ABSTRACT

Solar energy is absorbed, transformed and concentrated in a solar thermal collector over a period of time to produce usable energy. The oldest of the solar technologies, i.e. dish technology dates back to 19th century when number of companies developed solar-powered steam and stirling-based systems which involve paraboloid mirrors. Their utility and characteristics (concentrating and collimating properties) were described by Greek mathematician and geometer Diocles around 200 BC. The relevance of the dish geometry is yet pervasive in several applications such as satellite dishes, reflecting telescopes, radio telescopes, parabolic microphones, solar heater and many lighting devices that include spotlights, car headlights, par cans and LED housings. Even the olympic flame is kindled by sunlight by concentrating solar energy with a parabolic dish collector. Solar concentrators involve lenses or mirrors to focus a large spread of sunlight over a small area and thus trigger significantly higher temperatures than that of non-concentrating technologies. The application of solar concentrators for heat generation (concentrator solar heating- CSH) is not new, and the first parabolic trough collector was used in 1912 for steam generation to run a $45kW$ steam engine pump in Meadi, Egypt, and the first linear fresnel collector developed in Europe in the year $1960s$. A range of solar concentrator technologies has been developed and deployed with a primary focus to generate power (concentrator solar power – CSP) since the first oil shock of the modern era $(1973/74 and 1979/80)$. India is one of the most promising countries for large-scale CSH deployment as many of its industries are of small and medium scale where in coal-fired thermal power plants are excessively utilized clean burning, controllable and low-cost natural gas is not properly reticulated across industrial zone as it often happens in many other countries. CSH technologies applications have gathered growing interest from 2000 onwards because of fossil fuel prices being on rising trend.

Therefore, this research work was carried out with an aim to develop improved systems of dish and trough type solar concentrators and performance of the same were

investigated. The geometric concentration ratio, acceptance angle, sun beam angle, rim angle and intercept factors are the primary parameters that were considered in the design of concentrating collector. The development of collector systems was done by varying the geometry of concentrator and receiver system. Above mentioned systems were used to establish a relation between receiver and aperture area to obtain optimum performance. The experiments were performed on both collector systems that have parabolic dish and trough type. The values of concentration ratio for dish and trough type collector systems are 18 and 19.77, respectively, and accordingly remaining parameters i.e. focal length, receiver dimensions were set.

In dish type solar collector system, a new approach was adopted for the heat loss analysis. The experiment on the dish type collector system was performed to collect the data for calculation of performance parameters. The pot of 20 litre capacity was used to conduct the test on the system. The oven was kept at the focus of parabolic dish type concentrator and experiments were conducted to measure solar radiation intensity (direct and Indirect) using a pyranometer, temperature at the focus of parabolic dish using a thermocouple and air velocity using hot wire anemometer to investigate the heat losses from the oven. In this system, a numerical approach has been performed to define the new parameter called performance index of the oven which represents how the performance of the system approaches concentration ratio of the parabolic dish type solar collector. Concentration ratio is assumed as the highest performance level in the analysis of parabolic dish type solar collector system. It was found that the performance index varies from 15.45 to 17.66. Moreover, losses due to conduction, convection, and radiation are investigated. The contribution of side losses to the total loss is found to be more in comparison to the other losses. These losses reduce the thermal efficiency of the dish type solar collector system. But the losses can be minimized if the oven is covered with glazing material keeping vacuum between cover and surface of the oven. Keeping these points in view, a novel receiver has been designed for parabolic trough concentrator rather than parabolic dish type concentrator so that the system can be used for water heating; air heating, flash steam generation and building heating. The system can also be treated as the basis for high pressure steam generation in future.

Researchers have used solar receivers of straight tube geometry or the tube with different configurations like internal fins, converging-diverging sinusoidal geometry, fin pin arrays, perforated plates, and twisted tape inserts in parabolic trough solar collectors. They have modified the geometry of straight tube receiver keeping vacuum within receiver tube and glass cover annulus space but no work could be found where receiver of helical coil was enclosed within two concentric glass covers having vacuum between the 1^{st} and 2^{nd} glass cover. The objective of the present study is to develop a double glazing helical coil solar cavity receiver with vacuum tube outer cell to minimize the losses for enhancing the thermal efficiency of a parabolic trough concentrator. Helical coil solar receiver with vacuum created within the space between the 1^{st} and 2^{nd} glass cover have better performance in comparison to receivers having vacuum between the receiver and 1^{st} glass cover. This happens due to the higher temperature difference between receiver and the 1^{st} glass cover than between 1^{st} and 2^{nd} glass cover. Larger temperature difference is responsible for more losses thereby lower performance of collector. Moreover, glass to glass seal is easier than that of the glass to metal seal. Therefore, vacuum within the 1^{st} and 2^{nd} glass cover adds more to the performance of collector in comparison to vacuum within the space between receivers and the 1st glass cover. Helical coil solar cavity receiver system consists of a helical coil with 50 number of turns and 24.38 *mm* pitch. The tube was covered with double glazed borosilicate glass. The space between the 1st glass and second glass cover was evacuated with an intention to reduce the losses due to convection and conduction. It was kept at a focal line of PTC. The experimental setup has been designed in such a way that it enhances heat transfer coefficient and reduces losses due to conduction, convection, and radiation. Models for determining heat, optical and exergy losses are developed for the designed experimental setup. The model developed is based on energy balance equation and is applied for the performance analysis and validation of experimental results. The models proposed in the present work relates to three different categories: optical modeling, thermal modeling, and exergetic modeling. Optical modeling included the phenomenon of utilizing sun energy to convert it into thermal energy. In this modeling, the effect of geometry, improper alignment of PTC system, tracking error, mirror and glass cover transmittance effects, and dirt/dust on aperture as well as on receiver in relation to performance were studied. Shadowing due to support bracket, tracking error, mirror and glass cover transmittance effects arising due to mirror reflectance have been studied. In thermal modeling, heat losses from heat transfer fluid to the ambient were analyzed where as in exergetic modeling, irreversibility was considered for the flow of energy from/to the helical coil solar cavity receiver.

A curve has been plotted between concentration ratio and the ratio of height to depth (σ) of parabolic trough concentrator and it was found that the practically obtainable concentration ratio, CR for which the system gets optimum performance is 81.69. The ratio of the height of the parabola to the focal length (σ) is 1.7. The relation between aperture diameter (D) and focal length (f) has also been established and the ratio of aperture diameter to focal length is found to be 5.21. The value of rim angle corresponding to the optimum value of concentration ratio is 74.97^o. The experiment was performed in summer as well in the winter season to collect the data for the designed setup of double glazing helical coil solar cavity receiver system with vacuum at outer annulus. The results obtained were compared with horizontal tube receiver for the same experimental setup. It was found that the 87.96% enhancement in the convective heat transfer coefficient if horizontal tube receiver is replaced by double glazing helical coil solar cavity receiver. Maximum conversion efficiency achieved is 95% which is 21% more than that would be achieved for horizontal tube receiver. The vacuum significantly reduces the losses which are evident from a relatively higher temperature of a 565 K obtained at the surface of the helical coil. Heat loss from helical coil solar cavity receiver has also been investigated and it was found that with the increase in vacuum pressure at annulus by 50%, the losses from the receiver has been increased by 26.67%.The heat loss from receiver has been observed to be proportional to the vacuum pressure within the annulus space. Present work also investigates how the quality of vacuum degraded with the temperature of the glass cover. The rate of degradation of vacuum at annulus was found to be 2 $torr/min$ at a temperature of 350 K. The artwork used in the present thesis for drawing, simulation, and plotting purposes is being performed by using MATLAB, SOLIDWORKS, ORIGIN, EES etc.