	444.2767	495.9061	521.792	32
8	513.0729	464.5995	404.7939	344.5892	298.7689	277.0615	288.157	327.9455	384.1138	447.10002	501.0592	528.2167	33
9	519.065	468.3627	406.2229	344.2615	297.454	275.3977	286.6599	327.2175	384.8851	450.0995	506.4773	534.9667	34
10	525.3613	472.334	407.7882	344.0401	296.2411	273.8369	285.2649	326.5929	385.7788	453.28	512.1727	542.0591	35
11	531.9771	476.5211	409.4925	343.9245	295.1278	272.3762	283.9698	326.0705	386.7959	456.6475	518.1583	549.5117	36
12	538.9288	480.9323	411.3385	343.9149	294.1125	271.0132	282.7724	325.6497	387.9384	460.2086	524.4482	557.3445	37
13	546.2339	485.577	413.3294	344.0109	293.1935	269.7456	281.6707	325.3297	389.2078	463.9699	531.0576	565.5787	38
14	553.9119	490.4648	415.4686	344.2127	292.3695	268.5713	280.6629	325.1101	390.6064	467.939	538.003	574.2377	39

Table 3 Simulated solar radiation intensity with collector tilt angle equals to location latitude minus 25° (∅ − 25)

Latitude	January	February	March	April	May	June	July	August	September	October	November	December	Tilt angle
1	307.0781	337.8821	381.4402	425.6233	462.5434	479.495	471.165	439.328	395.808	351.447	314.2318	297.9407	−24
2	309.7679	339.7551	381.9106	424.2598	459.4031	475.4218	467.5694	437.3463	395.7123	352.9392	316.743	300.8405	−23
3	312.6017	341.7543	382.5003	423.0346	456.444	471.5599	464.469	435.5155	395.7385	354.5535	319.3932	303.8908	−22
4	315.5853	343.8835	383.2101	421.9459	453.6607	467.9017	460.9576	433.8328	395.886	356.2929	322.1875	307.0983	−21
5	318.7247	346.1465	384.041	420.9919	451.0485	464.4404	457.9293	432.2953	396.1569	358.1604	325.1318	310.4699	−20
6	322.0267	348.5473	384.9947	420.171	448.6026	461.1694	455.0787	430.9006	396.5497	360.1591	328.2318	314.0131	−19
7	325.4985	351.0902	386.0723	419.4821	446.319	458.0829	452.4006	429.6464	397.0658	362.2924	331.494	317.7362	−18
8	329.1476	353.7802	387.2758	418.924	444.1937	455.1753	449.8906	428.5307	397.7059	364.5642	334.9254	321.6478	−17
9	332.9827	356.6221	388.607	418.4958	442.2233	452.4415	447.5442	427.5517	398.4708	366.9785	338.5334	325.7575	−16
10	337.0125	359.6217	390.0681	418.197	440.4045	449.8766	445.3576	426.708	399.3621	369.5397	342.3261	330.0756	−15
11	341.2467	362.7847	391.6615	418.0269	438.7343	447.4763	443.3268	425.9981	400.381	372.2525	346.3122	334.6131	−14
12	345.696	366.1176	393.3899	417.9854	437.2099	445.2366	441.4489	425.421	401.5292	375.122	350.5009	339.382	−13
13	350.3714	369.627	395.2563	418.0725	435.8289	443.1535	439.7205	424.9758	402.8083	378.1538	354.9024	344.3953	−12
14	355.2853	373.3206	397.2636	418.2881	434.5893	441.2239	438.1389	424.6617	404.2208	381.3537	359.5277	349.6671	−11

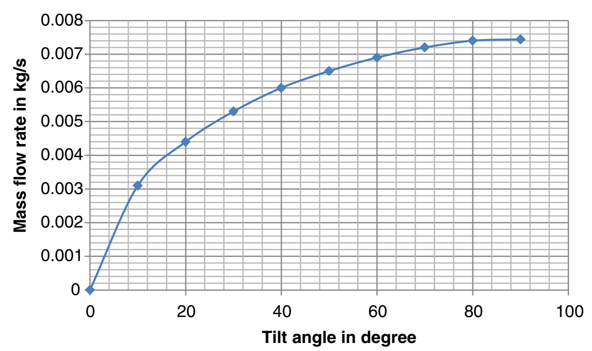

Figure 4 Measured solar radiation intensity in W/m^2 against hour of the day.

flow rates in the pipes increase with solar radiation intensity.

A pyranometer was used to measure horizontal radiation intensity at latitude 6.45° on a clear and sunny day at an hour interval from 7:00 am to 5:00 pm. The measurements are as shown in Table 1, and a bar chart plotted from them is shown in Figure 4. The assumption made in this study is that horizontal solar radiation received by similar solar collectors located at different latitudes within 1.0° and 14.0° is the same throughout the year. In other words, the measured data was assumed hypothetically for the different locations within latitude 1.0° and 14.0° throughout the year. The fundamental objective of this assumption is to investigate the resultant effect of the latitudes at the various locations, days of the year and tilt angles on the quantity of heat energy collected by the solar collectors. However, it should be noted that solar radiation measured at different latitudes are affected by humidity and other environmental conditions. The effects of these conditions are not considered in this paper to reduce avoidable complexities. The results from this analysis are expected to provide good platforms to predict the influence of the unconsidered factors. The appropriate tilt angles at different latitudes for different sessions of the year based on the above assumption were determined from a program developed from Equations (2) and (3) using C sharp software in Microsoft.net studio. The data simulated between latitudes 1° and 14° north of the equator are as shown in Tables 2 and 3.

Results and discussions

The graphs in Figure 5 show that methanol is better than water as thermal fluid for heat transfer in solar collector due to its low specific heat capacity and low viscosity. However, water is preferred to methanol where heat energy storage is required due to its high specific heat capacity. It is also observed that the size of the pipe, radiation intensity, tilt angle and properties of the thermal fluid determine the flow regime. The graph in Figure 6 shows the effect of solar collector tilting on flow rates of methanol in a 20-mm nominal diameter pipe under average solar intensity of 500 W/m^2. It can be observed that tilting increases the flow rate of the thermal fluid in the solar collector. In the flow rate Equation (21) above, it was observed that maximum flow rate is produced when the tilt angle is 90°; this angle is not appropriate for maximum solar radiation collection.

Several tilt angles for solar collectors as recommended from past and recent literatures were tested with the program developed from Equations (2) and (3). Tables 2 and 3 contain the data simulated for locations within latitudes 1° and 14° . The solar collector tilt angle in each location in Table 2 is equal to the location latitude ($\varnothing$) plus 25°, while that of each location in Table 3 is equal to the location latitude ($\varnothing$) minus 25°. It is important to note that a positive tilt angle in the northern hemisphere means that the collector is tilted facing south, while negative tilt angle in the northern hemisphere means that the collector is tilted facing north [1,18,19]. Figures 7 and 8 displayed the graphs of average monthly solar radiation against different months of the year for regions

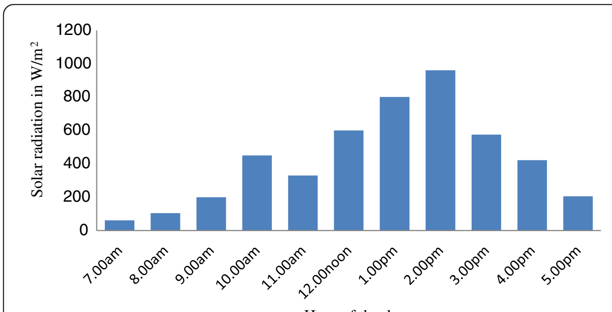

Figure 5 Flow regime in 30° tilted pipeline in solar collector.

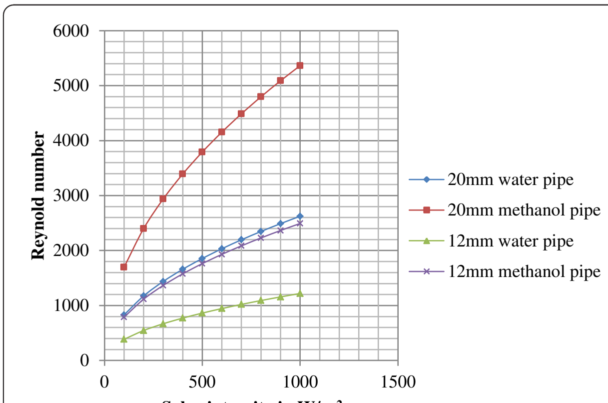

Figure 6 Methanol flow rate variation with tilt angles under 500 W/m^2 average solar intensity.

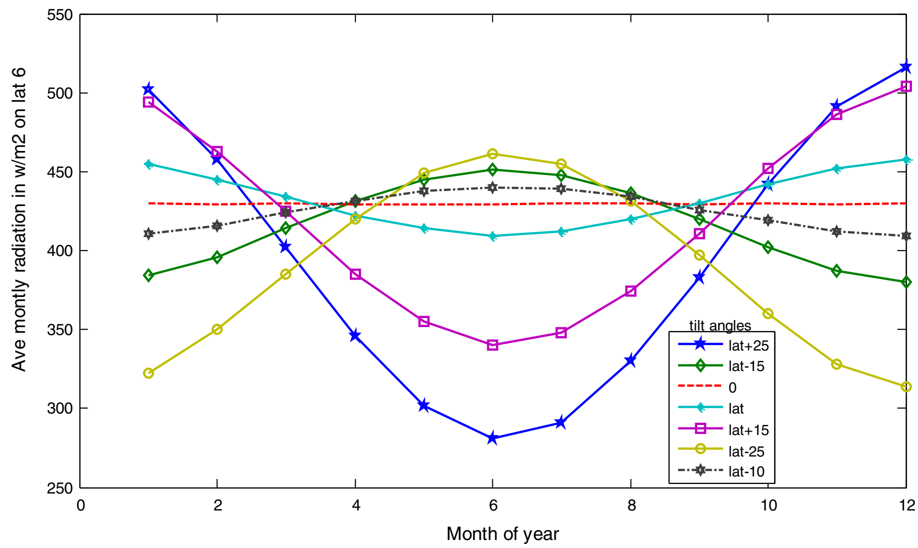

Figure 7 Average monthly solar intensity on tilted solar collector on location latitude 6°.

located on latitude 6° and 13°. The graphs show the different tilt angles investigated.

The average monthly solar radiation on horizontal solar collector surface for this simulation is 430 W/m^2. It is indicated by dotted line in Figure 7 and Figure 8. Many publications on optimum tilt angle for solar collector favoured ∅ + 15° and ∅ + 10°. The inclusion of Tables 2 and 3 was deliberate in order to show data distributions on latitudes from 1° to 14° for tilt angles ∅ + 25° and ∅ – 25°. From Figures 7 and 8, it can be inferred approximately that from November to mid of January, the tilt angle obtained from ∅ + 25° produces more solar radiation intensity in the solar collector than tilt angles ∅ + 15° and ∅ + 10°. Close observation further revealed that tilt angle ∅ + 15° has better performance from middle of January to March and from middle of September to middle of October. The figures also show that appropriate tilt angle for the first 2 weeks of April and the last 2 weeks of July is ∅ – 15°. After the first 2 weeks of April to the last 2 weeks of July, appropriate tilt angle for maximum solar radiation in the solar collector is ∅ – 25°. About the last week of March and middle of August, none of the tilt angles investigated produced radiation above the average radiation on horizontal solar collector. However, to sustain

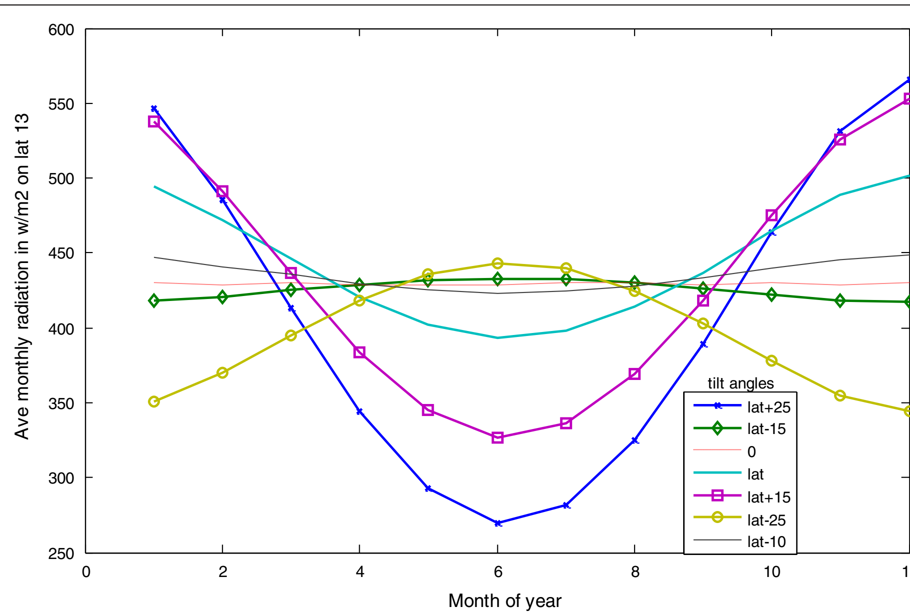

Figure 8 Average monthly solar intensity on tilted solar collector on location latitude 13°.

Table 4 Recommended tilt angles for optimum radiation collection for different months of the year

January	February	March	April	May	June	July	August	September	October	November	December
∅ + 25	∅ + 15	∅	∅	∅ − 25	∅ − 25	∅ − 25	∅ − 15	∅ + 15	∅ + 15	∅ + 25	∅ + 25

thermal fluid flow in the collector, the tilt angle recommended is the solar collector location latitude.

The above recommendations on tilting are ideal for system, the efficiency of which depends on instantaneous thermal energy received rather than average thermal energy received over a period of time. Solar collector with large surface area may be difficult to tilt as recommended; in that respect, such collector may be tilted permanently to its location latitude. An important observation from Figures 7 and 8 above is that when solar collector is tilted to a permanent angle without periodical tilting to track the sun position at certain months of the year, the received solar radiation on tilted surface is less than that on horizontal surface. Under this condition, solar collector tilting is counter-productive.

The thermo-siphon mass flow rate equation in solar collector for fluid heating based on periodic tilting at different latitudes is given by

$$\dot{m} = 0.28\left(\frac{\mu^2 Gr^* DL \sin(\phi + c)}{\Pr}\right)^{0.5}. \qquad (22)$$

Observations from the Figures 7 and 8 are summarised in Table 4.

The chart shown in Figure 9 above was produced from Figures 7 and 8. It can be used to estimate appropriate tilt angles of solar collectors at locations having different latitudes.

Conclusion

The induced flow generated from tilted solar collector has been established for effective monitoring of solar collector performance. This work has successfully investigated recommendations from past research activities on solar collector tilting for enhanced performances with simplified approach, as far as data collection for analyses is concerned. The results obtained can be summarised as follows: for periodic tracking of solar collector throughout the year, the following are the recommended tilt angles: ∅ + 25° for November, December and January; ∅ + 15° for February, September and October; ∅ – 15° for August; ∅ – 25^0 for May, June and July; and ∅ for March and April. These recommendations are appropriate for solar collectors with tilting devices. The tilt angles ∅ + 25° and ∅ – 25° are not common in the literature; however, the results showed that they are relevant for periodic tracking of solar collector even though they are for a short period. It is further showed that solar radiation on tilted surface increases with latitude. This method of analysis demonstrated efficient management of time, energy and capital investment required in data collection to analyse appropriate tilt angles of solar collectors in comparison with past works done in this area. Finally, this paper has been able to provide formula for estimating

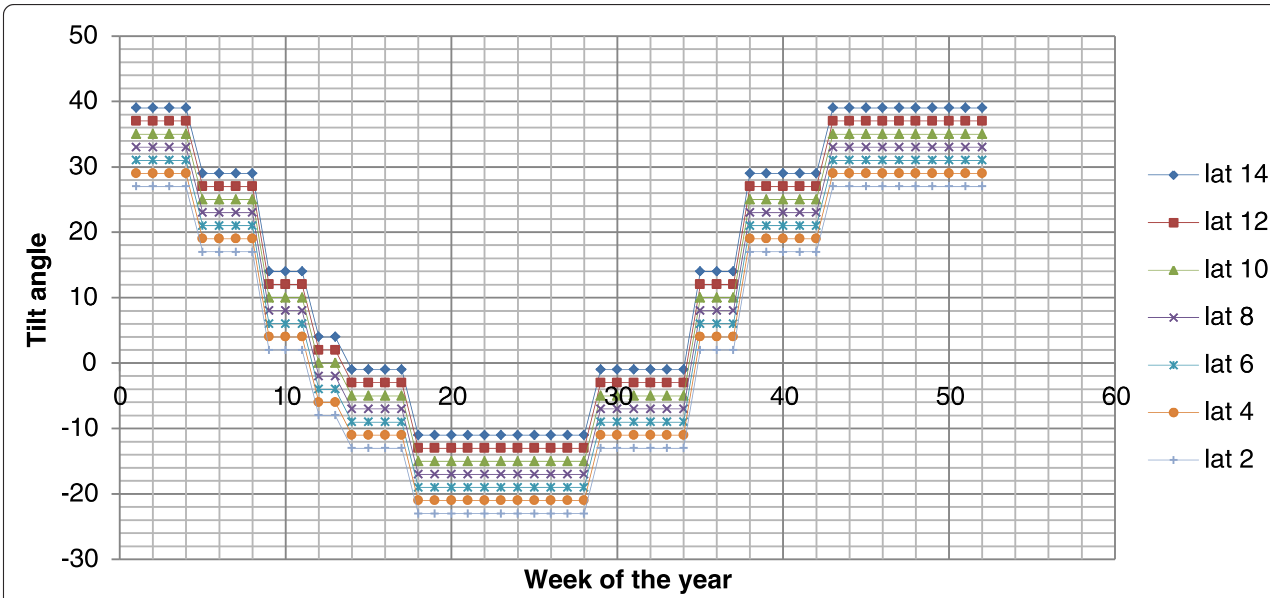

Figure 9 Chart for estimating weekly tilting for optimum solar radiation collection.

thermo-siphon-induced flow rate in solar collector, and it has established the need to incorporate tilting mechanisms in solar collectors for better thermal efficiency.

Abbreviations

B: Volumetric coefficient of thermal expansion; *δ*: Declination; *Ø*: Latitude (north positive); *M*: Dynamic viscosity of thermal fluid; *Ω*: Hour angle, solar noon being zero, and each hour equals to 150 of longitude with morning positive and afternoon negative; *P*: Fluid density in kg/m^3; *θ*: Thermal fluid tilt angle in radian; θ_T: Angle between the beam from the sun and the vertical on the tilted plane; θ_Z: Zenith angle; *c*: Constant (values 0 or ±15 or ±25, etc.); c_p: Specific heat capacity of thermal fluid at constant pressure KJ/kgk; *d*: Number of days starting from 1 January to the given date; *g*: Acceleration due to gravity; Gr^*: Modified Grashof number; *H*: Solar radiation on horizontal surface; H_p: Vertical distance between inlet and exit of the collector pipe; H_T: Solar radiation on tilt surface; *k*: Thermal conductivity of thermal fluid (w/mk); *L*: Pipe length; Lat: Latitude; *m*: Mass flow rate in kg/s; *p*: Fluid pressure in N/m^2; Pr: Prandt number; *q*: Heat flux per unit length (W/m^2); *r/R*: Pipe radius in m; R_b: Ratio of radiation on tilted surface to that of horizontal surface*S*, Angle between the solar collector and the horizontal plane (angle of tilt); *T*: Temperature in Kelvin; T_∞: Temperature at infinity in K; *u/v*: Fluid velocities in m/s; *x/y*: Coordinates in m.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

SIO carried out the preliminary studies, programming and prepared the draft of the manuscript. MOO and IFO both provided technical guide and review of the manuscript. All authors read and approved the final manuscript.

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Acknowledgements

The authors wish to acknowledge the World Bank for initiating STEP-B project in higher institutions of learning in Nigeria. The project provided the pyranometer and computer used for this work. We appreciate people that contributed in one way or the other towards successful completion of this publication.

Received: 7 March 2013 Accepted: 21 June 2013
Published: 14 Aug 2013

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10.1186/2251-6832-4-29
Cite this article as: Idowu et al.: Determination of optimum tilt angles for solar collectors in low-latitude tropical region. *International Journal of Energy and Environmental Engineering* 2013, 4:29