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Numerical Investigation of Thermal Performances of an Evacuated Tube Solar Collector

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***Abstract*- This research designs a solar evacuated tube collector (ETC) arrangement to meet the low intensity thermal energy requirement. The structure's number of parallel tubes is chosen based on the necessary mass flow rate and pressure drop. The number of arrangements can be coupled in series to get a higher goal temperature. Ten tubes make up the evacuated tube setup used in our investigation. Borosilicate glass makes up the outside tube, while copper plated in black makes up the inside tube. There is a vacuum in the area between the inner and outer tubes. The tilt angles at which the solar radiation strikes the setup are $\beta = \varphi + 15°$, $\beta = \varphi$ and $\beta = \varphi - 15°$, Maximum solar radiation measured at $\beta = \varphi + 15°$ is 6.15 MJ/m^2, while in the same month, it is 3.83 MJ/m^2 at $\beta = \varphi - 15$ and 4.12 MJ/m^2 at $\beta = \varphi$. It is also possible to calculate the maximum useable energy accounting for thermal losses at different times of the year. The maximum values are observed to be the 6.56 kJ/s in the summer (May -June – July), 4.58 kJ/s in the rainy season from the first of September to November, and 3.35 kJ/s in the December.**

***Keywords:* heat removal factor, solar radiation, evacuated tube collector, global solar radiation, Tilt angles**

I. INTRODUCTION

Our natural world is continuously harmed by the production of power from conventional sources like coal, oil, and gas. Carbon monoxide (CO) particles, nitrogen oxides (NOX), sulfur dioxide (SO_2), and carbon dioxide (CO_2) are among the dangerous pollutants that fossil fuels are contributing to. These fuels are not only harming the environment but also running out in the wild. As a result, technology related to renewable energy gained prominence. Due to its abundance in the natural world and environmental friendliness, solar energy is the most dependable renewable energy source among others, including hydro energy, geothermal energy, wind energy, and tidal energy. An hour's worth of solar energy collected by the earth is thought to be equivalent to all of the energy that people use in a year [1-2].Basically, depending on the needs, there are two distinct ways to gather solar energy. Solar energy can be converted into two different forms of energy: thermal energy can be produced using solar collectors or concentrators, and photovoltaic solar cells can be used to convert solar energy directly into electricity [3-4]. In the present study, an evacuated tube collector is used in conjunction with a solar thermal system to harvest solar energy for usage. This field had already seen a number of investigations. Soteris [5] had researched the uses of many kinds of solar thermal collectors. Concentrated collectors were described by Barlev et al. [6]. A tubular evacuated solar collector with rectangular performance characteristics was first introduced by Mahdjuri [7]. In order to transport heat from the absorber to the water tubing, he invented a heat pipe process. An evacuated tube solar collector is a heat-delivering device that is commonly used for thermal power plants, air conditioning, and water heating, among other applications. Because of their superior heat extraction capacity, evacuated solar collectors are the most appealing type of heating. These collectors have a comparatively longer lifespan and are highly dependable and cost-effective. In an evacuated tube solar collector paired with a latent heat storage device, Neeraj and Avdhesh [8] conducted an experimental investigation and comparison of circular fin type headers, where air was taken into consideration as a working fluid. They found that when compared to a standard solar evacuated tube collector, the outlet temperature of a solar air collector with a circular fin and copper coil performed better.

Statement of Problem

The purpose of this study is to develop a solar evacuated tube collector with an outside diameter of 65mm and an interior diameter of 58 mm. The tube is measured to be 2000 mm long. Borosilicate glass is used as the outside glazing, while black coating covers the inner surface of copper tube.

We were curious in the amount of useable energy that solar evacuated tube collectors gather throughout the year for our location, Tripoli, Libya. First, the Liu and Jordan model is used to calculate the solar radiation that will fall on the slanted surface at various tilt angles. It is calculated how much beneficial solar energy a slanted

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surface absorbs. The energy supplied by an evacuated tube solar collector is determined by accounting for losses from the collector through mathematical modelling of the system. The heat transfer process is considered to be stable, the specific heat of the fluid is constant, the solar intensity is constant throughout the collector, and the amount of axial heat transfer is insignificant in order to simplify the analysis.

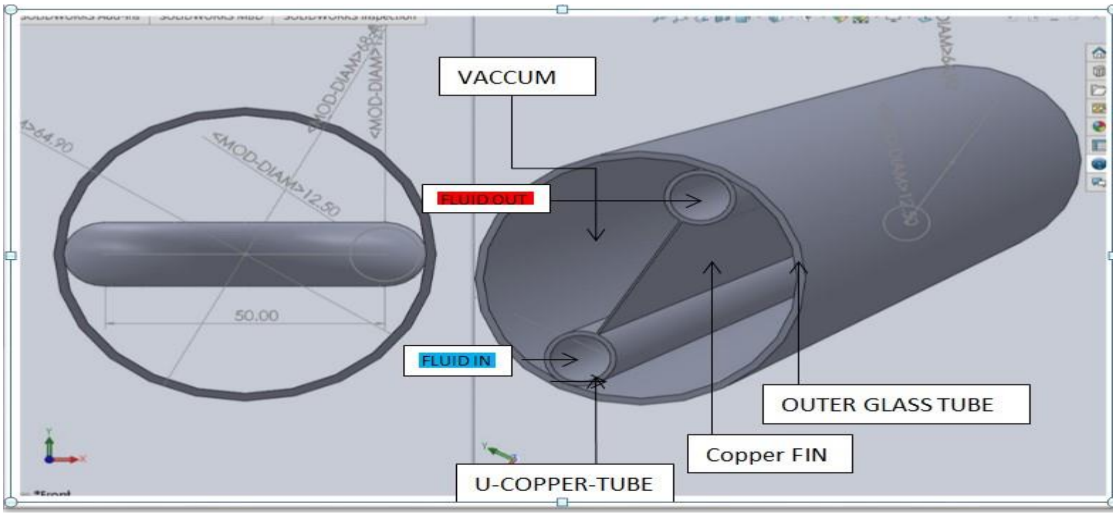

Figure.1 Geometry of Evacuated tube collector

Meteorological Information

The recorded meteorological information for Tripoli, Libya (32.8877° N, 13.1872° E) including wind speed, air temperature, beam, and diffuse sun radiation on a horizontal surface, comes from the Libyan National Meteorological Centre (LNMC).

II. METHODOLOGY

The LIU and JORDAN model [9] is used to estimate the solar energy on a tilted surface. This model gives the following solar radiation on a slanted surface facing south:

$$I_T = R_b I_b + R_d I_d + \rho_g R_g I_g$$

where ρg = 0.2 (ground albedo) and Ib, Id, and Ig are the monthly mean hourly beam, diffuse, and global solar radiation, respectively.

$$R_b = cos\theta / cos\theta z$$

$$R_d = (1 + cos\beta)/2$$

$$R_g = (1 - cos\beta)/2$$

$$cos\theta = cos(\varphi - \beta) * cos\delta * cos\omega + sin(\varphi - \beta) sin\delta$$

$$cos\theta z = cos(\varphi) * cos\delta * cos\omega + sin\,(\varphi) sin\delta$$

Where β represents the tilt angle; φ denotes the latitude of the place; δ signifies the declination angle; and ω indicates the hour angle.

The declination angle and hour angle can be calculated as follows:

δ=23.45 Sin [360365(284+n)]Here n is day of year

Hour angle,

ω = (Solar time − 12) ×15°

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$$\boldsymbol{\delta = 23.45 \sin \left[\frac{360}{365(284+n)}\right] n \text{ is day of year}}$$

$$\boldsymbol{\omega = (solar\ time - 12) * 15^{o}}$$

The mathematical simulation of solar evacuated tube collectors
Solar energy captured by the receiver surface of the ETC arrangement

$$s = (\tau\underline{\alpha})_{av}\boldsymbol{I_T}$$

Let τ represent transmissivity and α represent absorptivity, with the assumption that (τα)av = 0.72.
The effective thermal energy for the concentrating collector can be expressed as:

$$Q_u = F_R A_a [s - A_r A_a U_L (T_i - T_a)]$$

In where A_a is the aperture area and A_r is the receiver (absorber) tube area. heat transfer coefficient overall (U_L); where T_i and T_a The temperature of the inlet and outlet fluid, respectively
The factor of heat transfer

$$F_R = \dot{m} C_p A_r U_L [1 - Exp(-A_r U_L D_F / \dot{m} C_p]$$

Fluid mass flow rate

$$\dot{m} = \rho A v$$

where A stands for the area of inner tube cross-sectional, v stands for mean velocity of working fluid, ρ for working fluid density, C_p for specific heat capacity, and F_R for collection efficiency factor.
Regarding turbulent flow,

$$N_u = 0.027 R_e^{0.8} P_r^{1/3} (\mu/\mu_w{}^{0.14}) = h_{fi} D_i / K$$

Where the Reynolds number can be find from following equation:

$$R_e = \rho v D_i / \mu$$

(K) is the fluid's thermal conductivity; (μ) is the working fluid's viscosity; and (h_{fi}) its convective heat transfer coefficient.
The following formulas can be used to compute the collection efficiency factor:

$$F' = {}^{1}/_{U_L} / 1/U_L + D_o / h_{fi} D_i + \left[\frac{D_o}{2k_c} + in\left(\frac{D_o}{D_i}\right)\right]$$

where (k_c) is the tube material's heat conductivity and (D_i and D_o) are the inside and outside tube dimensions, respectively.

III. RESULT

The Liu and Jordan model has been used to compute the total amount of solar radiation that falls on the slanted surface for tilt angles$\beta = \varphi - 15$, $\beta = \varphi$, and $\beta = \varphi + 15^{o}$for various months of the year in Tripoli. These figures are calculated since 10:00 am to 03:00 pm. In Fig. 2, the average solar radiation at these times is displayed against the month. According to the figure, for every month of the year except August, the tilt angle $\beta = \varphi + 15^{o}$ yields the highest value of solar radiation. According to the graph, the month of May is when sun radiation peaks.

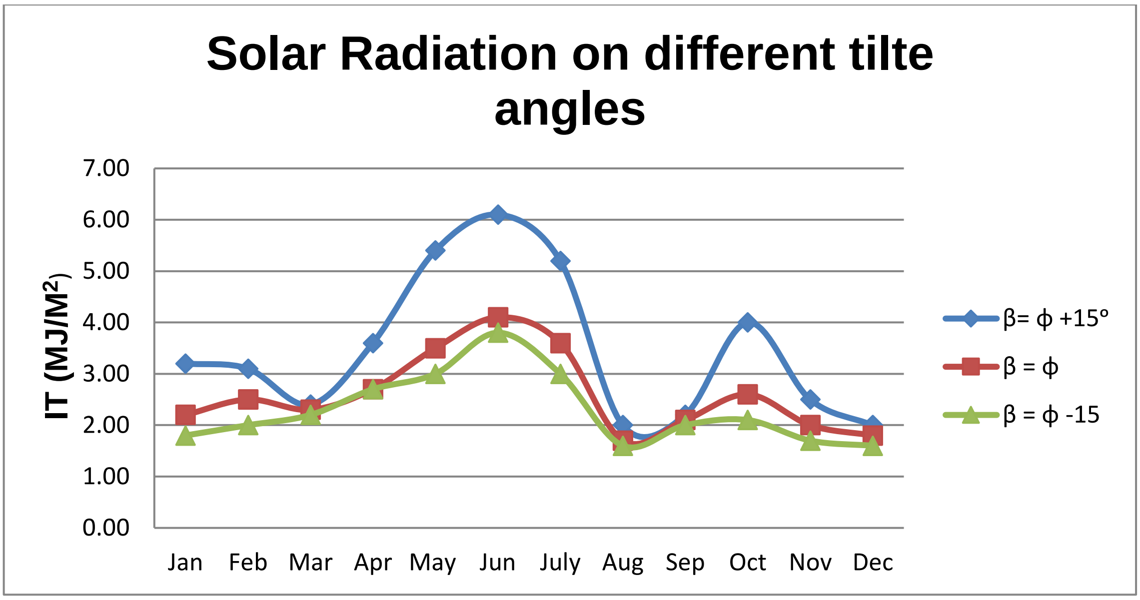

Figure. 2 Average solar radiation received by the ETC configuration at different tilt angles over the duration of a day in various months

The usable energy has been determined for various months of the year between 09:30 am and 04:30 pm, taking into account the losses in the evacuated tube collector. Fig.3. illustrates the average usable energy obtained across several months. The figure displays a similar curving trend. This demonstrates that, when collector losses are taken into account, the useable energy that the collector obtains is nearly proportional to the amount of solar radiation that falls on the surface.

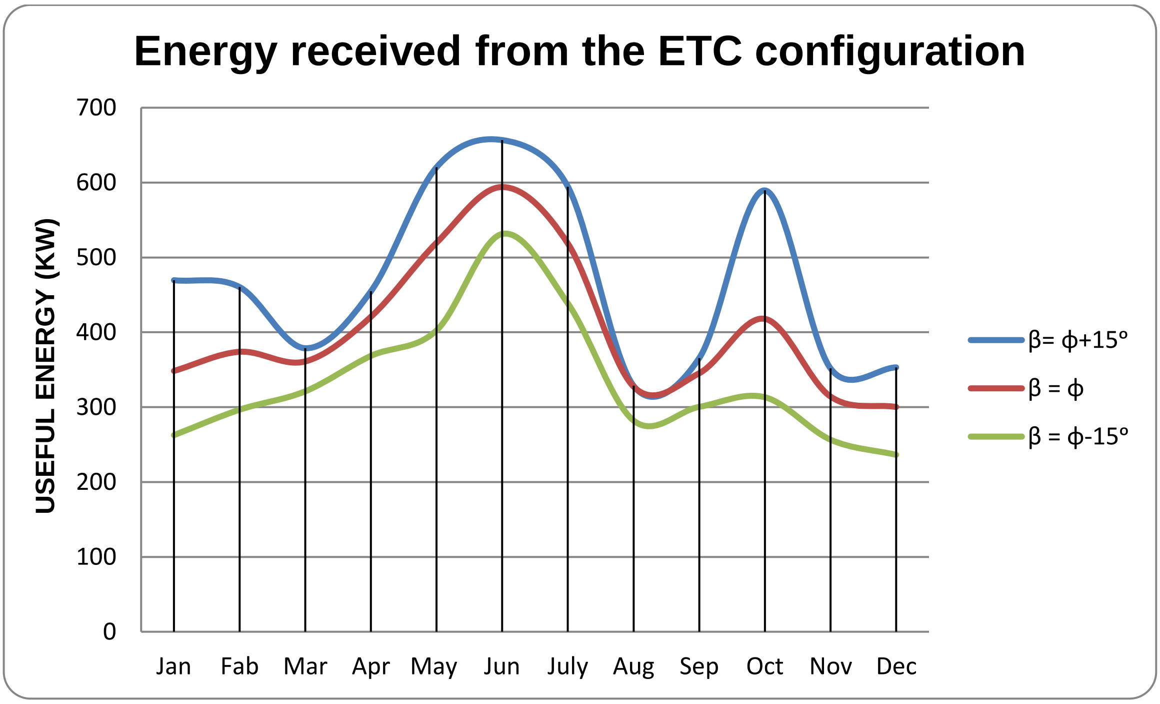

Figure.3 ETC configuration generated useful energy at tilt angles $\beta = \varphi + 15^{o}, \beta = \varphi$, and $\beta = \varphi - 15^{o}$ over the course of a day in various months.

Table. 1, 2 and 3 in the various months of the year, the ETC arrangement generated useful energy from 10:00 am to 15:00 pm tilt angle $\beta = \varphi + 15^{o}, \beta = \varphi, and\ \beta = \varphi - 15^{o}$

International Journal of Engineering Research & Technology (IJERT)
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Table.1: display the useful energy with tilt angle $\beta = \varphi + 15^{o}$ in during the day in different months.

Angle $\beta = \varphi + 15^{o}$												
Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Months
												Time
469.33	470.13	385.99	468.12	757.10	620.72	587.87	323.67	369.84	604.81	363.22	358.47	10:00
504.47	495.79	416.03	501.20	765.43	625.37	617.91	343.70	398.48	632.28	392.72	397.12	11:00
507.34	502.68	414.23	495.74	770.28	700.47	616.95	337.04	391.50	627.52	393.84	395.80	12:00
528.02	515.44	425.52	505.93	765.44	726.21	634.93	358.42	410.12	635.17	402.17	408.17	13:00
448.25	439.66	356.79	425.65	695.48	650.69	579.12	310.20	352.62	559.01	326.09	331.72	14:00
360.25	338.58	273.85	331.95	692.58	645.94	530.25	298.52	270.53	487.25	233.24	227.72	15:00

Table.2: display the useful energy with tilt angle $\beta = \varphi$ in during the day in different months.

Angle $\beta = \varphi$												
Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Months
												Time
352.42	383.72	372.24	434.53	541.97	504.44	506.61	320.74	351.21	434.18	323.66	302.19	10:00
384.16	407.83	396.45	463.13	561.02	621.95	560.23	433.54	378.25	461.31	349.78	337.21	11:00
420.63	447.4	432.51	493.82	592.52	650.28	566.66	367.35	406.25	493.96	385.45	368.98	12:00
402.56	425.50	406.94	468.98	561.52	623.25	560.23	350.58	388.59	466.02	360.38	347.05	13:00
305.23	330.25	319.28	373.35	465.89	590.56	450.65	274.56	310.78	368.68	275.87	264.40	14:00
223.54	249.19	239.69	290.58	395.13	547.02	412.56	218.2	236.85	283.56	189.97	181.64	15:00

Table.3: display the useful energy with tilt angle $\beta = \varphi - 15^{o}$ in during the day in different months.

Angle $\beta = \varphi - 15^{o}$												
Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Months
												Time
334.56	367.60	398.35	449.50	480.65	607.34	496.75	341.36	372.77	393.45	330.47	307.46	10:00
335.98	372.54	397.34	453.89	477.62	601.66	497.78	334.25	365.74	392.81	331.52	305.14	11:00
310.58	342.85	364.14	414.25	442.32	574.23	467.12	309.85	338.29	358.17	301.89	275.98	12:00
260.45	293.48	320.58	362.78	390.47	543.89	432.52	278.23	304.56	306.25	255.78	234.25	13:00
187.26	220.75	240.89	284.56	330.78	450.21	388.89	234.56	232.58	230.58	180.56	168.24	14:00
146.85	182.56	205.81	246.12	293.74	411.21	348.85	194.41	188.41	198.21	139.12	127.14	15:00

IV. CONCLUSION

The usable energy and total radiation seen on the slanted surface during the various months of the year are discovered. We have computed the usable energy and total radiation at three distinct tilt angles(β), i.e. , $\beta = \varphi$, $\beta = \varphi + 15^{\circ}$, and $\beta = \varphi - 15^{\circ}$. We discovered that the usable energy and total radiation calculations changed with time. The values in the three tables above change as the time varies from 10:00 am to 15:00 pm. The graph illustrates the change in usable energy. For each of the three tilt angle values, The tilt angle $\beta = \varphi + 15^{o}$ yields the highest value of solar radiation for every month of the year except August, it is evident that the useable energy value is highest in May and lowest in December.

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