**USE OF PARABOLIC SOLAR COLLECTOR FOR MULTAN: OPTIMIZING TILT ANGLE**

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**Abstract**

In Pakistan there is a growing gap between supply and demand of electricity and ever increasing cost per unit of fossil fuel based thermal power generation. This necessitates the need to diversify the energy-mix and increase the role of renewable energy sources like solar in the strategic planning for future. In this work, a low cost parabolic solar collector has been designed to heat water up to 150° C for use in city of Multan. Its orientation and average monthly tilt angles have been estimated & optimized on monthly bases. Moreover, solar radiations for the designed collector at the optimum tilt angles have been estimated. The importance of the work is that it will be helpful in disseminating the low cost indigenous solution which will help in reducing the fossil fuel import bill.

**Keywords:** Parabolic Solar Collector, Tilt Angle, Solar Energy

**1 Introduction**

Sun is a reliable source of power with no environmental implication. Pakistan is among those top ten countries in the world that have the longest resource of the sunlight averaging 282 days sunlight/year.

On the other hand; with ever increasing cost of fossil fuels, the era of fuel based electricity generation is approaching to an end. In Pakistan’s context the importance of solar power increases due to the growing gap between supply and demand and higher unit cost of fossil fuel based power generation.

In India, renewable energy is 5.5% of its energy mix and is growing continuously. In Germany, individual, cooperative, municipals and communities are setting up the solar power projects. Regardless of higher initial cost, it can be said that solar energy is a long term strategic option for Pakistan. Recently, the government of Punjab has embarked upon the 1000 megawatt solar energy based electricity generation project spreading over an area of 11 thousand acres with expected completion in March, 2014.

Use of solar energy for building application is getting popular. special windows, roof top making use of solar energy have been developed for this purpose.

Looking at the research made for the thermal analysis of solar parabolic trough with porous disc receiver, Ravi and Reddy ‎[1] examined the effect of solar radiation on different receiving discs which are helpful for designing and modeling a parabolic solar collector. A numerical investigation of various designs and orientations with different boundary conditions for solar parabolic collector has been carried out. In addition, observation upon orientation, discs height and the distance between them for different radiations is helpful for other researchers for obtaining results and to arrive to an optimum design of the system.

A lot of researches has also been reported for the optimum angle of the sun rays to obtain the maximum solar energy for a particular while very less interest is shown for such studies along with the solar collector design for Pakistan. Huseyin Gunerhan and Arif Hepbasli ‎[2] calculated the monthly and yearly optimum angle for the city of Izmir (Turkey) from the experimental values which was observed to be as 35.8 degrees yearly. A number of useful suggestions are given by these researchers regarding orientation and uniformly changing the optimum tilt angle on at least monthly basis in order to increase the utilization efficiency of solar collectors.

Further, Eduardo Zarza et al. ‎[3] presented a summary of the conclusions achieved in the DISS (Direct Solar Steam) project by direct steam generation in parabolic troughs. They conducted a test on parabolic solar collector for more than 3000 hours to investigate the Direct Steam Generation (DSG) process with a special focus on once-through, recirculation and injection of the steam under real solar conditions and hence the results were concluded. The numerical simulation was carried out for top half porous disc by varying its height (H). The height of porous discs varied from 0.227di to 0.75di in steps of 0.075di. The variation of Nusselt number and drag coefficient with the disc are graphically shown which is a step towards guidance for the other researches to be made. As the solar atmosphere in Pakistan is quite feasible for such operation, hence gives a significant step forward in the development of this technology, which is a promising option for cost-effective solar thermal power plants with parabolic trough collectors in the sunny belt areas of Pakistan.

Several investigations have also been made to design collectors with low initial costs and high energy collection. For such, H.M.S. Hussein; et al. ‎[4] has made a contributory research on optimization of operational and design parameters of plane reflector-tilted flat plate solar collector systems. The investigation includes geometric arrangements, optimal tilts and location in different seasons. The relationship between collector’s length and reflector’s height has a considerable impact on the energy collection through the solar collectors and tilting the reflector at its noon optimum tilt angle results in maximum daily boost factor. The suited geometrical arrangement of the collector is very essential for the maximum utilization of the solar energy by the collector. Its orientation and fixing at optimum tilt angle has also an important impact on the said research. This research aims to study the effect of different operational and design parameters of plane reflector-tilted flat plate solar collector systems and its effect on collector’s daily and yearly solar energy collection in different seasons. This has a significant effect for the further researches that are going to be made for Pakistan as the country enjoys all four seasons throughout the year along with facing the sun in south the whole year.

Soteris Kalogirou et al.‎[5] presented steam generation through parabolic solar collector by modeling, optimization and performance evaluation of a parabolic trough solar collector steam generation system. It is somehow, quite simple in its description and modeling but very helpful for developing the collector in practical way. Based on the discussed concept by Soteris et al, a lot of research has been made. Very adequate modeling program and optimizing the solar energy utilization and its analysis presented in the form of diagram. From the results presented, it can be concluded that the modeling program developed is accurate to within 1.2%. From a theoretical system energy analysis, it was shown that only about 49% of the incident radiation falling on the collector is utilized for steam generation. The rest are thermal and collection losses. The research also indicates the analysis of useful solar radiation that has been utilized for energy conservation hence concludes the radiation efficiency which is useful for analyzing many important results which are helpful for the solar energy researchers of present times.

In this work, determination of orientation and optimum tilt angle of a location in city of Multan has been dealt with for a Parabolic Solar Collector. A parabolic solar collector is designed to heat water from room temperature to 150° C based on the flow rate analysis.

**2 Modelling and nomenclature**

The following categorization is used in designing the model:

W = Aperture = 1.9 m

 d = Diameter of absorber = 19.05 mm

 r = radius of absorber = 9.525 mm

θs = Image of Sun = 4.6 x 10-3

ρc = Reflectance of the concenter /reflector = 0.94 (Material properties & has no unit)

α = Absorptance of the absorber = 0.97 (Material properties & has no unit)

 L = Length of the parabolic collector (as required but normally in meters)

For the above values, the aperture of the reflector foil and dia of the absorber tube are co-related in such a way that the sunrays strike at respective focal points and hence making a focal line which will be the longitudinal axis of the absorber tube.

**3 Designing methodology**

The basic elements making up the parabolic collector are:

1. The absorber tube located at focal axis through which liquid to be heated flows.
2. The parabolic concentrator/reflector.
3. The concentric transparent cover

 Various views of parabolic solar collector designed on a CAD software are shown in fig 3.1 below.

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| a) Front | b) back | c) side |
| Fig. 3.1 A Parabolic Solar Collector |

**4 Material**

The different parts of a parabolic solar collector are made up of different materials according to their individual requirement and properties as shown in Table.4.1 below

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| Table 4.1 Material composition of the parts of parabolic solar collector and properties |
| Part of collector | Material | Properties |
| Reflector Foil | Anodized silver coated aluminum mirror | Wavelength dependent reflectivitySilver coating protects from rust |
| Ribs and supporting pipe | Mild steel with 0.25% Carbon and 0.4%-0.7% manganese | Abundant and versatileStronger and stifferRust resistant |
| Parabolic Ribs | Polyproplene | Higher melting point (above 170° C)High elastic range |
| Absorber Tube | stainless steel pipe structure with chromium oxide coating | Rust protectedNon stickingHigh melting point |

*4.1 Reflector foil*

The material of the reflector foil is anodized silver coated aluminum mirror finished sheet with 0.4 mm thickness and 0.94 reflectivity. The reflectivity varies with the variation in wavelength of the light. The reflecting power of the aluminum-surfaced mirrors for sunrays is 0.85 with wavelenth range of 0.23µ to 0.6µ (where µ=10,000 angstroms) whereas the reflecting power of silver surfaced mirrors for the same wavelength range is 0.94. Further, aluminum oxide is formed rapidly on the surface of the aluminum metal mirrors which damages the surface and hence the reflectivity. However, the silver has quite higher optical reflectivity than aluminum as well as long life.

*4.2 Ribs and supporting pipe*

The ribs with square cross section and the supporting pipe are made up of mild steel with 0.25% Carbon and 0.4% - 0.7% manganese and some other metals. Carbon makes mild steel stronger and stiffer and makes it vulnerable to rust.

*4.3 Parabolic ribs*

The parabolic ribs which supports the collector are made up of polyproplene. It is hard and tough and is used to make molded articles and fibers. Having melting point above 170° C with a higher elastic range.

*4.4 Absorber tube*

The absorber tube being the most important part is composed of stainless steel pipe structure with selective coatings of chromium oxide (red chrome). Chromium that is responsible for making steel stainless, when added to the iron and carbon that make ordinary steel, react with oxygen to form an airtight coating. The airtight coating in turn protects the steel from rust. The reason for preferring stainless steel over aluminum is that the coefficient of expansion of stainless is quite higher as compared to that of aluminum.

**5 Methodology**

For the given location (i.e. Multan City in Punjab Province of Pakistan), the variation in the intensity of sun light due to seasonal variation pattern is estimated. Then the flux hitting a tilted plane at any moment is obtained. For 150 C the mass flow rate and heat required is calculated based on the principles of heat transfer. Design of parabolic solar collector is done with a commercial CAD software. The methodology adopted is as under.

In case of a titled surface facing towards south (i.e. γ = 0°):

cosθ = sin δ sin(φ – β) + cosδ cosω cos (φ – β) **----------- (1)**

While for the horizontal plane:

cos= sin φ sin δ + cosφ cosδ cosω **----------- (2)**

So, = = -**---------** **(3)**

The tilt factor for diffused solar radiation is actually the ratio between the diffused radiation flux hitting the tilted surface and that of hitting the horizontal surface. Assuming that sky is an isotropic source of diffused solar radiations that we have for a tilted plane with a slope β.

 = ------------ **(4)**

he tilt factor for the reflected sun ray is obtained as:

 = ρ **-------------- (5)**

The flux hitting a tilted plane at any moment is thus obtained as:

 = + + ( + **------------- (6)**

Whereas the values of , and are as mentioned in equations (3),(4) and (5). It has to be mentioned that eq. (1) is applicable for a tilted plane only with γ=0°, whereas equations (4) and (5) are applicable for any tilted plane with a slope β. Dividing both sides of eq. (6)by , we achieve the ratio between the flux falling on a tilted plane at any moment and that on a horizontal plane.

 = + +  **--------------------- (7)**

One difficulty faced while applying eq.(6)is that the value of the diffused reflectivity ρ is unknown in many circumstances. A value just about 0.2, generally expected with planes that are of grass or concretes, may be utilized.

Equation (7)may be utilized for computing the hourly radiation hitting a tilted plane if value of ω is obtained at the middle of the examined hour. It may be utilized for computing the average hourly value of month (i.e. ) if calculations are made for the respective day of the month as mentioned in Table-1 in the previous chapter, eq. (7) is used after modifications as:

 = + + **----------------- (8)**

Where, = on the representative day
 = =) / 2
 = = ρ(1 – cos β)/2

The daily radiation hitting a tilted plane is noticeable in many applications. Liu and Jordan ‎[6] have anticipated that ratio of the daily radiation hitting such a surface () and the daily global radiation on a horizontal plane () is obtained by an equation having an appearance similar to that of the eq.(7). Therefore:

 = + + **----------------- (9)**

For south facing surface (γ = 0°), it is demonstrated that:

 = **------------ (10)**

 = = **------------ (11)**

 == ρ **------------- (12)**

In equation (10), and are the sunset or sunrise hour angles (in radians) for the horizontal and tilted plane respectively.

Eq. (9) can also be utilized for computing the monthly average daily radiation hitting a tilted plane if the values needed are computed for the particular day of the month. Eq. (9) is then utilized after modifications as:

 = + + **------------- (13)**

Where,

 = (on the respective day)

 = =

 = =

Various correlations ‎[7] have been recommended, such as Eq.(14), for calculating the value of the daily diffused radiation i.e. by using the given value of the daily global radiation for some particular day. These correlations are very helpful as the daily diffused radiation is traced at many locations as compared to the daily diffused radiation which is supported by an examination of data examined at a number of locations.

 = 0.99 for 0.17

 = 1.188 – 2.272 + 9.473 – 21.856 + 14.648

 for 0.17 0.8 where, =

Similarly, correlations have also been made for finding out the hourly diffused radiation i.e. from determined values of . J.W. Spencer ‎[7] has recommended the correlation that is:

 = a – b --------------- **(14)**

The above equation is applicable for values: 0.35 () 0.75.

**6 Results and discussions**

The effect of tilt angle is vital for the analysis of collection of solar energy on a parabolic solar collector. The monthly radiation data for Multan is shown in Table 6.1

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| Table 6.1: Monthly daily average radiation on a horizontal surface in Multan  |
| Monthly daily average radiation (MJ/sqm) on a horizontal surface  | Average Annual Radiation (MJ/sqm) |
| January | February | March | April | May | June | 19.6 |
| 14.7 | 15.9 | 19.3 | 23.0 | 25.1 | 27.2 |
| July | August | September | October | November | December |
| 25.1 | 22.2 | 22.2 | 18.8 | 12.6 | 9.6 |

It is clear from the above table that for six months i.e. April ~ September the monthly radiation values are higher than the average annual radiation. This indicates the availability of solar power for any use at the desired location.

By analysis of the received radiation for Multan, it is concluded that orientation/direction at which a solar collector collects the maximum energy is due south as the collection of solar energy is maximum (73.853 KW/m² annually received radiation) when collector is south tilted.

To collect maximum energy from the sunrays, the tilt angle of the collector is required to be changed continuously.

The average monthly tilt angle of the solar collector is calculated by taking the mean of the tilt angle values for the days of the particular month respectively. However, the change in tilt angle after each day is very small and change in values of the received radiation is very small on daily basis. Fig. 6.1 shows the variation in tilt angle for optimum radiation in Multan.

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| Fig. 6.1: Variation of optimum tilt according to day of year for Multan |

The above graph shows a Gaussian Curve. This shows that the tilt angle gradually decreases from the 1st day of the year until it attains the minimum value on 173rd day of the year that is 22nd June and then it gradually increases until it reaches the maximum value on 22nd December.

The equation of time is the difference between apparent solar time and mean solar time, both taken at a given place (or at another place with the same geographical longitude) at the same real instant of time.

The graph for the equation of time collection is shown in Fig. 6.2.

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| Fig. 6.2: Equation of time correction according to number of day for Multan |

The graph shows the variation between apparent solar time and mean solar time. The position of the sun with respect to the time varies throughout the year.

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| Fig. 6.3: Variation of daily total flux for six hour collection on the optimum tilt angle |

It attains the minimum position on the 39th and then a little variation of up and down till 240th day of the year. Then it gradually increases and attains maximum position on 300th day of the year and then it is seemed to be gradually decreased in the rest days of the year.

The variation in daily total flux for six hour collection on the optimum angle is shown in fig 6.3. The graph shows that there is a gradual increase in the flux from the 1st day of the year till 69th day followed by a gradual decrease till 164th day of the year. Finally it increases with fluctuations till the end of the year.

Based on total daily average Flux per Unit area at optimum tilt angle for Multan, the average tilt angles for each month are calculated and are shown in Table 6.2

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| Table 6.2 Total daily average Flux per Unit area at monthly average optimum tilt angle for respective months for the city of Multan |
| Month | Average Daily Flux/Area (W/m²) | Average Optimum Tilt Angle |
| Jan. | 6093.2 | 50.94° |
| Feb. | 6377.1 | 44.68° |
| Mar. | 6564.7 | 34.13° |
| April | 6543.4 | 20.34° |
| May | 6403.9 | 11.16° |
| June | 6326.4 | 07.09° |
| July | 6395.7 | 09.27° |
| Aug. | 6548.2 | 17.23° |
| Sep. | 6577.9 | 28.60° |
| Oct. | 6309.2 | 40.41° |
| Nov. | 6112.1 | 49.47° |
| Dec. | 5967.6 | 52.58° |

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| Fig. 6.4 Variation of daily total flux per unit area at optimum tilt angle |

The Fig 6.4 shows that average monthly flux increases gradually and attains maximum value at almost beginning of the 4th month (April). Then it gradually decreases till the beginning of the 6th month. Then it increases and shows fluctuations till the end of the year.

*6.1 Mass Flow Rate:*

The mass flow rate () can be collected by the equation:

 q = C T (Eq 15) Where, C = 1000 (for water)

 = 25°C (ambient temperature)

 = 150°C (required temperature to be raised at)

 T = – = 125°C

For the value of ‘q’, we put some accepted calculated values ‎[8] as follows:

Since, q = S x A

Where,

S = Absorbed flux

A = Area of the collector = W x L x n = 1.9 x 6.094 x 3 = 34.74 m² (n = no. of turns)

Now S= ρ γ + ρ γ [ ]

where, = beam radiation = 1000 W/m²

= tilt factor = 1.013

 ρ = specular reflectivity of concentrator surface = 0.94

 γ = intercept factor = 0.84

 = Transmissivity of glass cover = 0.88

 = Absorbitivity of absorber tube = 0.95---0.97 (we take it as 0.95)

S = 480 W/m² (by putting values)

Now, q = S x A = 16675.2

Using these values in Eq (15), mass flow rate () can be calculated as:

Mass flow rate = = = = 0.1313 L/sec

*6.2 Efficiancy*

The efficiancy of the solar collector is the ratio of absorbed flux to the total average flux. So, the daily average absorbed flux of solar radiations per unit area at optimum tilt angle is obtained by taking the average of values of total annual flux as below.

Absorbed flux = 3993.99 W/m²

Now, total average flux per unit area striking the collector’s surface at optimum tilt angle is obtained by taking the average of values of total annual radiations striking the collector’s surface facing towards south at optimum tilt angle and it comes to be

Total average flux= 7385.29 W/m²

Hence,

Collector’s efficiancy = x 100 = 54.08 %

From the energy balance equation, total monthly average flux per unit area at optimum tilt angle and through pyranometer is calculated and hence error is estimated which is shown in Table-6 while Fig. 6.5 shows the graph between total monthly average predicted solar radiation and actually calculated solar radiation at optimum tilt angle.

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| Table 6.3 Monthly average predicted and calculated Flux at optimum tilt angle |
| Month | Monthly Optimum Tilt Angle | Total Monthly average Flux per Unit area at Opt Tilt Angle (W/m²) | Total Monthly average Flux per unit area through pyranometer (W/m²) | %age Error | Error\*100 |
| Jan. | 50.94° | 6093.249 | 5790.94 | 0.052204 | 5.22038 |
| Feb. | 44.68° | 6377.095 | 5779.5 | 0.103399 | 10.33991 |
| Mar. | 34.13° | 6564.720 | 5992.96 | 0.095405 | 9.540519 |
| April | 20.34° | 6543.394 | 6362.75 | 0.028391 | 2.839094 |
| May | 11.16° | 6403.911 | 6518.08 | -0.01752 | -1.75158 |
| June | 7.09° | 6326.416 | 6371.3 | -0.00704 | -0.70448 |
| July | 9.27° | 6395.736 | 6289.93 | 0.016822 | 1.682155 |
| Aug. | 17.23° | 6548.249 | 6061.85 | 0.080239 | 8.023931 |
| Sep. | 28.6° | 6577.950 | 6475.45 | 0.015829 | 1.582899 |
| Oct. | 40.41° | 6309.163 | 6259.15 | 0.00799 | 0.799046 |
| Nov. | 49.47° | 6112.087 | 6276.91 | -0.02626 | -2.62585 |
| Dec. | 52.58° | 5967.570 | 5674.07 | 0.051726 | 5.172646 |

From the Fig. 4.6, it can be seen that total average flux measured through pyranometer is lower as compared to total average daily flux per unit area at optimum tilt angle.

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| Fig. 6.5: Comparison of total monthly average predicted solar radiation and actual solar radiation at optimum tilt angles during a period of a year |

The difference between the two values is small and due to unusual energy losses faced by solar radiations. The main factors includes: dust in the atmosphere i.e. unclear sky, humidity level in the atmosphere etc. A large amount of solar energy is absorbed by these droplets as well as these droplets reflect back the rays in the same manner as the dust particles. Further, the absorptivity of the earth is considered to be as constant however in reality it varies from place to place. The discrepancy between actual measurements and predicted values can be attributed to these factors.

**7 Conclusions**

Pakistan’s vast renewable energy potential remains largely untapped due to a number of reasons. With large energy shortfall and ever increasing energy prices; there is a need to look towards renewable energy sources. In this work; P.S.C (parabolic solar collector) has been designed for building applications in Multan. Results can be organized as follows:

1) Pakistan is located in Northern Hemisphere. Therefore, for optimum solar energy absorption, the parabolic solar collector in Multan is due-South.

2) The optimum tilt angle varies from 7.09° to 52.58° in June and December respectively. The average monthly optimum tilt angles are given below (see Table 7.1)

Table 7.1 The average monthly optimum tilt angle

|  |  |
| --- | --- |
| Month | Monthly Average Tilt Angle |
| Jan | 50.940 |
| Feb | 44.68 |
| March | 34.13 |
| April | 20.34 |
| May | 11.16 |
| June | 7.09 (min) |
| July | 9.27 |
| Aug | 17.23 |
| Sep | 28.6 |
| Oct | 40.41 |
| Nov | 49.47 |
| Dec | 52.58 (max) |

3) Total monthly solar radiation at optimum tilt angles respectively are given below in Table 7.2

Table 7.2 Solar radiation for Multan (30.2° North) at optimum tilt angle

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| --- | --- |
| Month | Radiation at optimum Tilt Angle (W/m²) |
| Jan. | 5790.94 |
| Feb | 5779.50 |
| Mar. | 5992.96 |
| April | 6362.75 |
| May | 6518.08(max) |
| June | 6371.30 |
| July | 6289.93 |
| Aug. | 6061.85 |
| Sep. | 6475.45 |
| Oct. | 6259.15 |
| Nov. | 6276.91 |
| Dec. | 5674.07(min) |

4) An increase in aperture width decreases the image of sun on absorber and vice versa for Multan. The optimum rim angle range is found to be 70 to 120 degrees with aperture width of 1.5 meters

5) Mass flow rate of temperature range of 125 °C is found to be 0.1313 lit/sec.

**8** **References**

1. K. Ravi Kumar, K.S. Reddy, Thermal analysis of solar parabolic trough with porous disc receiver, Applied Energy 86 (2009) 1804–1812.
2. Huseyin Gunerhan, Arif Hepbasli. Determination of the optimum tilt angle of solar collectors for building applications. Building and Environment 42 (2007) 779–783.
3. Eduardo Zarza, Loreto Valenzuela, Javier Leo´n , Klaus Hennecke, Markus Eck, H.-Dieter Weyers, Martin Eickhoff . Direct steam generation in parabolic troughs: Final results and conclusions of the DISS project. Energy 29 (2004) 635–644.
4. H.M.S. Hussein, G.E. Ahmad, M.A. Mohamad. Optimization of operational and design parameters of plane reflector-tilted flat plate solar collector systems. Energy 25 (2000) 529–542.
5. Soteris Kalogirou, Stephen Lloyd, John Ward, Modeling optimization and performance evaluation of a parabolic trough solar collector steam generation system. Solar Energy 60 (1997) 49-59.
6. ASHRAE Standard 93 (1986).
7. J.W. Spencer. A comparison of methods for estimating hourly diffuse solar radiation from global solar radiation. Solar Energy 29 (1982) 19-32.
8. M. Iqbal, An Introduction to Solar Radiation, Academic Press, Canada, 1983.