Analysis of Pitch Variation of Helical Coil Receiver for Solar Parabolic Dish Concentrator

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Abstract
Solar parabolic dish concentrator is a point focus solar concentrator. This experimental research focuses on the effect of pitch variation of the helical coil receiver on the output temperature of the heating media used i.e. water. The material of dish concentrator is ionised mild steel(reflectivity: 92.5%) with manual tracking. The helical coil receiver (outer diameter: 8mm) made of copper material (conductivity: 401 W/mK) with diameter equal to length (13.5 cm) and number of turns equal to 13 is designed and manufactured which is used as receiver for the system. The pitch of the helical coil is varied from zero to 10 mm and the output temperature of the system is observed. It is observed that with increasein the pitch, the output temperature of the working fluid goes on increasing with the maximum temperature attained when the pitch becomes geometrically equal to the outer diameter of the copper coil. The result is reaffirmed with helical coil of 6 mm and 10 mm pitch coil.

Keywords
Dish Concentrators, Helical Receiver, Experimental Analysis and Pitch Variation

I. Introduction

The sun is the only star of our solar system located at its centre. The sun is a sphere of intensely hot gaseous matter with a diameter of 1.39×10^9m and is about 1.5×10^{11}m away from the Earth; the sun rotates on its axis once about every four weeks. The sun creates its energy through a thermonuclear process that converts about 650,000,000 tons of hydrogen to helium every second. The process creates heat and electromagnetic radiation. The heat remains in the sun and is instrumental in maintaining the thermonuclear reaction. The electromagnetic radiation (including visible light, infrared light and ultraviolet radiations) streams out into space in all directions [16].

The intensity of solar radiation per unit on a unit surface outside the Earth's atmosphere is known as "solar constant". Its value is 1353 W/m^2. The rate at which solar energy reaches a unit area at the Earth is called the solar irradiance or insolation. Solar irradiance is an instantaneous measure of rate and can vary overtime. The maximum solar irradiance value is used in solar system design to determine the peak rate of energy input into the system [12].

For low cost applications purposes parabolic concentrators are quiet popular due to its high concentration ratio and easy manufacturing.The two dimensional design of a parabolic concentrator is equals to a parabola. A distinct property that it has is that it can focus all the parallel rays from the sun to a single focus point. It is not necessary to use the whole part of the parabola curve to construct the concentrator. Most of the parabolic concentrator employs only a truncated portion of the parabola. Currently there are two available designs of parabolic concentrator. One is by rotating the two dimensional design along the x-axis to produce a parabolic dish, and the otherway is by having a parabolic trough. Both of the design act as a reflector and are used mostly in concentrating solar power system in big solar power plants. Though this concentrator could provide a high concentration, it requires larger field of view to maximize the sun energy collection. To obtain maximum efficiency, it needs a good tracking system, which is quiet expensive [5].

II. Design and Manufacturing of Solar Parabolic Dish Concentrator

The parabolic shape is widely used as the reflecting surface for concentrating solar collector because it has the property that, the angle between it and the surface normal is equal to the angle between the normal and the line to the focal point. Since solar radiation arrives at the Earth in essentially parallel rays and by Snell's law the angle of reflection equals the angle of incidence, all radiations parallel to the axis of the parabola will be reflected back to a single point F, which is the focus [12].

The construction of a parabolic dish starts from a plane sheet of material. The parabola Y = $X^2/4f$ represents a vertical section through a parabola having a focal length of f cm. If the parabola is slit symmetrically along eight radial directions and flattened out, then it would appear like an eight petalled flower. A part of the plane sheet which has to be cut out and removed for the facilitation of inlet and outlet nozzles. A circle of circumference ($2\pi R$) on the plane sheet would occupy a lesser circumference equal to in the parabola after fabrication. Thus the main consideration in the construction is to calculate the arc length of material that has to be cut out, namely ($2\pi R$- $2\pi X$) as a function of R [8].

The portion to be cut out was marked off on the ionised mild steel (reflectivity: 92.5%) sheet by means of brush and paint on either side of 16 symmetrically drawn radial vectors. After cutting out the unwanted painted portion, the 16 petals were raised and fixed in position with their edges touching each other by means of suitable arrangement i.e. wire clips. With care and gentle pressure it was possible to make the upper portion of the parabola more circular and less polygonal in shape. The frame structure is made of galvanized steel and is hollow to reduce the total weight of the frame structure which in turn reduces the overall weight of the system. Rollers were attached at the base for easy movement of the system.

III. Design, Mathematical Formulation and Manufacturing of Helical Coil Receiver

As all the radiations are not concentrated exactly on the focal point of the system due to unavoidable manufacturing defects of the concentrator, the helical coil receiver is designed having certain length to take into account maximum radiations (direct and diffused) to be absorbed by the receiver coil. Hence this study consists of a parabolic dish collector with a modified cavity receiver (operating in non-tracking mode). In order to design the system, simple mathematical formulations are used to calculate the major parameters of collector and receiver.

The focal distance/length (f) for the dish under study is given by [9]:

$f = D^2/16h$ (1)

Where h is the depth of the dish and D is the aperture diameter of the opening parabolic surface.

The focal length of dish is calculated to be 0.2902m which is approximately equivalent to 0.292 m provided by the manufacturing facility.

The focal length f can also be obtained from [10]:

$f/d = 1/(4 \tan(\varphi/2))$ (2)

Where is the rim angle.

The calculated rim angle is 100.34°.

The total surface area for the parabolic dish id given by [9]:

$S = 8\pi/3 \times f^2 \times \{[1 + (d/4f)^2]^{32} - 1$ (3)

The total area is calculated to be 2.002m². But as described before a small section of the parabola is removed for facilitation of input-output of the system. Hence the effective surface area (A_c) is 1.986m².

The concentration ratio is defined as the amount of light energy concentration achieved by a given collector. Mathematically it is given by [8]:

Concentration ratio (C.R) =

Collector area $(A_C)/($*Receiver area*$)$ (4)

The concentration ratio of the system is assumed to be 40.

Considering a zero pitch helical coil, the concentrated radiation falls over the half part of the total receiver area. Hence the receiver area can be calculated as:

Receiver area $(A_r) = \pi dl/2$ (5)

Where d is the diameter of the copper coil and l is the length of the coil tube.

The diameter of the coil is found to be 0.1778m and is approximated to 0.18m i.e. 18cm.

Copper metal was selected as receiver material due to its high thermal conductivity (k = 401W/mK). The copper tube was procured from the market with outer diameter of 6 mm, 8 mm, 10 mm and thickness 1mm for experimental purpose.

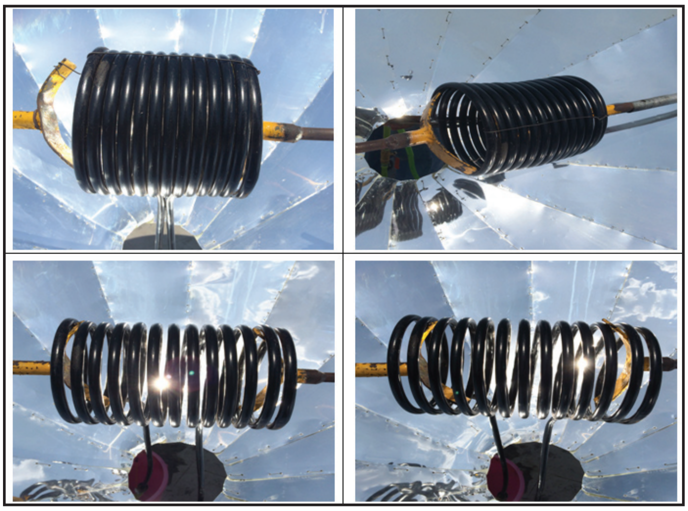

Fig. 1: Variations in Pitch of Helical Coil Receiver

The helical coil was manufactured using bending process in which sand is inserted in the tube and the tube is enclosed on both sides by a cork. This helps in avoiding the pitching of the helical coil. To increase the absorptivity of the receiver, the helical coil is powdered coated with black colour which further increases the overall efficiency of the system. In this analysis of helical receiver, the pitch is varied to achieve the optimum output temperature of the working fluid i.e. water and hence the system.

IV. Experimental Setup

The setup used for the experimental work is shown below:-

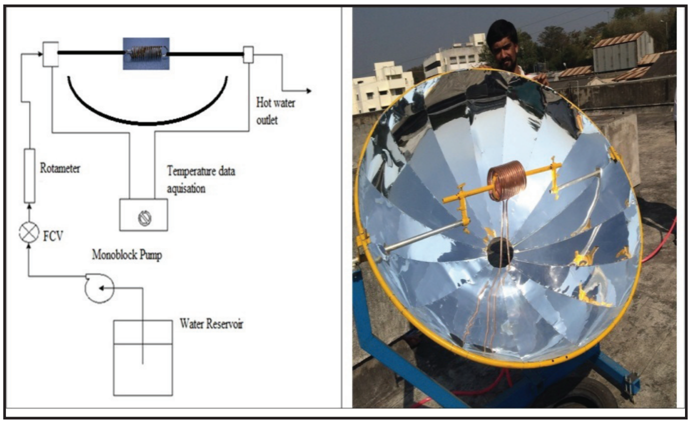

Fig. 2: Setup of the System for Experimental Analysis

The input is taken from the reservoir with the help of a submersible pump. The water from the reservoir goes to the input side of the helical coil through the flexible pipe via rotameter. A flow control valve is also attached for flow rate control. The water absorbs the heat while flowing through the receiver coil and is collected in the collection tank of the outlet. Temperature sensors (K-thermocouple) are provided at the inlet and outlet of the helical coil for temperature measurement. The surface temperature of the coil is also noted in similar fashion.

V. Results and Discussions

The main aim is to observe the temperature variations in temperature with the changing receiver pitch. The pitch of the helical coil is varied from zero to 10 mm while keeping all other constant. Initially the helical coil with outer diameter 8 mm is tested. The testing for variations in pitch is carried out on simultaneous days to ensure that the climatic condition is only slightly varied. The testing is done from 11.00 to 15.00 and the following results are obtained which is given below in table.

Table 1: Temperature Variations with Increment in Pitch of the Helical Receiver

Time of Day	Pitch (mm)				
	0	3	6	8	10
	Temperature (K)				
11:00	361	359	345	349	359
11:30	364	361	348	350	361
12:00	362	367	350	353	366
12:30	362	369	363	369	370
13:00	365	372	371	377	374
13:30	364	369	368	376	373
14:00	359	371	369	376	369
14:30	362	367	365	375	369
15:00	351	363	361	377	365

This data shows that the maximum output temperature for the helical coil is achieved when the pitch is equal to the outer diameter of the coil i.e. 8 mm. The above collected data is plotted as shown below:-

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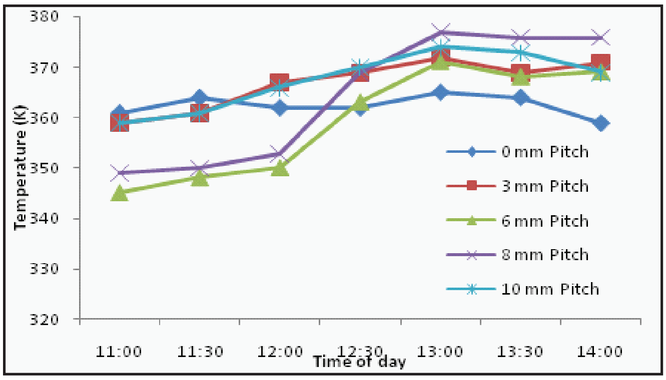


Fig. 3: Pitch Variations Graph for 8 mm Outer Diameter Coil

This graph clearly indicates that the 8 mm pitch coil is the most efficient as compared to the other coils with different pitch. The maximum temperature obtained for the 8 mm pitch coil is 104ºC (377 K). The possible reason for pitch to be equal to outer diameter of the coil for maximum results is that for such a coil the total surface area directly exposed to the solar radiation is maximum which can be concluded based on the helical geometry. The same experimental work is carried out with helical coil of outer diameter 6 mm and 10 mm respectively for reaffirmation of the previously concluded result that the optimum pitch is equal to the outer diameter of the coil. The other geometrical parameters and experimental conditions are kept relatively constant. The results for 6 mm and 10 mm outer diameter coil are discussed below:-

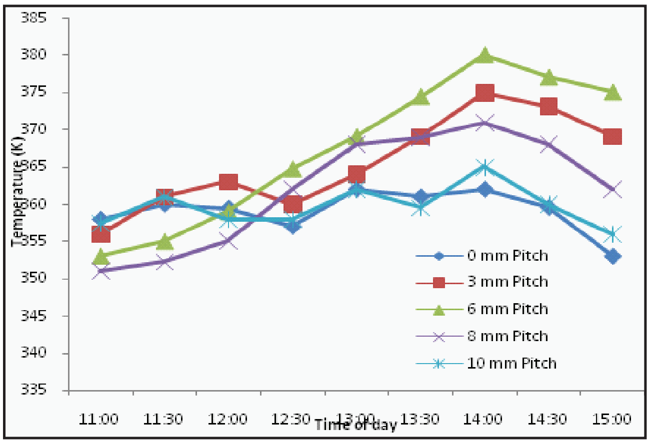


Fig. 4: Pitch Variations Graph for 6 mm Outer Diameter Coil

The above graph shows that the optimum pitch is 6 mm for the helical coil with 6 mm outer diameter. The maximum temperature is higher as compared to 8 mm coil due to higher no of turns.

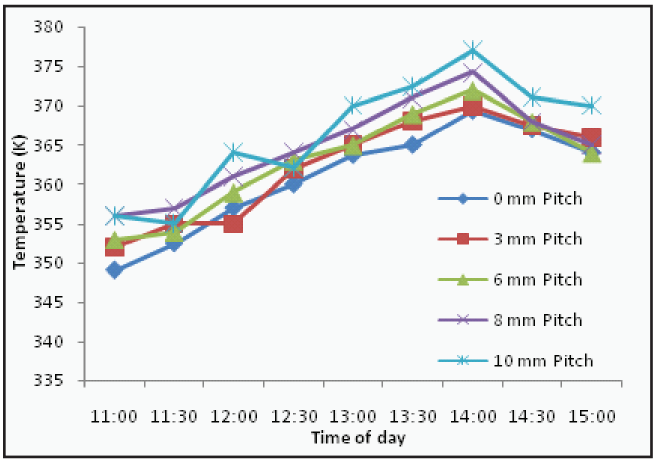
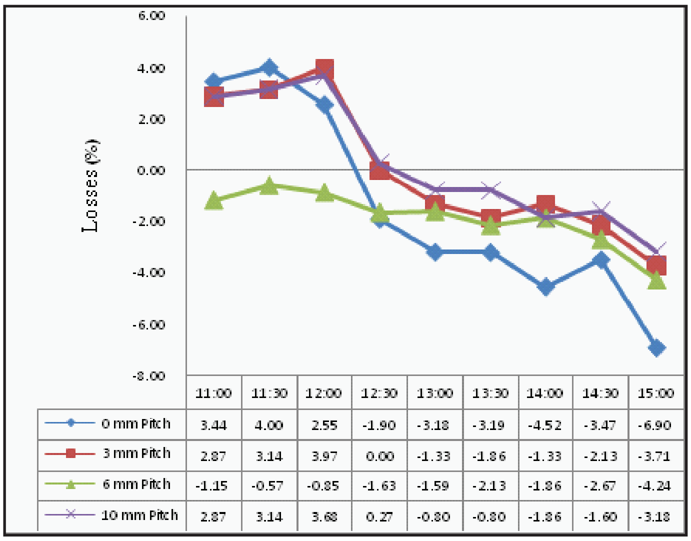


Fig. 5: Pitch Variations Graph for 10 mm Outer Diameter Coil

The above graph validates the conclusion made from early results that the optimum pitch is equal to the outer diameter of the helical coil. The maximum temperature is lower mainly due to the lower number of turns of the coil.

In other words we can say that when the pitch is equal to the outer diameter, the losses are minimum. Taking this pitch value (8 mm) as the reference for the helical coil of outer diameter 8 mm, the percentage losses for other pitch values is plotted below:-



	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00
0 mm Pitch	3.44	4.00	2.55	-1.90	-3.18	-3.19	-4.52	-3.47	-6.90
3 mm Pitch	2.87	3.14	3.97	0.00	-1.33	-1.86	-1.33	-2.13	-3.71
6 mm Pitch	-1.15	-0.57	-0.85	-1.63	-1.59	-2.13	-1.86	-2.67	-4.24
10 mm Pitch	2.87	3.14	3.68	0.27	-0.80	-0.80	-1.86	-1.60	-3.18

Fig. 6: Comparison of Pitch Variation Based on Percentage Losses

The graph compares the losses occurred during the variations in the pitch of the receiver coil. The negative sign indicates the losses incurred when the pitch variation is not optimum. The maximum losses occur for 0 mm pitch. The probable reason lies in the fact that for zero pitch coil, the incident radiation falls only on one side of the receiver hence it leads to uneven heating of coil as well as significant amount of diffused radiations are lost. The losses are compared by assuming that the 8 mm pitch is an ideal coil with zero losses excluding the convective losses and losses due to surrounding conditions.

VI. Conclusion

The helical coil receiver is a conventional choice for small scale solar parabolic dish concentrator. This research work concludes that the optimum pitch for the helical coil receiver to be utilized in the system should be equal to the outer diameter of the helical coil. The output temperature of the heating media increases with increase in pitch from zero till the optimum pitch value is achieved. Thereafter, the temperature reduces with further increase in the pitch of the helical coil receiver. The receiver efficiency can be atleast increased by 2-3% when optimum pitch value is utilized.

References

[1] Eric W. Brown,"An introduction to solar energy", 1988.

[2] Tarujyoti Buragohain,"Impact of solar energy in rural development in India", International Journal of Environmental Science and Development, Vol. 3 No. 4, 2012.

[3] Geoffrey Jones, Loubna Bouamane,"Power from sunshine: A business history of solar energy"; Harvard Business School Paper 2012.

[4] Yinghoa Chu, Peter Meisen,"Review and comparison of different solar energy technologies", Global Network Energy Institute, 2011.

[5] F. Mohammed Sukki, R. Ramirez–Iniguez, Scott G McMeekin, Brian G Stewart, Barry Clive,"Solar concentrators", International Journal Of Applied Sciences (IJAS), Vol. 1 Issue1, 2012.

[6] Carl W. Richter, Arthur G. Birchenough, Gerald A. Marquis, Thaddeus S. Mroz,"Design and fabrication of a low specific weight parabolic dish concentrator", NASA Technical Paper 1152, 1978.

[7] Lloyd C. Ngo,"Exegetic analysis and optimization of a parabolic dish collector for low power application", Centre for Renewable and Sustainable Energy Studies, University of Pretoria.

[8] Ibrahim Ladan Mohammed,"Design and development of a parabolic dish thermal cooker", International Journal Of Engineering Research And Applications (IJERA), Vol. 3, Issue 4, pp. 1179-1186, 2013.

[9] A.R. El Ouederni, A.W. Dahmani, F. Askri, M. Ben Salah, S. Ben Nasrallah,"Experimental study of a parabolic dish concentrator", Reveu Des Energies Renouvables, Vol. 12, No. 3, pp. 395-404, 2009.

[10] Ibrahim Ladan Mohammed,"Design and development of a parabolic dish for solar water heater", International Journal of Engineering Research And Applications (IJERA), Vol. 3, Issue 4, pp. 822-830, 2012.

[11] Kailash Karunakaran, Hyacinth J. Kennedy,"Thermal analysis of parabolic dish snow melting device", International Journal for Research in Technological Studies, Vol. 1, Issue 3, 2014.

[12] Fareed M. Mohammed, Auatf S. Jassim, Yaseen H. Mahmood, Mohamad A.K.Ahmed,"Design and study of portable solar dish concentrator", International Journal of Recent Research and Review, Vol III, 2012.

[13] N.D. Kaushika, K.S. Reddy,"Performance of a low cost solar paraboloidal dish steam generating system", Centre for Energy Studies, Indian Institute of Technology, Delhi, 1999.

[14] Atul Sagade, Nilkanth Shinde,"Performance evaluation of parabolic dish type solar collector for Industrial Heating Application", International Journal Energy Technology and Policy, Vol. 8, No. 1, 2012.

[15] Meenakshisundaram Arulkumaran, William Christraj: "Experimental analysis of Non Tracking solar parabolic dish concentrating system for steam generation".

[16] Manav Sharma, Nitesh Bihani, Jaykumar Vaghani, Niranjan Shinde,"Design, Fabrication and Analysis of Helical Coil Receiver with Varying Pitch for Solar Parabolic Dish Concentrator", IRD India, Vol. 4, Issue 2, 2015, pp. 49-54.

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