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Investigation of Hourly Optimum Tilt Angle for Srinagar City using CuO Nanofluid in Solar Flat Plate Collector

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Abstract – *Theoretical analysis has been carried out for determining the hourly optimum tilt angle and Hourly total solar radiation on optimum tilted surface of nano fluids in flat plate collector year for Srinagar city (Latitude =34˚), Jammu and Kashmir. The water based Copper oxide (CuO) nanofluid is used as a working fluid. A mathematical model and a program, written in MATLAB code were used. The results showed that the monthly optimum tilt angle for December, one of the coldest winter month of Srinagar city, is found to be 87˚ where the hourly solar radiation incident on the collector surface obtained for noon is 2.19 MJ/m^{2}h. Also the monthly total solar radiation, incident on the collector surface south facing, changes throughout the year with its maximum value of 2.492 MJ/m^2 h in July (summer month) and minimum value of 1.416 MJ/m^2 h in December (winter month).*

***Key Words*: Theoretical, Latitude, Flat plate collector, CuO, Mathematical Model, MATLAB, Optimum tilt angle..**

1. INTRODUCTION

The flat plate collector forms the heart of any solar energy collection system designed for operation in the low temperature range, from ambient to 60˚C, or the medium temperature range, from ambient to 100˚C.A solar collector is a special kind of heat exchanger that transfers the radiant energy of the incident sunlight to the sensible heat of a working fluid-liquid or air. The invention of the liquid heating flat plate solar water heater is credited to H.B Saussure, during the second half of the seventeenth century [4].Flat Plate collectors have the following advantages over other types of solar energy collectors:

(i) Absorb direct, diffuse and reflected components of solar radiation

(ii) Are fixed in tilt and orientation and, thus, there is no need of tracking the sun,

(iii) Are easy to make and are low in cost,

(iv) Have comparatively low maintenance cost and long life,

(v) Operate at comparatively high efficiency.

1.1 Objectives of the Study

The objectives of the current study are:

1. To develop a mathematical model and MATLAB Code for evaluating various parameters.
2. To determine hourly optimum tilt angles,β_opt, for the average day of each month in the year for Srinagar city (Latitude =34˚), Jammu and Kashmir.

1.2 LITERATURE REVIEW

Morcos [1] developed a mathematical model for calculating the total solar radiation on a tilted surface. The model was then used to determine optimum tilt angles for a flat plate collector and the optimum tilt angle and surface azimuth angles for concentrating solar collectors on a daily basis, as well as for a specified period.

Saraf et al. [2] developed a mathematical model for calculating the useful energy gained by a flat plate collector under various operating conditions. The model was then used to determine the optimum tilt angles for a typical collector in Basrah on a daily basis, as well as on the basis of a specified period. The optimum tilt angle was found by searching its value for which the useful energy gained by the collector is a maximum for a particular day or a specified period. From the results, it was observed that changing the tilt angle eight times in a year determines the useful energy in Basrah near its value which is found by changing the tilt angle daily to its optimum value.

Choi and Eastman [3] studied low thermal conductivity is a primary limitation in the development of energy-efficient heat transfer fluids that are required in many industrial applications. They proposed that an innovative new class of heat transfer fluids can be engineered by suspending metallic nanoparticles in conventional heat transfer fluids. The thermal conductivity of metallic liquids is much greater than that of nonmetallic liquids. Therefore, the thermal conductivities of fluids that contain suspended solid metallic particles were enhanced when compared with conventional heat transfer fluids.

Yimin and Wilfried [4] described nanofluid as a solid-liquid mixture in which metallic or nonmetallic nanoparticles are suspended. The suspended ultrafine particles change transport properties and heat transfer performance of the nanofluid, which exhibits a great potential in enhancing heat transfer. The mechanism of heat transfer enhancement of the nanofluid was investigated. Based on the assumption that the nanofluid behaves more like a fluid rather than a conventional solid-fluid mixture, two different approaches for deriving heat transfer correlation of the nanofluid were developed.

2. Methodology

2.1 Estimation of Heat transfer coefficient and Nusselt number

Liu and Jordan [1] considered the solar radiation on the tilted surface, I_T, as the sum of the beam radiation, isotropic diffuse radiation, and solar radiation diffusely reflected from the ground and obtained the equation for an hour as follows:

$$I_T = I_b r_b + I_d r_d + (I_b + I_d) r_r$$

The tilt factor r_b for beam radiation is the ratio of the beam radiation flux falling on a tilted surface to that falling on a horizontal surface. For an hour, it is given by:

$$r_b = cos\theta / cos\theta_z$$

For the case of a tilted surface facing south $cos\theta$ is given by:

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

Where $\emptyset$ and δ are site latitude angle and solar declination angle.

Cooper [2] has given the following simple relation for calculating the declination angle, δ

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

The tilt factor r_d for diffuse radiation is the ratio of the diffuse radiation flux falling on the tilted surface to that falling on a horizontal surface .the value of this tilt factor depends upon the distribution of diffuse radiation over the sky and on the portion of sky dome seen by the tilted surface. Assuming that sky is an isotropic source of diffuse radiation, we have for a tilted surface with a slope β,

$$r_d = \frac{1 + cos\beta}{2}$$

Since $\frac{1+cos\beta}{2}$ is the radiation shape factor for a tilted surface with respect to the sky, it follows that $\frac{1-cos\beta}{2}$ is the radiation shape factor for the surface with respect to the surrounding ground. Assuming that the reflection of the beam and diffuse radiations falling on the ground is diffuse and isotropic, and that the reflectivity is ρ, the tilt factor for reflected radiation is given by

$$r_r = \rho\left(\frac{1 - cos\beta}{2}\right)$$

Liu and Jordan suggested values of diffuse ground reflectance of 0.2 when there is no snow and 0.7 when there is fresh snow cover.

The total solar radiation on the horizontal surface, *I*, Can be expressed as:

$$I = H \times \frac{\pi}{24}(a + bcos\omega) \times \frac{Cos\omega - Cos\omega_s}{Sin\omega - \frac{\pi\omega_s}{180} Sin\omega_s}$$

Where constants are given by:

$$a = 0.409 + 0.5016 \sin(\omega_s - 60)$$

$$b = 0.6609 - 0.4767 sin(\omega_s - 60)$$

The hour angle ω which is an angular measure of time and is equivalent to 15° is given by

$$\omega = \pm(360/24)t$$

The convention of measuring it from noon based on local apparent time, being positive in the morning and negative in the afternoon.

The hour angle corresponding to sunrise or sunset (ω_s) on a horizontal surface can be calculated from the equation:

$$\omega_s = cos^{-1}(-tan\varphi tan\delta)$$

The above Equation yields a positive and a negative value for ω_s, the positive value corresponding to sunrise and the negative to sunset.

The monthly mean daily solar radiation intensity on a horizontal surface, H, is estimated according to the Angstrom model.

$$\frac{H}{H_O} = a + b\left(\frac{S}{S_O}\right)$$

where H is the monthly average global radiation on horizontal surface, S is the monthly average daily bright sunshine hours, S_O is the maximum possible monthly average daily sunshine hours or the day length, a and b are constants, and H_O is the monthly average daily extraterrestrial radiation (MJ/m^2 day) which can be expressed as

$$H_O = \frac{24 \times 3600}{\pi} I_{SC} \left[1 + 0.033 cos \frac{360n}{365}\right] \left[cos\emptyset cos\delta sin\omega_S + \left(\frac{2\pi\omega_S}{360}\right) sin\emptyset sin\delta\right]$$

For optimum tilt angle, β_{opt}, which gives the maximum solar radiation on the flat plate solar collector in a specific period, the derivative of I_T with respect to β must be zero, i.e. $\frac{dI_T}{d\beta} = 0$

In this study, the β_{opt} calculation was based on maximizing the solar radiation reaching on a tilted collector surface using the Morcos model (Morcos, [3] and is given by:

$$\beta_{opt} = tan^{-1}\left\{cos\gamma(cos\delta sin\emptyset cos\omega - sin\delta cos\varphi) / \left[\tau_d(1-\rho_g) \times \frac{cos\theta_z}{2\tau_b} - \frac{\rho_g cos\theta_z}{2} + sin\delta sin\emptyset + cos\delta cos\emptyset cos\omega\right]\right\}$$

Where the transmission coefficient for beam and diffusion radiation are given by

$$\tau_b = a_o + a_1 exp\left(\frac{-k}{cos\theta_z}\right)$$

$$\tau_d = 0.2710 - 0.2939\tau_b$$

The constants a_o, a_1 and k are determined according to the relations given below

$$a_o = 0.4237 - 0.00821(6 - A)^2$$

$$a_1 = 0.5055 - 0.00595(6.5 - A)^2$$

$$k = 0.2711 - 0.01858(2.5 - A)^2$$

Where A is the altitude of the observer in kilometers.

Using the above relations, maximum total solar radiation on an optimum tilted surface is calculated for the specific days of the year. The collector location considered in this study is at Srinagar, Jammu and Kashmir (Latitude=34°N, Longitude=74°50', Altitude=1586m above sea level).

3. Results and discussion

The following results were obtained in MATLAB program using data of Srinagar city, Jammu & Kashmir.

3.1 Hourly Optimum Tilt Angle

The hourly optimum tilt angles, β_{opt}, for the average day for each month in the year were computed based on the geometric data of Srinagar city (Latitude = 34°N, Longitude = 74°50'E and altitude = 1586 m above sea level) in Jammu & Kashmir by using MATLAB program. Srinagar has four distinct seasons. The average temperature in Spring (March to ending April), Summer (May to August), Autumn (September to November) and Winter (December to February) seasons are 15°C, 30°C, 25°C, 5°C respectively.

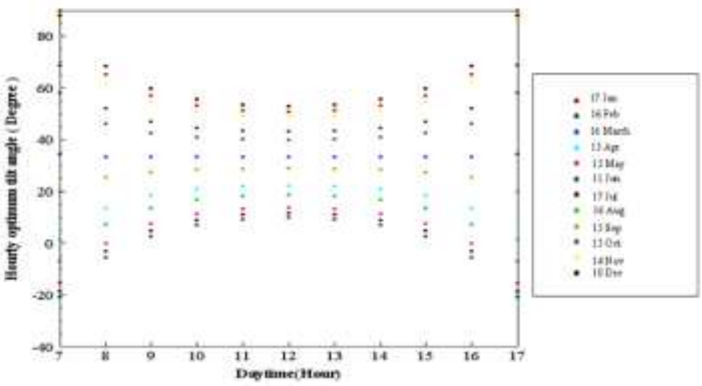

Fig -1: Variation of hourly optimum tilt angle for the average day for each month in the year.

Fig.1 shows the variation hourly optimum tilt angle for the average day of each month in the year with daytime from 7a.m-5p.m.The flat plate solar collector is facing south in Srinagar. The value of the hourly optimum tilt angles increases with daytime before solar noon and reaches maximum at noon during the months of April-September as depicted from figure. The hourly optimum tilt angles decreases after solar noon during the months of April-September and the reverse trend of the curve occurs during the months of October-February. The maximum and minimum optimum tilt angle varying in the range of (50°to82°) and (-20°to-2°) occurs in December and June respectively. It is noticeable that the optimum tilt angles varying with the daytime for the average day for the months of May, June, July are observed to be negative. When the tilt angle is negative, the collector is facing the north and when it is positive, the collector is facing the south. The hourly optimum tilt angle for the month of March remains almost constant throughout daytime which is approximately equal to the latitude angle of Srinagar (34°N). The optimum tilt angle for a flat plate solar collector facing south is 82° in December. The optimum tilt angles for the month of May to August are observed to be negative values. According to the results, the collector must be set north facing during those months. In this study, all the negative values of the optimum tilt angle were considered zero (horizontally). This is due to the fact that the practical orientation for the collector installed in the northern hemisphere is south facing with the positive tilt angle. The monthly optimum tilt angles were used for estimating the monthly total solar radiation, I_T, for an hour on the tilted collector surface.

3.2 Hourly total solar radiation on optimum tilted surface

The total solar radiation on the south-facing flat plate solar collector for an hour, tilted with the optimum tilt angle ($\beta = \beta_{opt}$) at solar noon, was computed for the average day for each month in the year using the standard solar data of Srinagar city. The set of Equations given in methodology section were used in the MATLAB program for this computation. Fig. 2 shows that the variation of hourly total solar radiation, I_T, on optimum tilted surface for the average day of each month. The value of total solar radiation increases with daytime and reaches its peak valve at solar noon. The highest hourly solar radiation (3.323MJ/m^{2}h) occurs in July at noon, and the lowest one is 2.199MJ/m^2 h in December at noon.

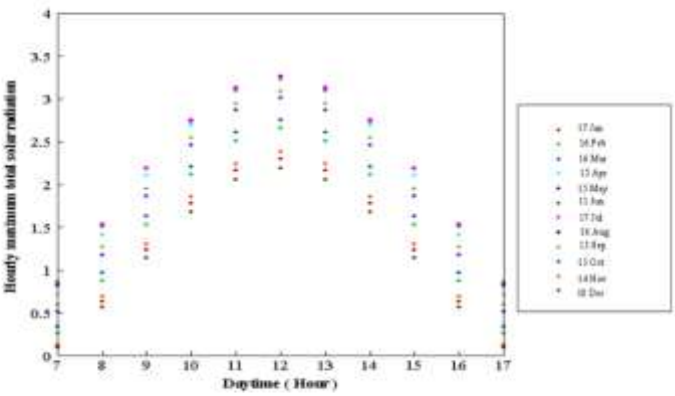

Fig -2: Variation of hourly total solar radiation with the daytime on the tilted collector surface with the optimum tilt angle at solar noon.

4. Conclusions

The present study analyzed theoretically the efficiency of CuO-water nanofluid based flat plate solar collector for water heating applications using the MATLAB program. Following conclusions can be drawn from the current study:

1. Hourly optimum tilt angles, β_opt, for the average day of each month in the year has been determined for Srinagar city (Latitude =34°), Jammu and Kashmir. The monthly optimum tilt angle for the collector changes throughout the year, it is to notice that the monthly optimum tilt angle is the average of the hourly optimum tilt angles for the average day of each month in the year. The monthly optimum tilt angles are found to be negative for the months of May to August and they are considered zero for the south facing solar collector. The monthly optimum tilt angle for December, one of the coldest winter month of Srinagar city, is found to be 87° where the hourly solar radiation incident on the collector surface obtained for noon is 2.19 MJ/m^{2}h.
2. The monthly total solar radiation, incident on the collector surface south facing, changes throughout the year with its maximum value of 2.492 MJ/m^2 h in July (summer month) and minimum value of 1.416 MJ/m^2 h in December (winter month).

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