Effect of slope angle and truncation level on heat pipe based Compound Parabolic Collector for Kano, Nigeria

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Presentation overview

1. Introduction and Aims of this work
2. Mathematical modelling of solar radiation in Kano, Nigeria
3. Effects of truncating the collector height on its geometry
4. Effects of truncation on the optical efficiency of the collector – Using ray tracing technique
5. Effects of sun hour angle on the irradiance distribution and intensity
6. Conclusions
1. INTRODUCTION

Major parameters that affect the performance of a solar collector are:
- Geometry
- Solar radiation available
- Collector orientation

Aims of this work is to:

- assessing the solar potentials in Kano
- determine missing radiation data from measured global
- determine the best collector slope angle for Kano
- determine the effects of truncating the height of heat pipe based compound parabolic collector on the geometric parameters and optical performance
1.1 Compound Parabolic Collector (CPC)

- CPCs are non-imaging collectors that accept incoming radiation and concentrate it onto receivers located at the bottom of the collector

**Choice of CPC for this work:**
- Advantages
- Climatic condition of the area
- Economy of the people

**Advantages of CPC**
- Possessing of properties of both flat plate and concentrating collectors
- High optical and quantum efficiencies
- Ease of fabrication and simple support structure
- No need of continuous tracking
- Wide applications: power generation, air conditioning, desalination, refrigeration, cooking, e.t.c.
- More economical compared to other concentrating systems, e.t.c.
2. MATHEMATICAL MODELLING OF SOLAR RADIATION FOR KANO, NIGERIA

Why modelling the radiation?

- Measured radiation obtained from meteorological agency are global radiation values for horizontal surfaces.
- Determination of other radiation components like hemispherical, beam and diffuse on both horizontal and slope surfaces.
- Determination of best collector slope angle.
- Determination of key radiation parameters such as Clearness index, Daylight hours and Incident angle.
2.1 MATHEMATICAL MODELLING OF SOLAR RADIATION FOR KANO, NIGERIA

The model make use of the:

1. Correlations available in literature such as Rabl, 1985, Duffie, 1991 & 2006, and Goswami et. al, 1999

2. Recommended average days for months (mean day)

**Mean day is the day having average extraterrestrial radiation closest to the monthly average (Duffie, 2006).**

<table>
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<th>Month</th>
<th>n for ith Day of Month</th>
<th>Date</th>
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<td>December</td>
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<td>10</td>
<td>344</td>
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2.2 MODELLING RESULTS

Fig. 1 Monthly average Global radiation on horizontal surface

Fig. 2 Predicted monthly average clearness index

Fig. 3 Predicted beam and diffuse radiation on horizontal surfaces

Fig. 4 Monthly average daylight hours
2.3 MODELLING RESULTS (cont.)

Missing radiation components were predicted from the measured data and the results revealed that Kano (12.05°N) has:

i. High solar radiation between 17 MJ/m\(^2\).day to 26.8 MJ/m\(^2\).day

ii. Annual average clearness index of 0.63

iii. Long day throughout the year with annual average daylight hours of 12

iv. Annual average diffuse radiation of 7.59 MJ/m\(^2\).day to collect

v. High beam radiation (annual average of 14.5 MJ/m\(^2\).day)

*The solar radiation falling on collector surface can be maximized by tilting the collector to an angle relative to the horizontal.*
3.4 MODELLING RESULTS (cont.) - Radiation on 6 different slope angles

- Kano, being in the Northern hemisphere, the collector would be tilted towards south

- Six collector slope angles, $\beta$ simulated relative to latitude of Kano, $\phi$ (12.05°N)

Findings:
1. Radiation falling on the collector increases as slope angle increases in the winter months of January, February, March, October, November & December
2. Radiation falling on the collector decrease as slope angle increase in the summer months of April, May, June, July, August & September

Suggested slope options:
1. Biannual adjustment: $\beta = 0$ (April to September) and $\beta = \phi + 15$ (October to March)
2. For Static collector: $\beta = \phi$
4 EFFECTS OF TRUNCATING THE COLLECTOR HEIGHT

Truncation means reducing the large reflector area, because the top portion does not intercept much radiation - Rabl, 1985

Researches in the literature recommends truncation up to 50% of the total height

**Aim:** To find the best truncation level for the heat pipe based compound parabolic collector (HPCPC), study the effects and link it with the collector optical efficiency

![Fig. 6 Full and truncated HPCPC](image)

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**Fig. 7 1 geometry at 5 different truncation levels**

0 % 10 % 30 % 50 % 70%

Geometrically, truncation effects;

i. Collector height
ii. Aperture width
iii. Height to aperture ratio
iv. Concentration ratio
v. Acceptance angle
vi. Average no. of reflection
4.1 Effects of truncation on the collector performance

\( HPCPC_{xRy} = \) Heat pipe based compound parabolic collector with \( x \) acceptance angle and \( y \) receiver radius

*Previous work showed that HPCP60R12.5 offered best optical performance among the geometries simulated, hence it is selected for the investigation of the effect of truncation in this work.*
4.3 Principles of Ray tracing Technique

Fig. 11 law of reflection

Fig. 12 Law of refraction

Fig. 13 Schematic diagram of HPCPC showing rays behaviours

Reflected on the receiver

Lost rays

Incident rays

Lost rays

Reflected on the receiver
4.4 Methodology of Ray tracing Technique using Optisworks

Figure 14  Flow chart of ray tracing procedure

Figure 15 Detector definition

Figure 16 Ray tracing

\[ \eta_{opt} = \frac{\text{Average Power On The Receiver}}{\text{Average Power}} \]
4.5 Effect of truncation on the collector optical efficiency using Ray Tracing Technique

Fig. 17 optical efficiency of HPCPC60R12.5 at different truncation levels
5 Effect of sun position on the irradiance distribution and intensity

Rays at the collector aperture at different sun hour angles

a. Rays at 0° (12 noon)

b. Rays at 45° (9 am or 4pm)

c. Rays at 75° (7am or 6pm)
5.1 Effect of sun position on the irradiance distribution and intensity (cont.)

Rays concentrated at the bottom of the receiver at different sun hour angles

- At 0°

Irradiance at 0°

- At 75°

Irradiance at 75°
7. Conclusion

i. Kano, Nigeria has abundant solar radiation to harness in most times of the year

ii. Kano has significant amount of diffuse radiation to collect, hence collector of wide acceptance angle can be a good option

iii. Biannual adjustment is the best option for a solar collector in the area; the collector can be oriented horizontal (i.e. $\beta = 0$) from April to end of September, then sloped to angle of $27.05^\circ$ (i.e.$\phi + 15^\circ$) from beginning of October to March

iv. But if the collector is to be static throughout the year, then the best slope is $12.05^\circ$ (i.e. $\beta = \phi$)

v. As the truncation level increase the optical efficiency increases but the concentration ratio decreases due to increase in the acceptance angle.

vi. Truncated HPCPC performs better than the full geometry due to increase in acceptance angle, decrease in number of reflection, etc

vii. At noon, 50% truncation increases the optical efficiency by 3.3 % but cause a drop in concentration ratio by 11 % together with 50% material and space savings

viii. At noon, 70% truncation results in increase in optical efficiency of 4% and 25% decrease in the concentration ratio, together with 70% material and space savings

ix. Depending on the input requirement of the collector, the priority between the optical efficiency and the concentration ratio can be judged
THANK YOU

FOR Listening