Chapter 5

Results and Discussion

This section includes the results and their explanation using various relevant literature. Results of performance of both parabolic dish and trough type solar collector systems was elaborated. Environmental as well as the experimental data are collected to analyze the effect of wind speed, wind direction, solar radiation intensity, relative humidity and the ambient temperature on the performance of receiver. Effect of vacuum pressure at the annular space of receiver on heat loss that occurs from receiver to ambient has been investigated.

5.1 Parabolic Trough Type Solar Collector

Parabolic trough solar collector is a line concentrating unit. In this unit, reflected solar radiation from the aperture of parabolic trough is intercepted by the newly designed helical coil solar cavity receiver with vacuum tube at outer annular space. The performance analysis has been done using experimental data obtained on the experimental setup on typical days March, April 2017. In the present experimental set up, losses have been minimized using helical coil solar cavity receiver with double glazing vacuum tube outer cell. The present research provides a comprehensive design of helical coil solar cavity receiver and its performance analysis under the Varanasi climatic zone. A blackened helical coil copper absorber tube was covered with two concentric borosilicate glass having vacuum at annulus, kept at the focal line of a parabolic trough concentrator. A parabolic trough concentrator with aperture area of $2.23\,m^2$ and receiver area of $0.113\,m^2$ was kept under solar radiation intensity in such a way that surface azimuth and tilt angle of the system became equal to solar azimuth and zenith angle respectively. The validation of model used in this analysis has been done using EES software. Input parameters have been obtained on experimental set up dated from 03.04.2017 to 14.05.2017 with the variation of vacuum pressure from 1 $torr$ to 760 $torr$. Following are the results which have been obtained on experimental set up and explained below.

5.1.1 Environmental Parameters

From fig. 5.1 to 5.4 show the variations of environmental parameters like ambient temperature, direct solar radiation, wind speed and relative humidity with respect to time of the day on dated January to May, 2017. Although, the data has been collected through out the year 2017 but some of the data from January to May, 2017 have been adopted for calculation and during these months the data on experimental setup was extracted. High value of air temperature reduces convection loss from helical coil solar cavity receiver. Parabolic trough technology performs well at high value of direct radiation and low value of air speed. Solar radiation intensity, Wind speed and its direction were measured by weather monitoring station installed at roof top near experimental set up at CERD, IIT (BHU). Fig. 5.3 shows clearly that the wind speed is fluctuating in nature with respect to time of the day thereby too much sensitive in the performance analysis of PTC system. Direction of air speed plays vital role in losses because parabolic trough concentrator is a line concentrating unit. When air flows along the length of helical coil, losses will be higher in comparison to the flow of air in any other directions. Relative humidity affects the solar radiation intensity. Increase in the value of relative humidity will increase the percentage of water droplets thereby increase in scattering effect and hence reduce the intensity of solar radiation. Optical path length is also affected by relative humidity. Direct solar radiation intensity reduces as the optical path length or air mass increases during the day hour. Environmental parameters are vital in solar thermal applications and hence environmental data analysis is important for the best study of solar parabolic trough concentrated technology.

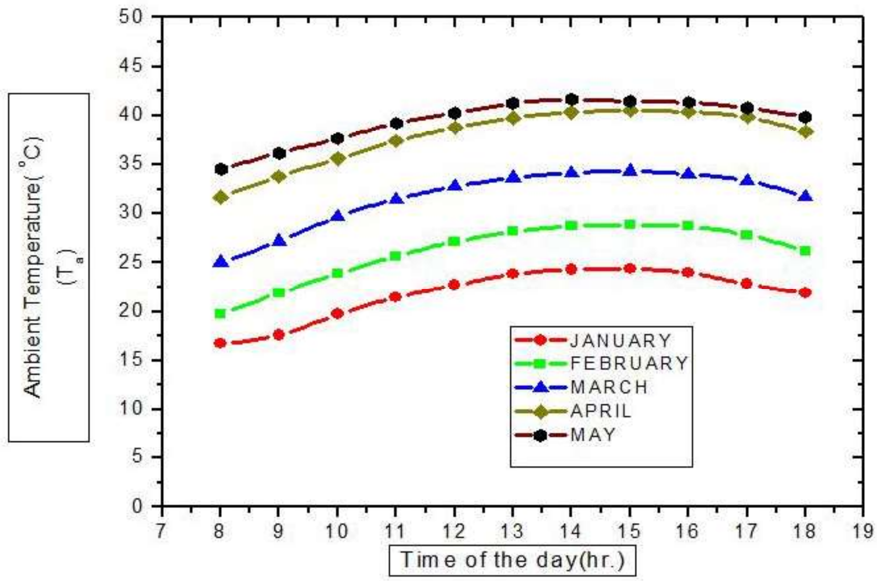

Figure 5.1: Variation of ambient temperature with time of the day

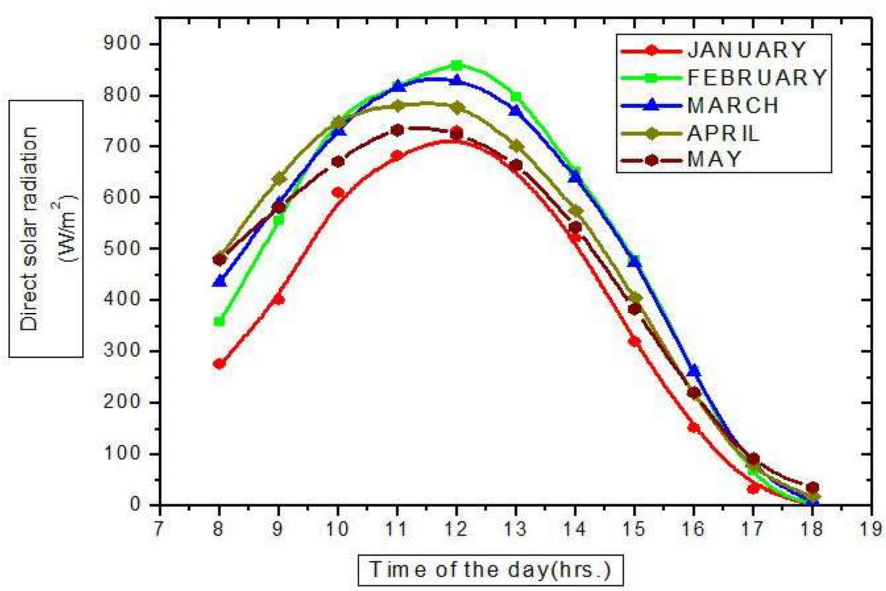

Figure 5.2: Variation of direct solar radiation with time of the day

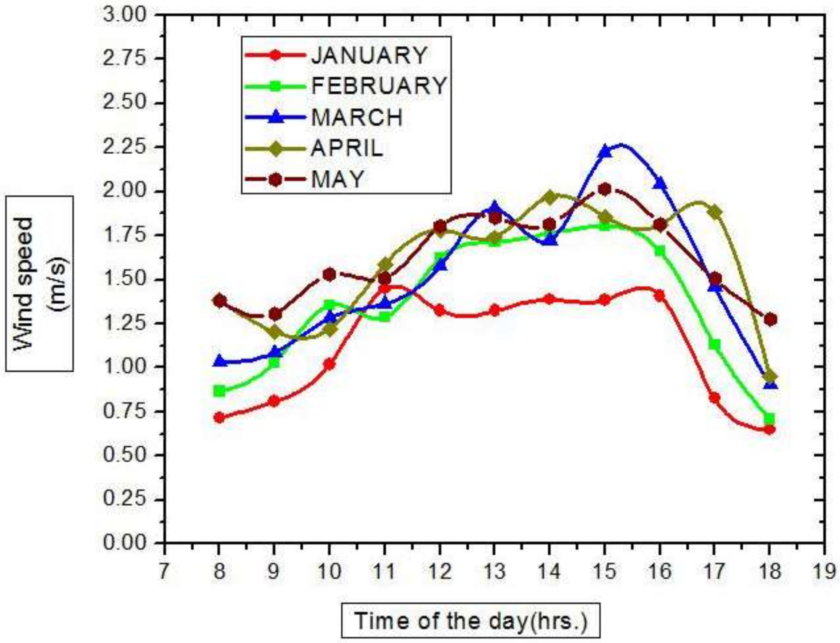

Figure 5.3: Variation of wind speed with time of the day

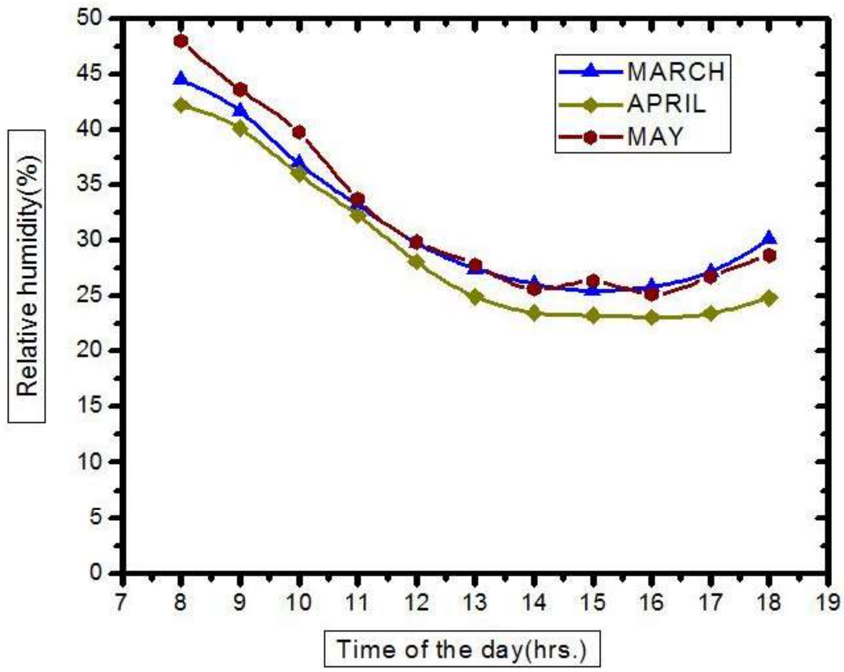

Figure 5.4: Variation of relative humidity with time of the day

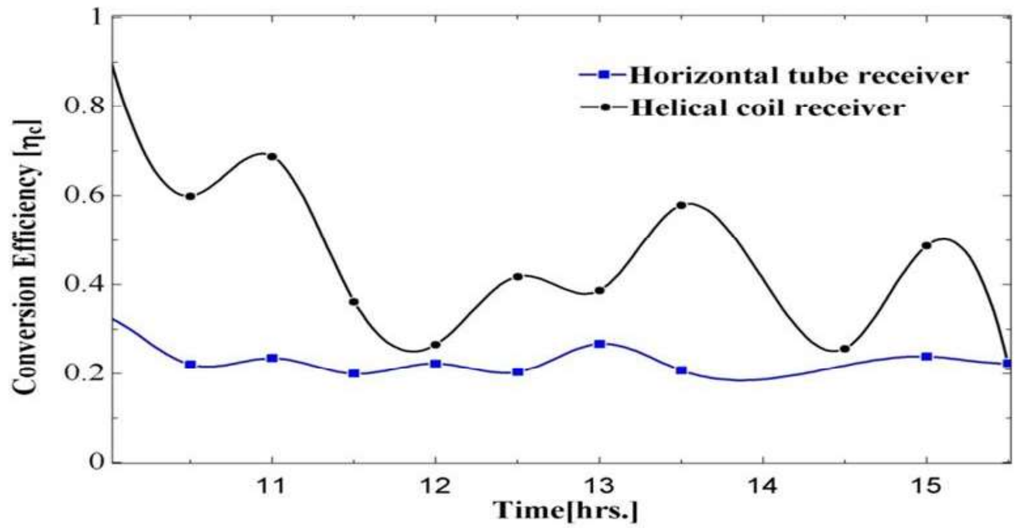

Figure 5.5: Comparision of double glazing helical coil receiver with the horizontal tube receiver under the enviromental contions: solar radiation intensity range $600-900W/m^2$ and the wind speed range $0.3-2.0m/s$

5.1.2 Conversion Efficiency

In this section, an experimental analysis to determine the performance of the parabolic trough concentrator has been carried out under the climatic conditions of Varanasi (Latitude 25.31 and Longitude: 82.97), Uttar Pradesh, India. Since, the meteorological cycle on average repeats itself every year, the results presented here would be invariant of change in year. Fig. 5.5 shows the comparision between the helical coil receiver and the horizontal tube receiver of the parabolic trough concentrator in terms of conversion efficiency.

Fig. 5.5 represents how the conversion efficiency of double glazing helical coil receiver and empty horizontal tube receiver (non evacuated) varies with respect to the time of the day. Above figure for conversion efficiency has been plotted considering all environmental conditions of Varanasi climatic zone with solar radiation intensity range $600-900W/m^2$ and the wind speed range $0.3-2.0m/s$. X-axis represents the time of the day in the plot because all the parameters that affect the conversion efficiency depends upon the time. Solar radiation intensity, wind speed, wind direction, air temeperature and relative humidity all these parameters vary from morning to evening. It was found clearly from the plot that the maximum conversion efficiency for bare horizontal tube receiver and evacuated helical coil receiver are 31% and 85% respectively. However, some of the researchers like Milton Matos Rolim et al. (2009)[145]and of Dudley et al. (1994) [164]examines the variation of conversion efficiency for evacuated horizontal tube receiver with respect to the temperature difference which exists between mean fluid temperature and the ambient temperature. They found the maximum conversion efficiency of 73%. Ricardo Vasquez Padilla et al.(2011)[177] also study the variation of conversion efficiency with the average temperature of receiver above ambient in the case of evacuated horizontal tube receiver and found the maximum conversion efficiency of 73%. In all those cases, the receivers are sigle glazing evacuated horizontal tube and conversion efficiency being a continuously decreasing function. In the case of double glazing evacuated helical coil solar cavity receiver, this function is not continuous but shows the continuous formation of maxima and minima in the plot. This is due to the fluctuation of solar radiation intensity and wind speed during sun shine hour. On the whole, it can be realize that the conversion efficiency depends on mainly the two thinks, first the environmental conditions and second the design of receiver system. It will be some what difficult to control over the environmental changes but the efficient design of solar receiver is totally in our hand.

5.1.3 Effect of Vacuum Pressure and Wind Speed

It is novel to create vacuum in annulus to minimize losses in PTC system. Fig. 5.6 shows clearly the variation of heat losses with annulus vacuum pressure under the Varanasi climatic conditions during the months of March to June, 2017. Result shows that the vacuum level is a parameter that strongly affects heat losses from helical coil solar cavity receiver. Pressure in the annulus is varied from 10 *torr* to 50 *torr* during the course of experiment. The pressure greater than 50 *torr* add to tremendous losses where as the vacuum pressures below 10 *torr* contribute significantly to the performance of system owing to reduce more losses. Effect of pressure at annulus on heat loss has been investigated by R. Vinuesa et al.(2016) [178]. They kept air and hydrogen separately in the vacuum chamber below

10 $torr$ and analyse the loss due to convection from evacuated metallic tube receiver. R. Forristall (2003) prepared a technical report under National Renewable Energy Laboratory, U.S. Department of Energy Laboratory, presents the variation of heat loss per unit length of receiver with respect to the annulus pressure in torr. Annulus pressure was varied from 0.0001 $torr$ to 1000 $torr$ and losses has been observed for single glazing evacuated metallic tube receiver. The plot in this report shows clearly that the pressure in the vacuum chamber below 0.1 $torr$ add maximum to the performance of parabolic trough receiver. The vacuum chamber pressure greater than 100 $torr$ increase losses rapidly thereby reduce thermal performance. In the present work, the pressure in the vacuum chamberhas been varied between 10 $torr$ to 50 torr to analyse the performance of double glazing helical coil solar cavity receiver with vacuum chamber at outer annulus.The trough and crest formation in fig. 5.6 is due to the flow of wind along or across the length of helical coil solar cavity receiver and the impact of relative humidity. Appearance of maxima and minima on the above plot is very interesting and it includes the effect of all environmental parameters described earlier. Solar radiation intensity on earth's surface is affected by relative humidity but it is beam radiation not the global radiation that is affected by relative humidity.

The values of relative humidity, solar radiation intensity and ambient temperature for the month of April, 2017 at 01:00 are 26%, 731 W/m^2 and 39.6^oC respectively as shown in environmental data tab. 3. It was found that 3.84% increase in relative humidity is responsible the decrease in the intensity of solar radiation by 16%. Antonio J. Gutiérrez-Trashorras et al.(2018) [179] reported in their paper the variation of monthly average solar radiation in clean and turbid atmosphere and prove the effect of relative humidity on solar radiation. Jiann Lin Chen et al.(2017) [180] also presented the variation of solar irradiance with relative humidity. They found that 0.91% increase in relative humidity is responsible for the decrease in the intensity of solar radiation by 12.58%. Another environmental parameter that affects the formation of maxima and minima in the above plot under discussion is wind speed. It has been shown clearly in the fig. 5.8 that how the heat loss coefficient varies with respect to wind speed when solar receiver is exposed

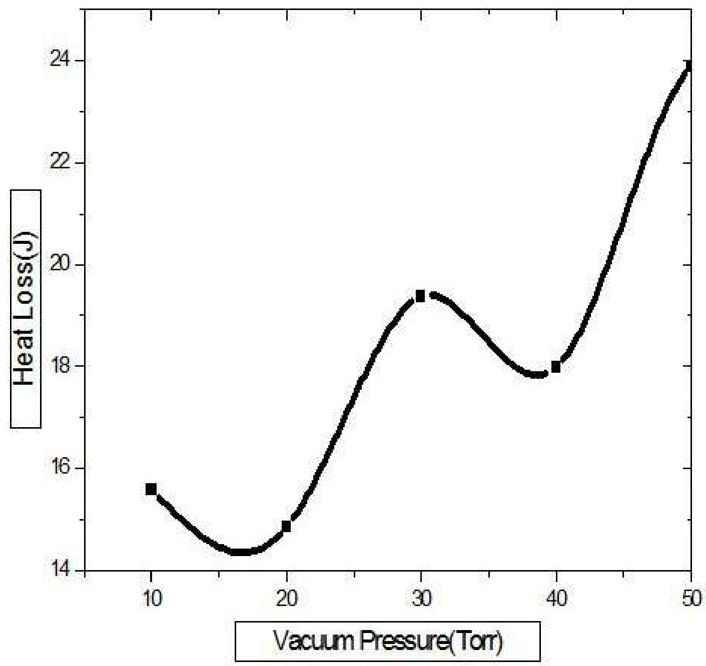

Figure 5.6: Variation of heat loss with respect to vacuum pressure

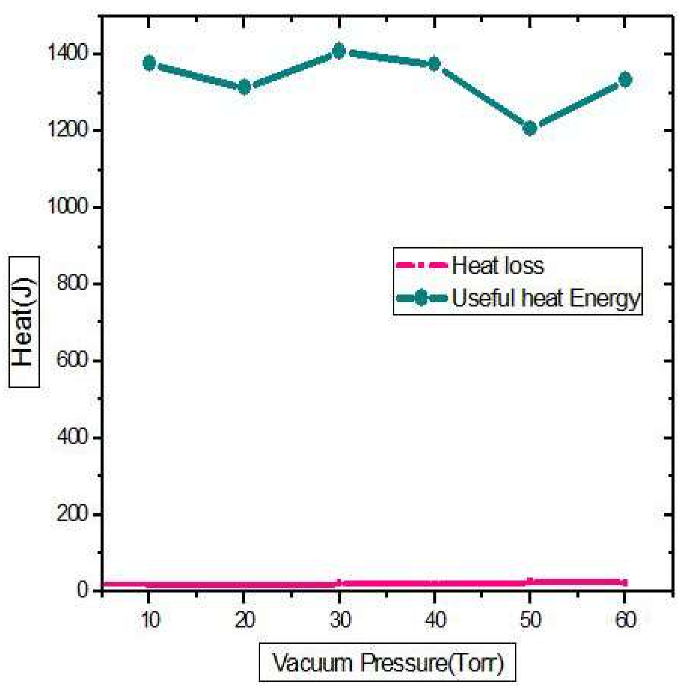

Figure 5.7: Variation of useful energy and heat loss with vacuum pressure

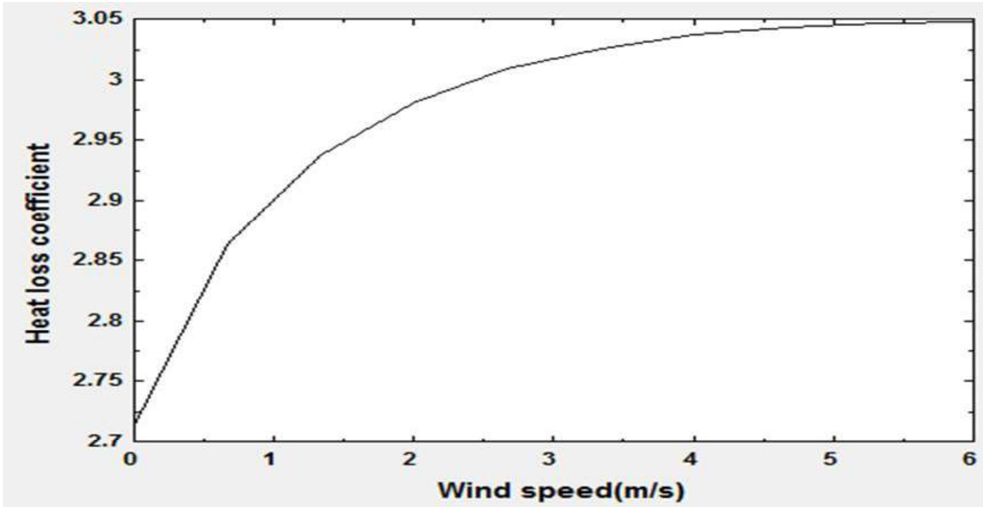

Figure 5.8: Variation of heat loss coefficient with respect to wind speed

to atmosphere. McAdams (1954) suggests the effect of wind speed on loss coefficient over flat plate collector. He found that the trend is linear with a constant slope 3.8 but the trend becomes non linear with decreasing slope in the case of flow of wind over helical coil solar cavity receiver. Fig. 5.7 shows the difference between useful energy gain and heat losses. Useful energy curve appears at the top of the plot while the heat loss curve appears at the bottom of the plot. This significant difference between the useful energy gain and heat loss shows the beauty of helical coil solar cavity receiver.

5.2 Dimensionless Numbers for Internal Flow through Helical Coil Solar Cavity Receiver

Figs. 5.9, 5.10, 5.11 represent the curves for Nusselt number which varies with Reynolds number, Prandtl number and curvature ratio respectively for the present experimental setup. Fig. 5.12 shows the curve Dean number versus Reynolds number for internal flow through helical coil solar cavity receiver. The correlation for Nusselt number between heat transfer fluid and helical coil tube has been used for constant heat flux boundary conditions were proposed by Xin et al.(1997). Fig. 5.9 illustrates a variation of Nusselt number with Reynolds number for different curvature ratio for boundary conditions of constant heat flux. It can be shown in fig. 5.11 that the Nusselt number increases when the curvature ratio varies from 0.1 to 1. For a helical coil tube with a certain diameter, a greater curvature ratio means that the radius of curvature is small; therefore the helical tube has more turns than helical tubes with smaller curvature ratios. As a result, fluid flowing through the tube has to change its main flow direction more times. Therefore, the forced convection provided by Dean vortices works longer but at the same time it increases the pressure drop. The similar study has been done by Hui Zhu et al.(2014) [181] for spiral tube. Therefore, greater value of curvature ratio favour the enhancement of convective heat transfer coefficient through the coil tube but at the same time more input power will be required for that flow. Although, repeated experiments has been done throughout the year from January to December 2017 except in rainy season but the data obtained on April 27, 2017 has been used for performance analysis proposes. Since, the climate change is very much sensitive to thermal performance of parabolic trough concentrator that is why the study of climate change or its variation with time of the day is important. Parabolic trough technology performs well at high value of direct radiation and low value of air speed. Solar radiation intensity, Wind speed, wind direction and ambient temperature were measured by weather monitoring station installed at roof top near experimental set up at CERD, IIT (BHU).

5.3 Temperature and Heat Flux Distribution over Helical Coil Receiver System

When solar radiation falls on aperture of a parabolic trough concentrator then the intensity at the focus (receiver) is equal to the concentration ratio times the intensity that would be falls on aperture. The temperature of receiver is strictly increasing for a certain period of time goes up to a maximum value and then decreases as shown in fig. 5.14. For the time duration 10:15 am to 10:45 am temperature increases without fluctuation even the intensity of solar radiation fluctuated between 450 W/m^2 to 770 W/m^2 with the variation of wind speed in the range of 0.1 to 1.6 m/s^2. After half an hour i.e. after 10:45 am

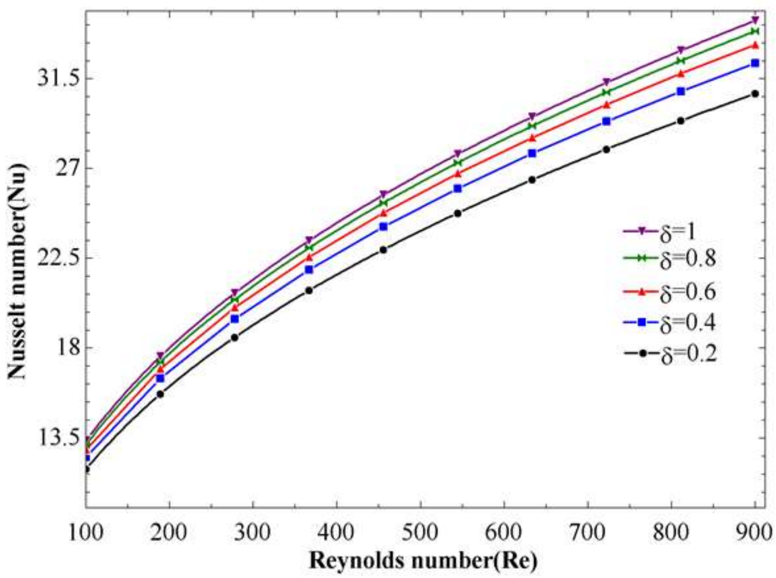

Figure 5.9: Variation of coiled tube Nusselt number with Reynolds number for different curvature ratio

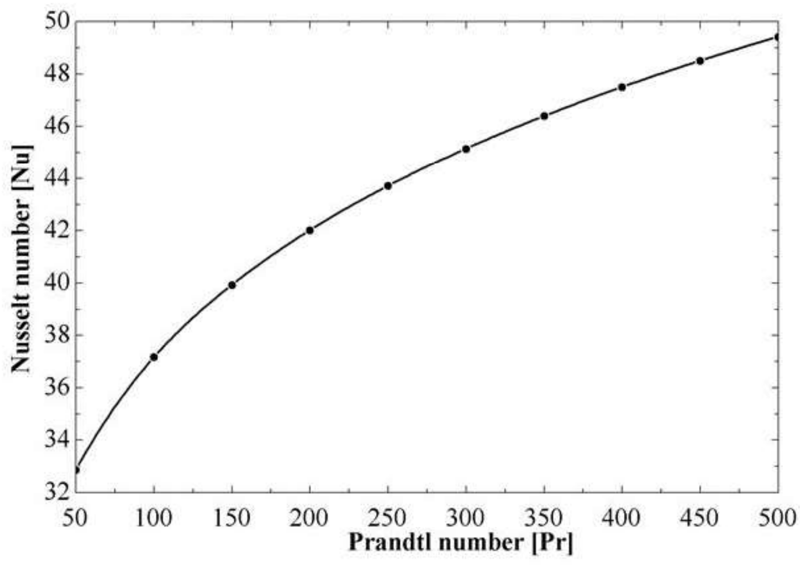

Figure 5.10: Variation of coiled tube Nusselt number with Prandtl number

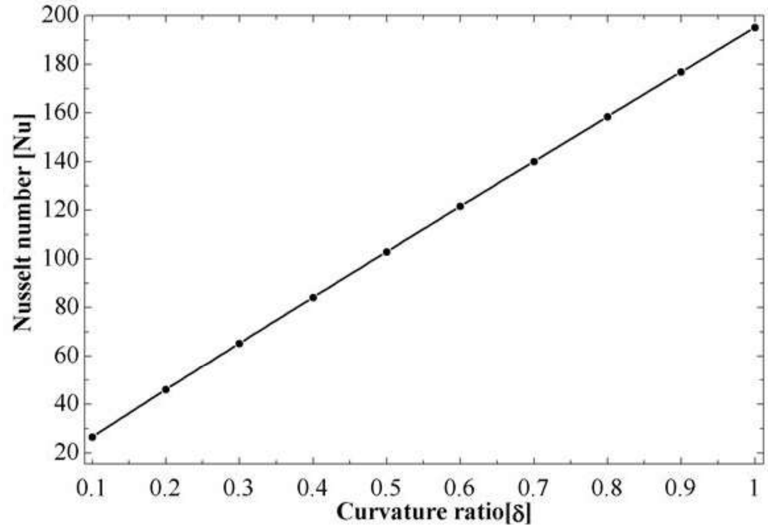

Figure 5.11: Variation of coiled tube Nusselt number with curvature ratio

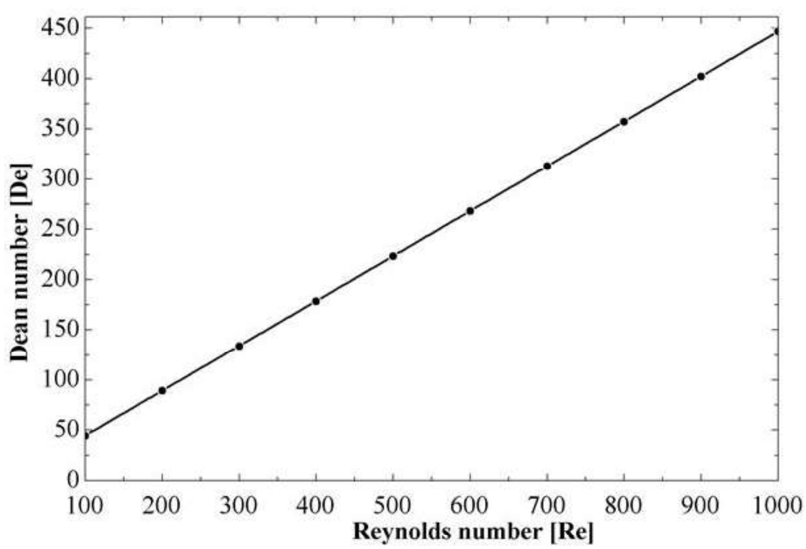

Figure 5.12: Variation of Dean number with Reynolds number

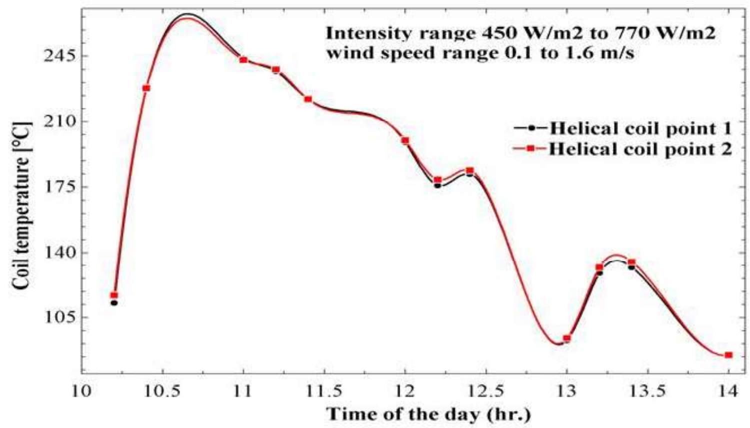

Figure 5.13: Temperature distribution over the helical coil surface of receiver

temperature decreases with tremendous fluctuations with continuous maxima and minima appearing in the plot. Physical significance of the plot is that the experiment should be conducted after 10:45 am since at this temperature the steady state condition reached. After that receiver temperature is too much sensitive to the fluctuation of solar radiation intensity and wind speed and hence the experiment can be started after this point of time.

Above plot also shows the isothermal behavior of helical coil solar cavity receiver at the focus of a parabolic trough concentrator since the J-type thermocouple had been kept at two different points of receiver. Temperatures at two different points are approximately same which also illustrates the line concentrating ability of the experimental setup. Uniform temperature distribution throughout the line of helical coil receiver indicates the uniform solar radiation intensity distribution over the entire length of parabolic trough receiver.

Fig. 5.14 represents how the temperature of helical coil receiver, glazing cover surface and the environment under which experiment has been conducted. This variation was found in winter season November-December 2017 where the temperature of helical coil receiver reached up to548K but in summer season, the temperature of helical coil surface was reached up to 565 K. The difference in temperature of helical coil surface in summer and winter season is due to the reason: solar radiation intensity and loss to environment. In winter season, the solar radiation intensity range 600 W/m^2 to 800 W/m^2

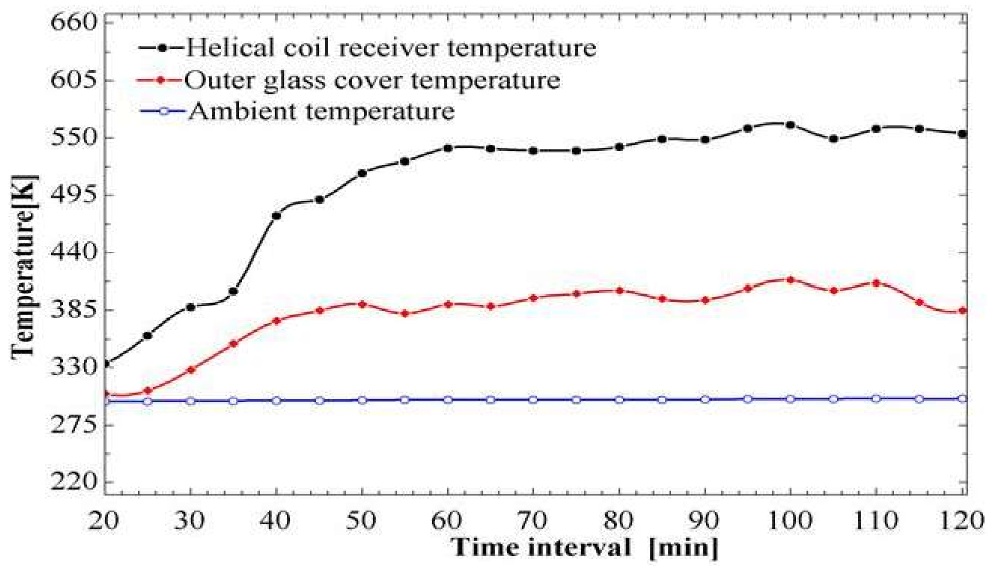

Figure 5.14: shows the higher temperatures of helical coil receiver in comparison to the temperature of the glass cover and the ambient

is available for a short span of time while in summer season the same intensity range is available for higher duration. At the same time, the losses are more if the receiver is kept in the environment of lower temperature as in the case of winter season. In summer season, losses are lower in comparison to the winter season. However, the wind speed as well as wind direction have the greater contribution towards the heat losses and hence in this case, the combined effect of wind potential as well as ambient temperature are essential for the comparison of losses in summer and winter season. The parameters that contributes to the variation of temperature of receive surface with respect to the time of the day has been shown in fig. 5.14. Solar radiation absorbed by the helical coil receiver is first passes through the two concentric borosilicate glass cover; responsible for high difference difference between the helical coil receiver surface and the surroundings. Borosilicate glass has the property that would allow only lower wave length radiation to pass through it and at the same time it protects the radiation of higher wavelength that is radiated by the helical coil receiver at lower temperature of up to 600 K.

Above plot represents the solar absorption phenomenon:the extent of solar absorption by the environment, the glass cover, and by the helical coil receiver. The solar absorption into the glass cover is treated as a heat flux to simplify the performance model.

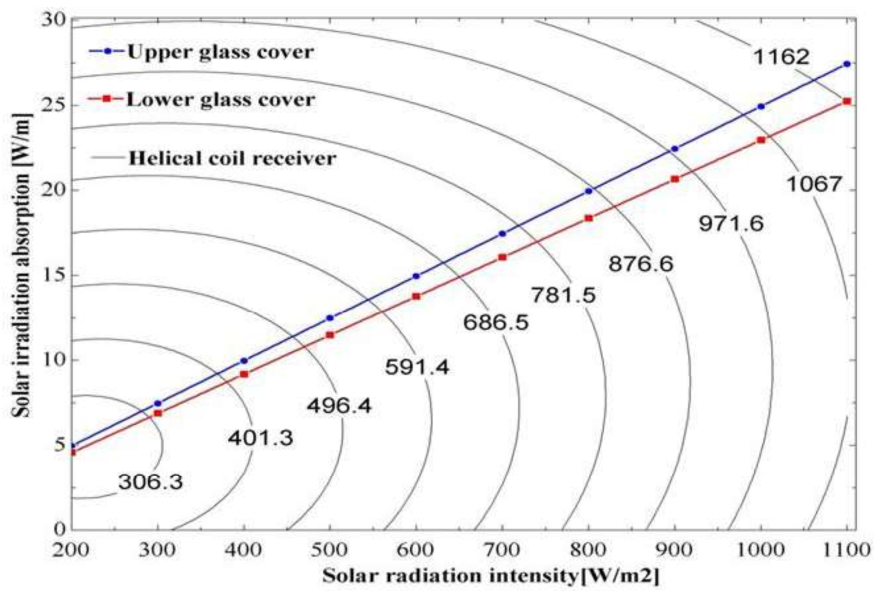

Figure 5.15: shows the solar irradiation absorption by the lower and upper glass cover and the helical coil per unit length of receiver

Physically this is not true. The solar absorption in the glass cover is a heat generation phenomenon and is a function of the glass thickness. However, this assumption introduces minimal error since the solar absorptance coefficient is small for glass, 0.02 [Touloukian and DeWitt 1972], and the glass cover is relatively thin, 2.5 mm. Solar irradiation absorption per unit length of the helical coil receiver system (helical coil , lower glass cover and upper glass cover) has been shown in fig. 5.15. Contour line presents the constant heat flux lines that have been absorbed by helical coil receiver and straight lines indicate the solar irradiation absorption by the lower as well as upper glass cover. Only 4% of the total solar radiation which falls on receiver system is absorbed by the upper and lower glass cover and the rest is absorbed by helical coil receiver through which heat transfer fluid is flowing. Glass envelop over helical coil is important to reduce losses but while entering the solar radiation through it, some percentage of solar radiation is absorbed by covers depending upon its thickness and at the same time if thickness is lower then there is a case of failure due to lack of material strength. To overcome these problems a robust design of helical coil receiver system is required so that material failure as well as radiation absorption phenomenon can be minimized. In the present experimental setup, glass thickness has been taken as 2.5 mm which is standard for helical coil solar cavity receiver

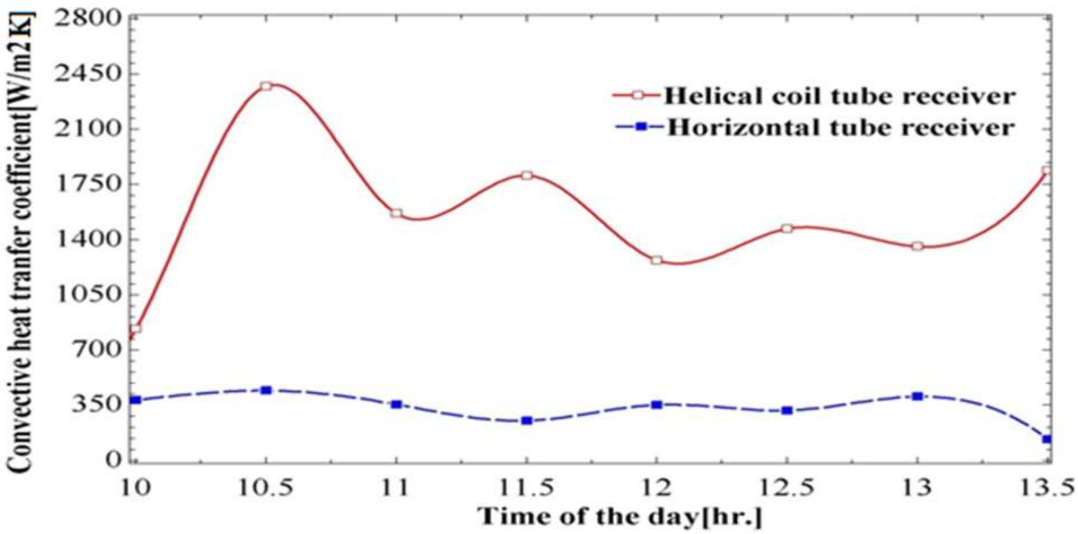

Figure 5.16: Comparison of convective heat transfer coefficients for horizontal and helical coil receiver with respect to time of the day

system.

5.3.1 Comparison of Horizontal Tube Receiver and Helical Coil Tube Receiver

Above plot shows the comparison of helical coil tube receiver and the horizontal tube receiver for the same experimental setup. First experiment was done using horizontal tube receiver with inner diameter of 0.023 m and thickness of 0.002 m and then second experiment was done by replacing horizontal tube receiver with double glazing helical coil receiver having coil tube diameter of 0.005 m and curvature ratio of 0.2. In both cases, copper material is used. Convective heat transfer coefficients were found experimentally in both cases and compare the variations with respect to time of the day as shown in fig. 5.16. It is clear from the graph; the value of convective heat transfer coefficient is more in the case of helical coil in comparison to horizontal tube receiver. In the case of horizontal tube receiver, the value of convective heat transfer coefficient is almost constant while in the case of helical coil the value of h varies with maxima and minima formation continuously with respect to time of the day. This variation of convective heat transfer coefficient in the case of helical coil is due to the following reasons: secondary flow due to centrifugal force and the variation of viscosity of thermal oil with temperature. That

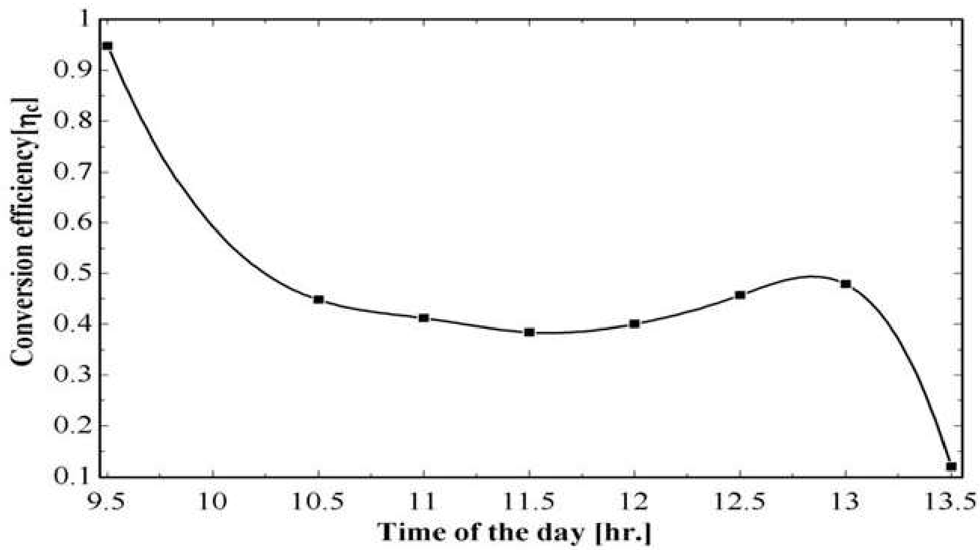

Figure 5.17: Solar to thermal conversion efficiency as a function of time of the day for evacuated tube parabolic trough concentrator

is why the flow through a curved pipe has been attracting much attention and helical coiled pipes are widely used in practice as heat exchangers and chemical reactors. This secondary flow in the tube has significant ability to enhance the heat transfer due to mixing of fluid. The intensity of secondary flow developed in the tube is the function of coil tube diameter(d) and coil diameter (D) as suggested by Dravid et al.and Naphon et al. The several studies have indicated that the helical coiled tubes are superior to the straight tubes when employed in heat transfer applications. The centrifugal force due to the curvature of the tube results in the secondary flow development which enhances the heat transfer.

5.3.2 Conversion Efficiency of Parabolic Trough Concentrator

The conversion efficiency of solar radiation intensity into thermal energy, calculated as:

$$\eta_c = \frac{Q_u}{I_a A_a} \tag{5.1}$$

has been plotted as shown in fig. 5.17 Conversion efficiency of parabolic trough concentrator system first decreases as time of the day increases then becomes constant for a certain period of time and finally decreases rapidly with respect to time of the day. Initially, the helical coil receiver is kept at high temperature (250^oC to 280^oC) and then the thermal oil is allowed to flow through it. Since the temperature of helical coil is larger at the start of experiment and hence the conversion efficiency as shown in fig. 5.17 is higher. As the time duration of experiment increases, a time comes when the stagnation temperature will be reached. Here the stagnation temperature means the temperature with minimum fluctuations when the thermal oil and helical coil inner surface comes in contact with each other with time of the day. After the stagnation temperature reached, the conversion efficiency becomes approximately constant between 10:30 am to 1:00 pm. After 1:00 pm, the difference between the inlet and outlet temperature of thermal oil flowing through the helical coil decreases as shown in figure 5.18 thereby decrease in the useful energy gain by thermal oil but there is no considerable change in the intensity of solar radiation between 1:00 pm to 2:00 pm as shown in figure 5.17 i.e. why after 1:00 pm conversion efficiency decreases rapidly. Conversion efficiency also depends on the temperature difference between glass cover and the surroundings. Greater the difference between receiver temperature and the surroundings greater will be the convective and radiative losse. Milton Matos Rolim et al. (2009) compares the simulated results with the experimental data of Dudley et al. (1994) and they found that the same trend of decreasing conversion efficiency with respect to the temperature difference which exist between mean fluid temperature and the ambient temperature. Air speed also affects the conversion efficiency since major losses occurs due to wind speed.

Figure 5.19 represents how the fluid outlet temperature through the helical coil varies with respect to the fluid inlet temperature. An exponential curve fitting has been plotted using experimental data that have been collected on 24.04.2017 at the roof top of CERD, IIT (BHU), Varanasi. It was found that the correlation which exits between the receiver exit and inlet temperatures is . In each cycle, the heat transfer fluid takes heat from solar radiation while flowing through helical coil and then gives it to water in the tank. Figure 5.18 compares the temperatures at the inlet and exit of helical coil solar cavity receiver. Larger temperature difference between the heat transfer fluid at inlet and exit of helical coil accounts for the high value of useful energy gain and hence higher conversion efficiency. The film coefficient between the thermal oil and receiver wall is

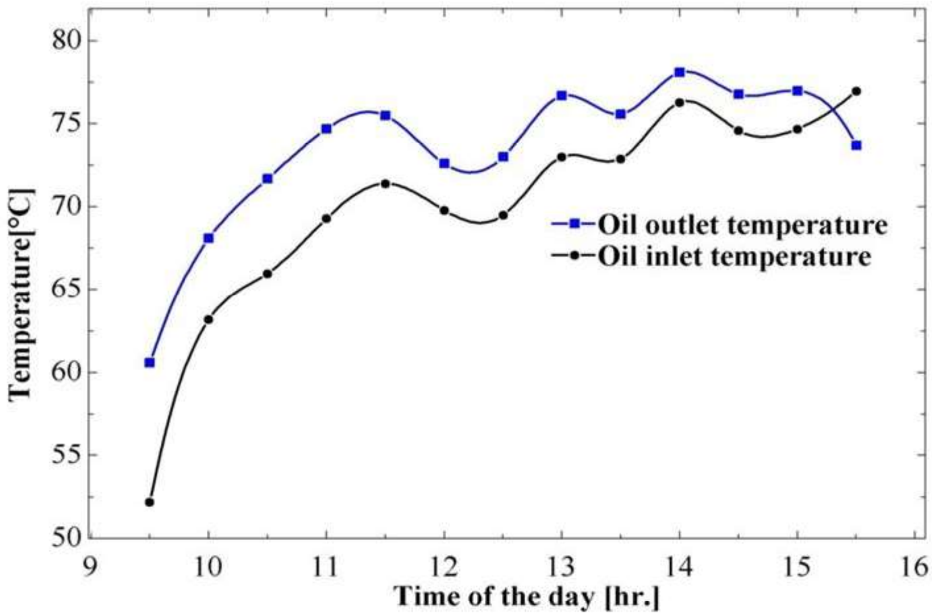

Figure 5.18: Variation of inlet and outlet temperature of heat transfer fluid as a function of time of the day

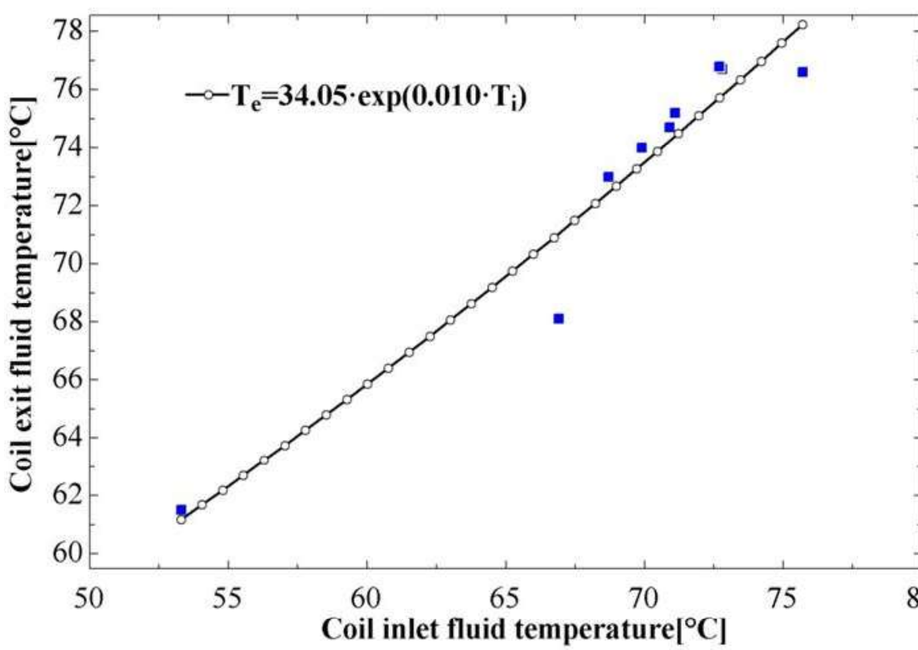

Figure 5.19: Variation of exit fluid temperature as a function of inlet fluid temperature for the flow of thermal oil through the helical coil solar cavity receivery

more in the case of helical coil receiver in comparison to horizontal tube receiver and hence the temperature difference between the fluid inlet and exit of helical coil is more as compare to horizontal tube receiver. It was found experimentally that the value of film coefficient in the case of double glazing helical coil is 87.96 % more than that of horizontal tube receiver. When horizontal tube is converted into helical of with customize receiver length and diameter, the change in surface area is only 9.96 % but change in the value of heat transfer coefficient is 87.96 %. Although, increase in surface area is responsible for losses but due to the helical coil enclosed by two concentric double glazing surfaces, resistance to loss increases and hence the difference in temperatures at the inlet and outlet of helical coil increases as compared to horizontal tube receiver.

5.3.3 Effect of Pressure at Annular Space on the Performance of Helical Coil Receiver

The heat gain, heat losses and efficiency were calculated by many researchers for the horizontal tube receiver at different vacuum level in the annulus space. Different values of the annulus pressure were selected to study its effect on the heat transfer by convection from the absorber tube to the envelope glass at different absorber tube temperature. In all those cases, receivers were horizontal tube where the vacuum was created at the annular between metallic receiver and the glass cover. In the present performance analysis of parabolic trough concentrator, a receiver has been designed in such a way that horizontal tube is replaced by helical coil and vacuum has been created at the annular of two concentric glass covers which encloses the helical coil receiver. Figure 5.20 represents how the receiver temperature varies as a function of time interval with different pressures at the annulus. Receiver temperature at 350 *torr* is more than that of receiver temperature at 650 *torr*. Increase in pressure at the annulus results in the decrease in receiver temperature thereby increase in the losses due to convection, conduction and radiation. Creation of vacuum at the annulus of two concentric glass cover is better than that of the vacuum created between the space of receiver and glass cover. Double glazing surfaces over helical coil receiver as described in the present experimental work are isothermal due to its high

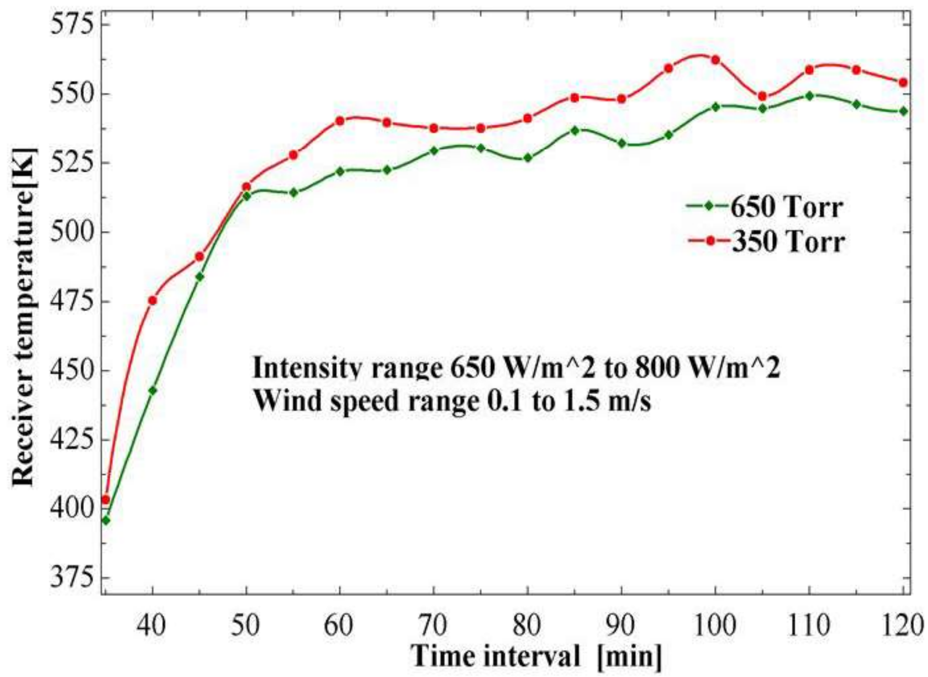

Figure 5.20: Variation of helical coil receiver temperature as a function of time interval at different annulus pressures under the given conditions of solar radiation intensity and wind speed

transitivity and small gap between them. Due to isothermal surfaces, no losses occur between these surfaces either by conduction, convection or radiation since losses depends on temperature difference. This is the beauty of creating vacuum at the annulus of two concentric glass cover than that of space between receiver tube and glass envelop. Guillermo Espinosa-Rueda et al. [182] plot the curve which represents the variation of glass cover temperature with the pressure at annulus for single glazing horizontal tube receiver. They varied the vacuum at annulus from 76 $torr$ to 760 $torr$ and found the variation of glass cover temperature from 60^oC to 80^oC. Higher pressure at the annulus accounts for the higher glass cover temperature thereby more losses. The present experimental setup in which vacuum has been created at the annulus space of two concentric glass covers, the glass cover temperature varies from (57^oC) to (73^oC) with the same variation of annulus pressure from 76 $torr$ to 760 $torr$. Figure 5.21 shows the very interesting results about how the quality of vacuum degraded with the time of the day even if there is no chance of leakage through any porous holes. This experimental result has been observed during the month of November- December 2017 when the experiment was performed under low

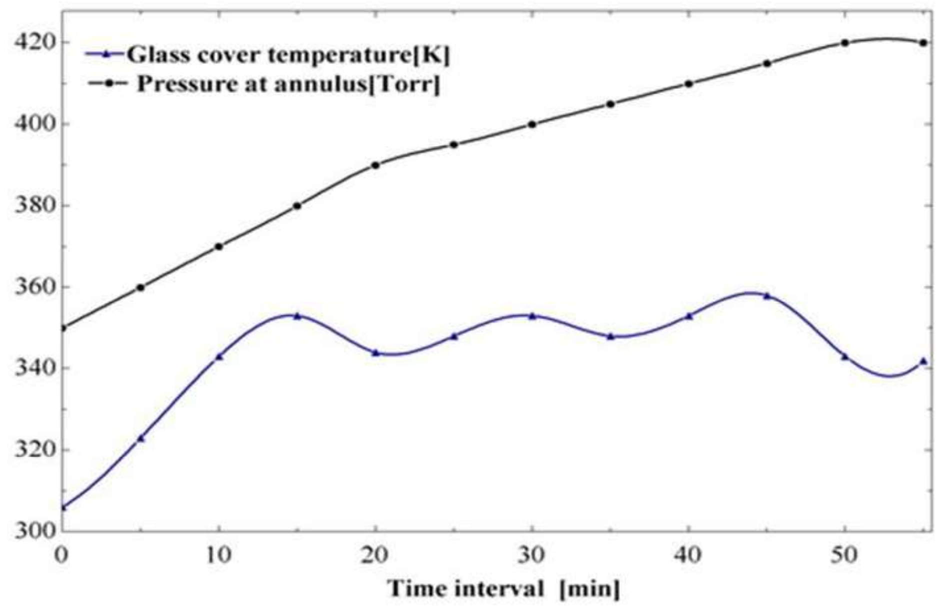

Figure 5.21: Quality of vacuum degraded with glass cover temperature

vacuum pressure at annulus (pressure of about 750 $torr$). At this pressure a large number of air molecules is present at the annulus space due to which expansion of air starts. As the time interval for the experiment increases, intensity of solar radiation increases thereby increase in back pressure due to the expansion of air molecules at the annulus space. Above figure shows clearly that the experiment was started at the annulus pressure of 350 $torr$ after some time the pressure rise up to 420 $torr$. Lower pressure at the annulus always favours the performance of receiver. Lower pressure at annulus increases heat gain by thermal oil at the same time it reduces loss due to conduction and convection. To overcome the loss of vacuum due to expansion air at annulus, it is desirable to calculate the rate of change of pressure at annulus. Above figure shows that the $dp/dt = 2\,torr/min$ i.e. rate of increase of pressure at annulus is $2\,torr/min$ under the constant environmental conditions. Vacuum must be created at the same rate at the annulus using rotary vane vacuum pump by creating bypass air. The same provision has been done in our experimental setup installed at the roof top of CERD, IIT (BHU), Varanasi to maintained the quality of vacuum thereby increase in conversion efficiency.

5.4 Parabolic Dish type Solar Collector

Parabolic dish type solar collector is a point concentrating unit. The incoming solar radiation after reflection from the aperture of parabolid is intercepted by receiver at the focus. In the present experimental setup, a cylindrical pot (solar cooker) of 25 L capacity was kept at the focal point to analyze the performance of dish type solar cooker. The experimental tests on the dish type parabolic solar cookers were carried out during the duration December 24 to 31, 2015 between 10:00 am to 4:00 pm (maximum irradiation timings). The experiments were fully carried out on the roof top of Centre for Energy and Resources Development (CERD) laboratory, Indian Institute of Technology (Banaras Hindu University). The dish concentrator was constructed using aluminum rectangular facets. A solar cooker of 25 L capacity was used for the experiment and was coated with black paint. The concentrator used was non-tracking and thus had to be operated manually so that the radiation was continuously focused at the same point. Solar intensity radiation was measured by Kipp and Zonen Pyranometer type (CM5) and fixed at a horizontal position. The device records the data on an accumulative basis and shows the radiation on an instantaneous basis. Two Pyranometers were used for obtaining the direct irradiance and the indirect or diffused irradiance. For obtaining the indirect irradiance the Pyranometer was shadowed so that no direct radiations strike it. Thermocouples were used for obtaining the temperature of the desired points on the cooker and ambient temperature. Consequently, the air temperature was also measured. Basically, three thermocouples were used for the experiment. The thermocouples were connected to the data logger and digital output was obtained which had greater accuracy. The wind speed, which has a major effect on the performance of a solar cooker, was measured using cup-type anemometer which was fixed at the same height as the cooker so that accurate values of wind speed could be obtained.

5.4.1 Environmental Parameters

Figure (5.22-5.24) shows the variations of the various environmental parameters with the time of day as on 29^{th} Dec, 2015. As quite evident from figure 5.22 the solar insolation depends on the time of day and accomplishes its maximum value at noon. The diffused

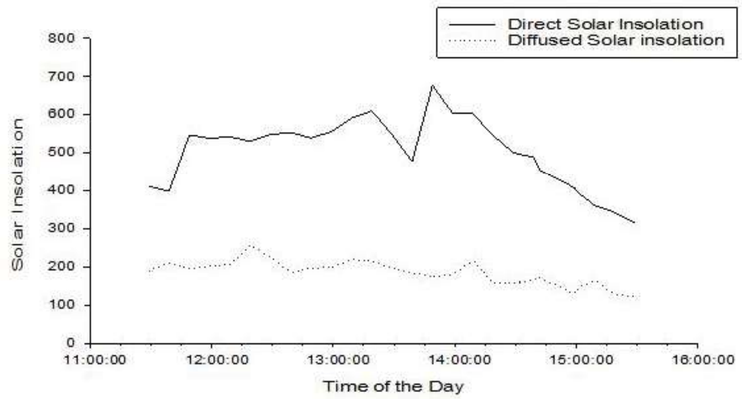

Figure 5.22: Variation of solar radiation intensity with time of the day

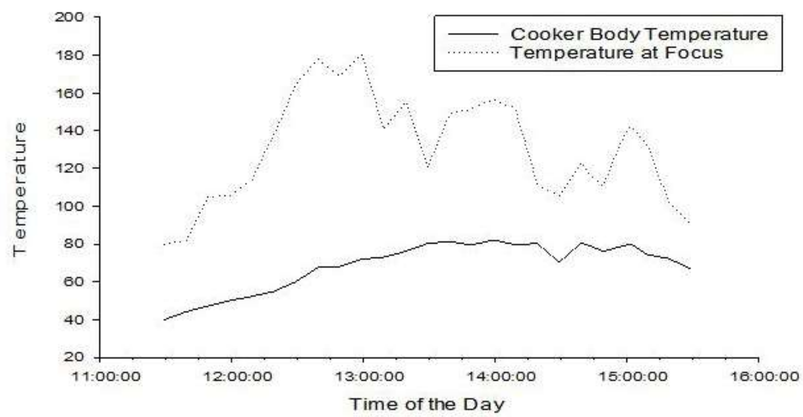

Figure 5.23: Variation of temperature with time of the day

radiation also experiences the same variation and is quite small as compared to direct insolation value. Figure 5.23. shows variation of temperature of different points with time of the day. The temperature at focus reaches as high as 181.5^oC whereas the cooker body temperature reaches a maximum value of 82.1^oC with average solar insolation during the day 500 W/m^2. These maximum values are obtained at hour from noon as the solar intensity is at its peak during this period. Figure 5.24 compares the variation of various environmental parameters throughout the day. The ambient temperature shows very small variation and the maximum ambient temperature reached is 31.9^oC with average 30.32^oC. The wind speed average during the day was $1.94 m/s$ with a maximum of $3.8 m/s$ at evening. The above-discussed parameters have the significant effect on the heat loss, performance index and the efficiency of the system.

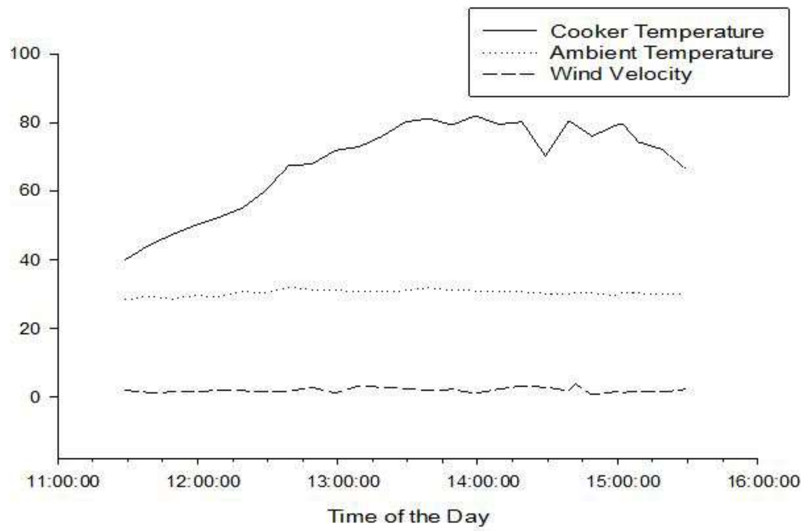

Figure 5.24: Variation of cooker temperature, ambient temperature and wind velocity with time of the day

5.4.2 Heat Loss Analysis (side loss, bottom loss, and top loss)

Figures (5.25-5.30) illustrate the variation of various losses occurring from the solar cooker. Figure 5.25. shows the variations of heat loss from the cylindrical side of the cooker calculated from experimental data throughout the day. The side loss as evident from equation 5.25 is dependent on three parameters wind velocity, ambient temperature and receiver temperature which are again a function of time. The side loss variation with these parameters has been plotted by putting specific values of the parameters in equation 7. Side loss is found to increase with increasing wind velocity (figure 5.26), decreasing ambient temperature (figure 5.27) and increasing cooking pot temperature (figure 5.28). Figure 5.29. and figure 5.30. illustrates the variation of the bottom and top losses from the receiver with the time of the day. The maximum losses occurring from the cooker was hours from noon (cooking pot temperature very high). It is minimum at the start of the experiment when the receiver temperature is low and increases with the receiver temperature.

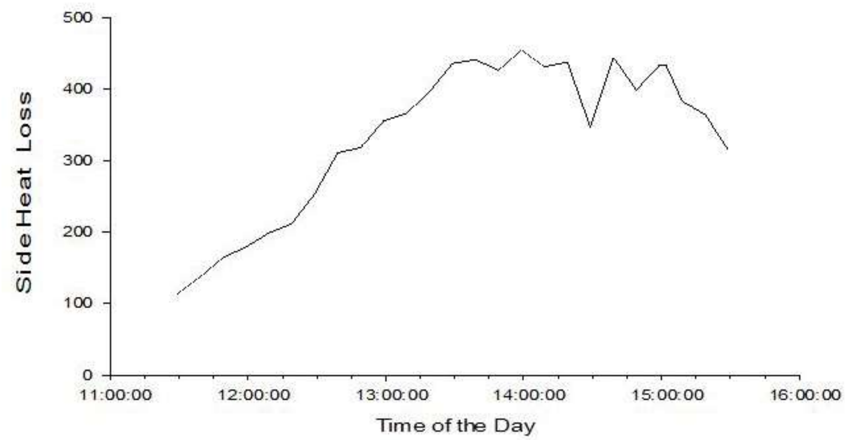

Figure 5.25: Variation of side heat loss with time of day

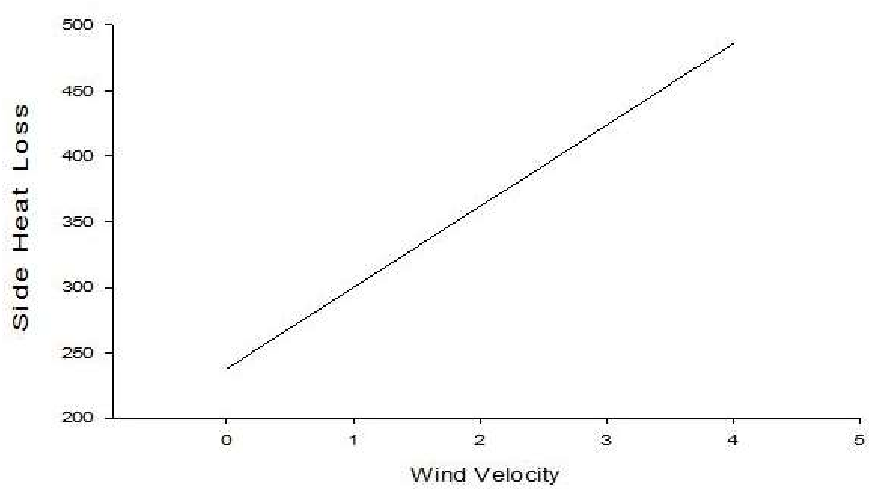

Figure 5.26: Variation of heat loss from the side (W/s) with velocity (m/s) at 303 K ambient temperature

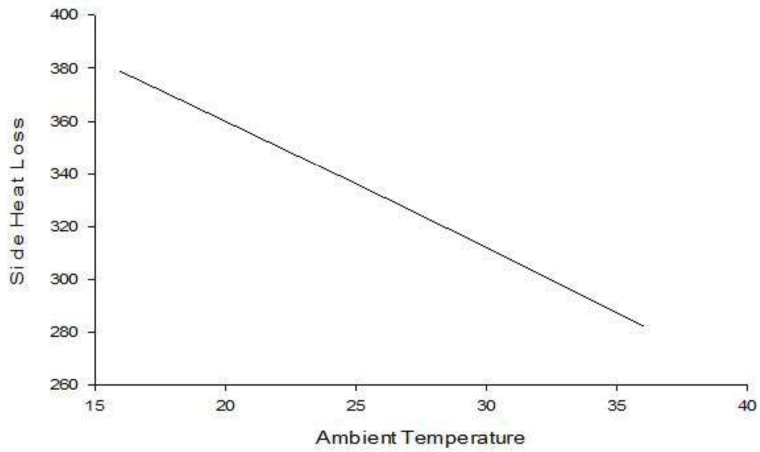

Figure 5.27: Variation of heat loss from side (W/s) with ambient temperature $(°C)$ at wind velocity= 1.2 $m/s$and cooker temperature= 84°C

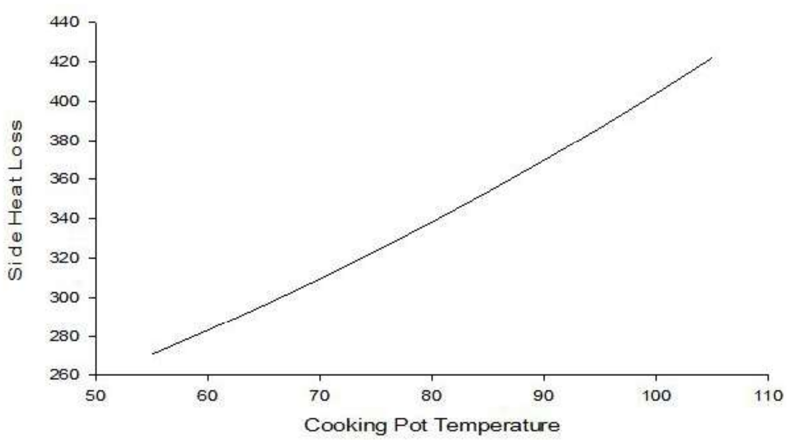

Figure 5.28: Variation of heat loss from side (W/s) with cooking pot temperature $(°C)$ at wind velocity= 2.0 m/s and ambient temperature= 30°C

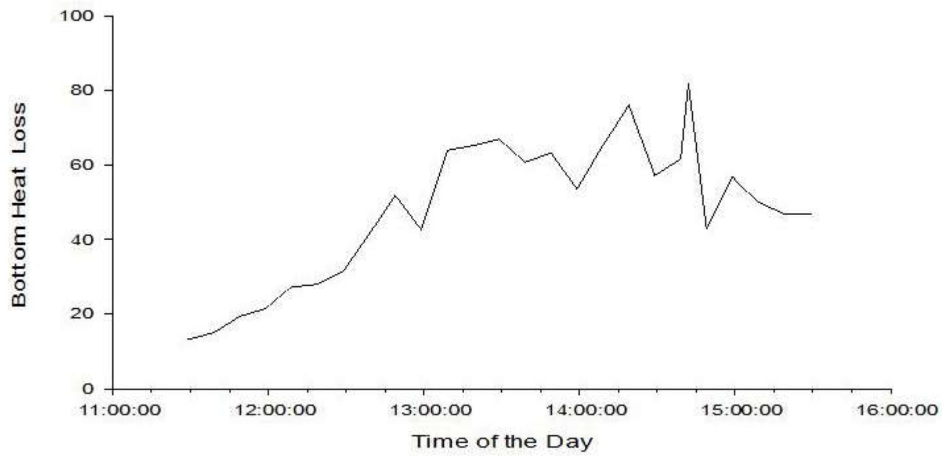

Figure 5.29: Variation of bottom heat loss (W/s) with time of the day

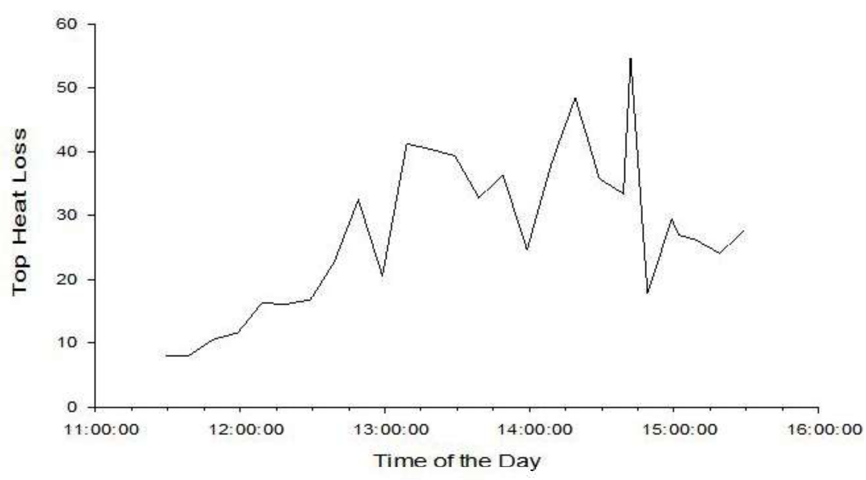

Figure 5.30: Variation of heat loss from top (W/s) with time of day

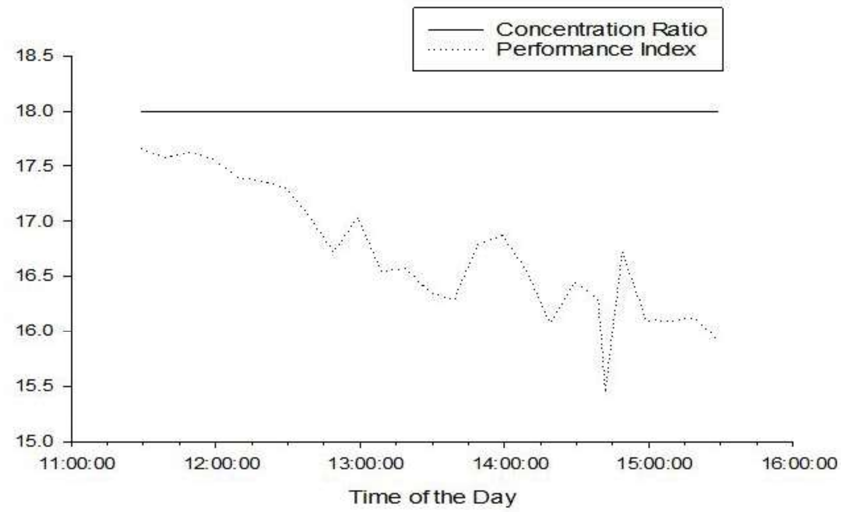

Figure 5.31: Variation of performance index and concentration ratio with time of the day

5.5 New Approach to Measure the Performance of Dish Type Solar Collector System

In this section, a noble approach has been established to measure the performance of parabolic dish type solar collector. Various experiments have been done on it to get the input parameter for calculation purposes. Cylindrical receiver (cooking pot) was kept at the focus of a parabolic dish type concentrator and repeated experiments have been done 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 data monitoring station at CERD, IIT (BHU), Varanasi. A numerical approach has been performed to define the new parameter called performance index of the cylindrical receiver (cooking pot) which decides how the useful energy of working fluid inside the cooking pot approaches concentration ratio of the parabolic dish type solar collector. The performance index approaches 18, the concentration ratio not 1 the efficiency as shown in figure 5.31.

5.5.1 Performance Index and Efficiency Analysis

The performance index and efficiency of cooking pot vary with the time of the day as shown in figures below. Figure 5.31. shows that how the performance index approaches

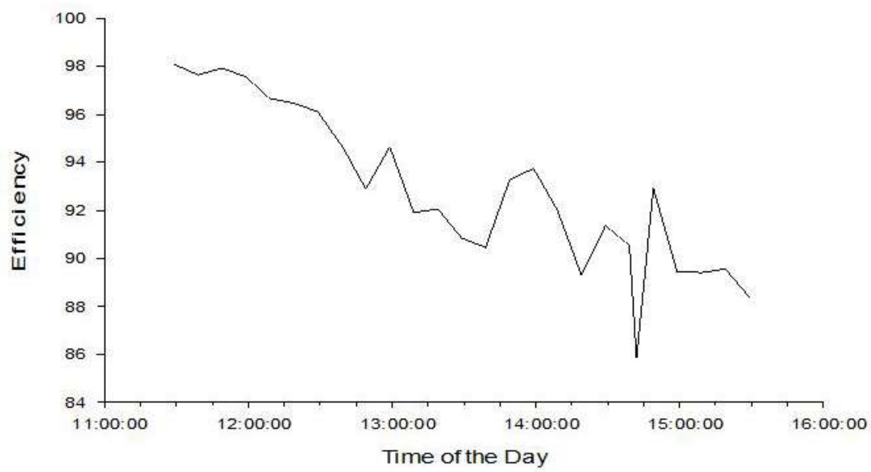

Figure 5.32: Variation of efficiency of cooking pot with time of the day

towards the concentration ratio. The deviation of the performance index curve with the line of concentration ratio shows the heat losses due to the combined effect of conduction, convection, and radiation. Figure 5.32. shows the variation of efficiency of the cooking pot with the time of the day. A maximum efficiency of 98.10% was obtained on 29^{th} Dec, 2015.

The present chapter discussed about the variation of performance parameters with reference to the time of the day. Effect of vacuum on heat loss and receiver temperature has been mentioned. Conclusion and future research direction has been mentioned in the next chapter-6.