IJCTA, 9(37) 2016, pp. 333-344

Receivers of Solar Parabolic Dish Collector System for Low and Medium Temperature Applications: A Review

V. Thirunavukkarasu* and M. Cheralathan**

Abstract: Concentrated solar technology deals with concentrating solar power on one point have specific advantage of high temperature and improved efficiency. Solar parabolic dish collector is one of the most efficient energy conversion technologies among the concentrating solar power (CSP) systems. The application includes solar water heating, solar steam cooking, power generation and other industrial steam processing. The receiver of parabolic dish plays an important role of converting the concentrated radiation to thermal energy and it has to be well designed such that it can achieve high temperature with minimal heat losses. Conversion efficiency as well as thermal losses of the receiver at different radiation and windy conditions are a major concern for the researchers. In the present work, a review has been made to study all the research and development work carried out in the field of receivers of solar parabolic dish collector system for low and medium temperature applications. The work includes review of experimental and numerical investigations on energy and exergy factors and different heat loss mechanisms with varied shapes that have been considered up to date. It is believed that this review will be beneficial to the design, simulation and performance assessment of solar parabolic dish receivers.

Index Terms: Solar parabolic dish concentrator, cavity receivers, thermal efficiency, exergy efficiency, convection and radiation heat losses.

1. INTRODUCTION

Concentrated Solar Power (CSP) systems operate on the principle of concentrating the incident solar irradiation into small enclosures via parabolic reflectors. Conventional CSP systems consist of four different configurations: parabolic dish, parabolic trough, central receiver and linear Fresnel lens. Parabolic dish systems are considered to be the most efficient of all solar technologies [1]. A parabolic dish system (Figure 1)

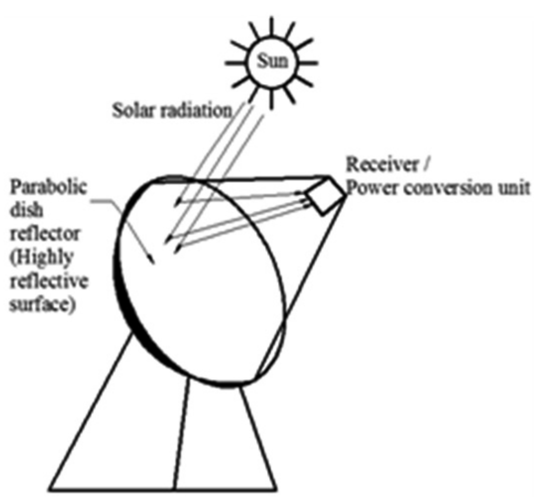

Figure 1: Solar parabolic dish system

* Assistant Professor (Senior Grade), Department of Mechanical Engineering, SRM University, Kattankulathur – 603203, India. *Email: thirunavukkarasu.v@ktr.srmuniv.ac.in*

** Professor, Department of Mechanical Engineering, SRM University, Kattankulathur – 603203, India. *Email: cheralathan.m@ktr.srmuniv.ac.in*

consists of a parabolic dish with highly reflecting mirrors and a receiver located at the focal point of the dish. The solar radiation incident on the dish are reflected toward the focal point of the dish where the receiver is located. Highly concentrated solar radiations enter the receiver through a small opening and significantly increase the temperature of the receiver and the receiver fluid. High collection efficiencies can be achieved in a parabolic dish system due to its high concentration ratio. Due to higher achievable temperatures and higher heat fluxes in the absorber, such systems could be used in a wide range of applications. Thermal absorber is the vital component in concentrating solar system. Absorber or receiver absorbs the concentrated solar beam radiation reflected by the concentrator and achieves very high temperatures which becomes a high heat source. Aperture area of the absorber determines the concentration ratio of the system. Commonly used materials for absorber are high grade mild steel, copper and stainless steel.

Various research works carried out by researchers on different type of receivers are reviewed and presented in this paper.

2. EXTERNAL AND CAVITY ABSORBERS

There are two types of absorbers namely external absorbers and cavity absorbers which are commonly used in solar parabolic dish concentrator system. An external absorber is essentially a flat plate. The reflected radiation impinges on the plate and heats the surface. External absorbers are easy to manufacture and economically cheaper than cavity absorbers but have many inefficiencies. External absorbers as shown in Figure 2 are directly exposed to ambient air at high temperatures. With all of the heating being done solely on one end of the receiver, the internal temperature will vary depending on the distance away from the absorber surface. Consequently, the heat exchanger efficiency can be reduced. Another drawback is effective absorption. For an external absorber, a part of the concentrated radiation is reflected and lost and it is not possible for recovering the radiant energy.

In cavity type absorbers as shown in Figure 3, solar radiation is reflected by the concentrator to the receiver aperture, and is collected on the absorber surface. Cavity absorbers are expensive and complicated than external absorbers, but are much more efficient.

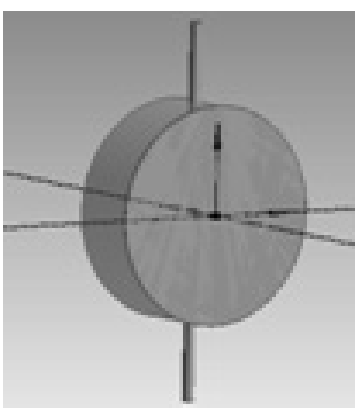

Figure 2: External absorber

Figure 3: Cavity absorber

If any radiation reflects from one portion of the absorber surface, it is reflected onto the succeeding portion of the absorber, until the aperture opening. In this way, the absorber has an increased chance of absorbing solar radiation. The effective absorptivity of a cavity is always higher than that of a flat plate.

Various studies have been carried out on cavity absorbers for central receiver systems and solar parabolic dish systems. The literature review shows that the types of receivers investigated both experimentally and numerically are cubical, rectangular, cylindrical and hemispherical. Fewer studies have been done on external type and conical cavity type receivers. Extensive study has been carried out by researchers on the study of heat losses from cavity absorbers. Studies on the effect of varying tilt angle of absorber was also studied extensively. Natural convection correlations for receivers employed in parabolic dish systems are derived by many researchers. During the past three decades, both experimental and numerical investigations on natural convection heat transfer in cavities have been carried out.

A. External type Cylindrical Receiver

Shiva Gorjian et al. [1] conducted thermal performance analysis of a point focus solar steam generating system (Figure 4) with parabolic concentrator together with external type cylindrical receiver under various climatic and operating conditions (including windy conditions) in Terhran round the year. The receiver is a short cylinder made of stainless steel with diameter of 200 mm and length of 150 mm with a concentration ratio of 10 for the parabolic dish system. For calculating the total heat loss from the receiver, simulation is done by assuming a total of four wind directions (0°, 30°, 60° and 90°) with speed in the range of 3.5 m/s to 7.2 m/s and ambient temperature of the air for year round in Tehran. The receiver was assumed to be performed in medium temperature systems (150°C to 250°C). They have reported that the highest wall temperature is about 250^{o}C, which is higher than the water saturation temperature. Changing the wind angle affected the convection heat loss coefficient. Their results shows that head-on wind flow was found to cause higher convection heat loss than the side-on wind flow. The higher the air temperature and wind speed, higher the value of convection heat loss coefficient. Higher the absorber temperature, lesser the thermal performance of the parabolic dish system . It was found that overall thermal efficiency of the system is above 40%, depending on the environmental condition and the average temperature of the receiver.

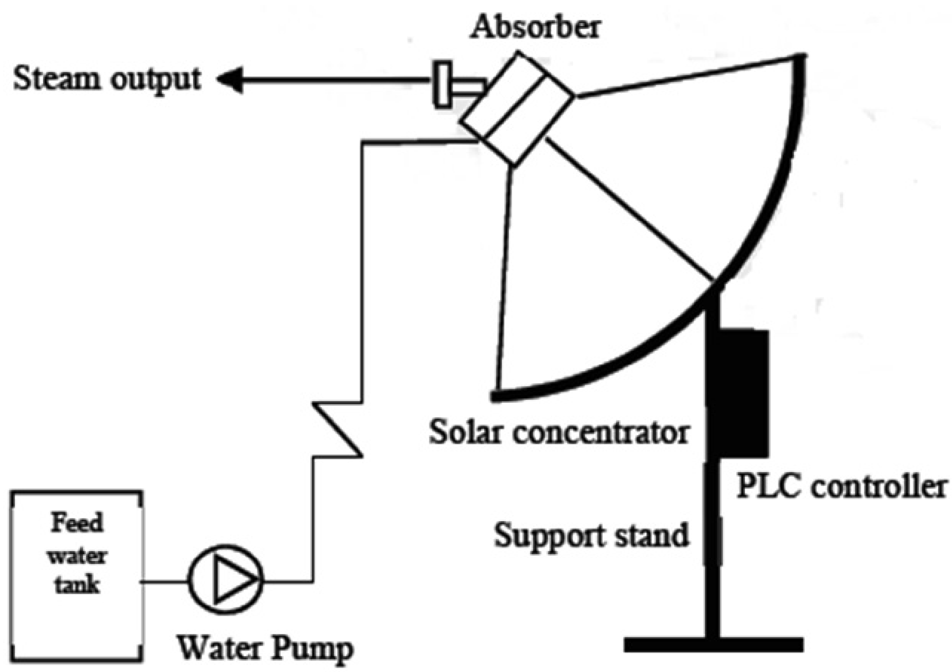

Figure 4: Parabolic dish steam generating system

B. Cubical Cavity Receiver

Investigation on thermally driven laminar natural convection in an open cubical cavity was done by Le Quere et al. [2] numerically and experimentally. All the sides were at isothermal conditions, one of which facing the opening. He found out that the convection heat loss strongly depends on inclination of the cavity and correlation were established for each inclination. In the nusselt number correlation, the effect of varying temperature and tilt angle are included, while the effect of varying aperture sizes is not included.

Clausing [3-4] and Clausing et al. [5] developed a model to calculate the convection heat loss of a large cubical cavity based on the hypothesis that two factors governed the convection heat loss, i.e. (i) the ability to transfer mass and energy across the aperture and (ii) the ability to heat air inside the cavity. An analytical method was developed based on the above assumption and it is concluded that the latter factor was of greatest importance. This model is an implicit one, the cavity is divided into a convective zone and a stagnant zone, thus more complicated but the best fit for all the models.

Based on the work by Clausing et al. [5], Leibfried and Ortjohann [6] developed a more generalized model that can be used for both downward and upward facing cavities with various geometries. The definitions of dimensions used in the modified Clausing model (Leibfried and Ortjohann, [6]) are shown in Figure 5. The definitions of characteristic length L_c, buoyancy height L_a as well as the wall area of the convective zone, A_{cz} were generalized for geometries with varied directions, including upward-facing orientations.

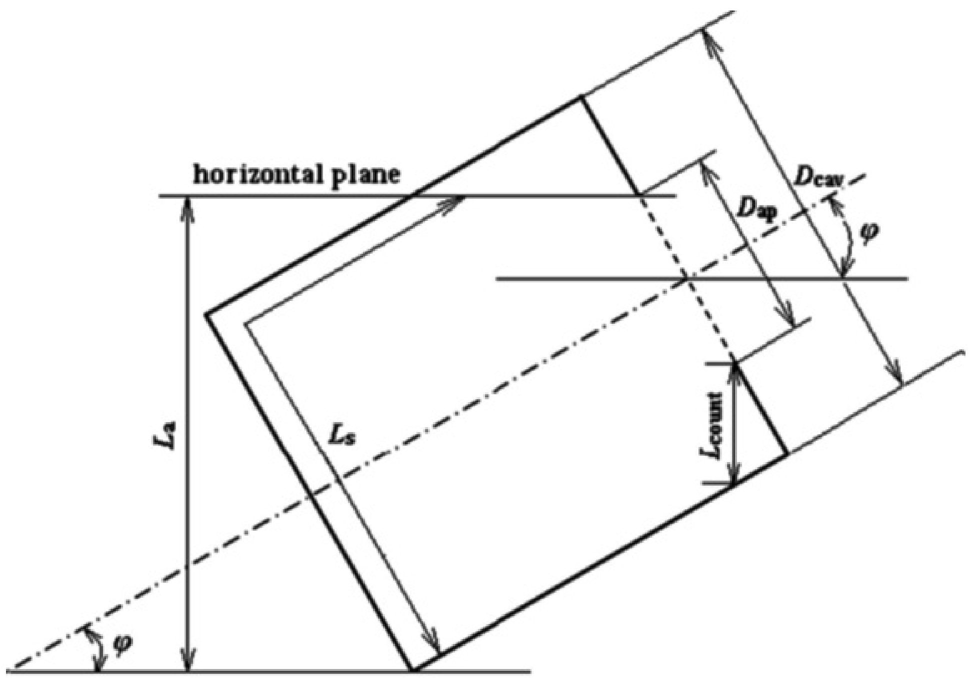

Figure 5: Definitions used in the modified Clausing model

Siebers an Kraabel [7] did experimental studies and presented a simple model for the convective heat transfer from a solar cubical cavity. They reported a correlation that accounts for the physical property variations present in a strongly heated cavity with elevated wall temperature. The nusselt number correlation is simple, but has a large degree of uncertainty.

C. Cylindrical Cavity Receiver

A model was proposed by Koenig and Marvin [8] to study the convection heat loss from cylindrical cavity receiver. Based on Siebers and Kraabel model, Stine and McDonald [9] proposed an extended correlation of the Nusselt number for a cylindrical shaped frustum receiver. The correlation includes the effect of aperture size, surface temperature and receiver tilt angle. Leibfried and Ortjohann [6] extended the model of Stine and McDonald [9] and the newly generalized model could be used for both downward and upward-facing cavities with various geometries. Comparing the calculating results of convection heat loss from upward-facing cavity receivers with the measured data, it was concluded that the simpler explicit modified Stine and McDonald correlation gave slightly better results than the implicit modified Clausing model.

Ma[10] has reported the experimental investigations on the convective loss under wind conditions for a cylindrical receiver having an aperture diameter smaller than the receiver diameter. The tests have been carried out at wind speeds greater than 3 m/s. The trends obtained from these studies are similar to that of the no-wind case.

Taumoefolau and Lovegrove [11] experimentally investigated the natural convection heat losses from a 70 mm electrically heated cylinder receiver (model cavity receiver) with cavity temperatures ranging from 350°C to 500°C. They have found that convection loss is maximum at 0^o and with increasing inclination the convection loss reduces to a minimum at 90^o. They have also reported that the experimental and numerical results obtained were in good agreement qualitatively with those predicted by various correlations proposed by previous researchers.

Paitoonsurikarn and Lovegrove [12] numerically investigated the natural convection heat losses from model cavity receiver, 20 m^2 dish receiver and 400m^2 dish receiver (Figure 6) using CFD software package Fluent 6.0. It was concluded that the Clausing [3] correlation shows the closest prediction to both numerical and experimental results despite its original use for bigger-scale central receivers. As the inclination of the receiver increases, there was a decrease in losses.

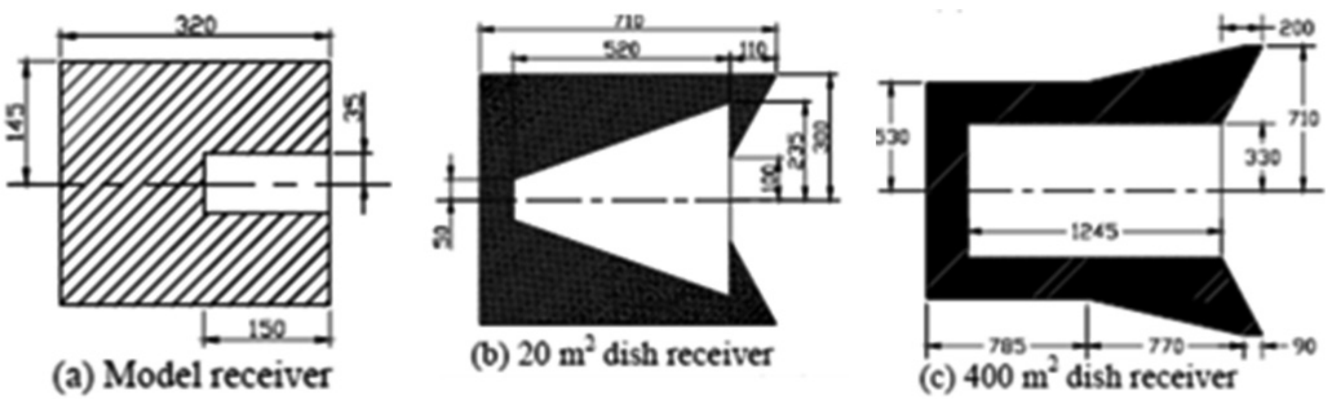

Figure 6: Cross sectional diagram of All Three receiver models

A correlation was developed by Lovegrove et al. [13] using the concept of the ensemble cavity length Ls as the characteristic length to account for the combined effect of the cavity geometrical parameters and the inclination. Paitoonsurikarn and Lovegrove undertook the numerical investigation of natural and combined convection heat loss from cavity receivers. A new correlation was developed for prediction of heat transfer coefficients. The ensemble cavity length Ls was modified to include the aperture geometry.

Later, Paitoonsurikarn et al. [14] carried out a parametric study of several relevant parameters in natural convection heat loss from open cavity receiver in solar dish application. The previously proposed correlation model in Paitoonsurikarn and Lovegrove[13] has been modified to take into account the variation of additional parameters. Moreover, a correlation based on the modified Stine and McDonald model was developed. Both models are quite promising in the natural convection heat loss prediction in most cases. Based on the numerical simulation results of three different cavity geometries and the previous works, an improved version of correlation was presented by Paitoonsurikarn and Lovegrove [14].

Yeh et al. [15] presented an experimental method of modeling natural convective flows in solar cavity receivers using water as a working fluid with density differences due to salt concentration. The flow was visualized for a range of cavity receiver orientations of 0-90^o, and the flux Grashof numbers $7 \times 10^4 – 10^{10}$. It was found that the flows observed inside the model cavity receiver are laminar over the range of flux Grashof numbers applicable to actual receivers. However, a transition to turbulent flow happens when the Grashof number exceeds 10^7.

Prakash et al. [16] made experimental and numerical study of the steady state convection heat losses occurring from a downward-facing cylindrical cavity receiver with a wind skirt. Study of convective losses from cylindrical cavity receiver of length 0.5 m, internal dia. of 0.3 m, wind skirt dia. of 0.5 m was carried out. Experiments were conducted for fluid(water) inlet temperatures between 50°C and 75°C with receiver inclination angles of 0°, 30°, 45°, 60° and 90°. Investigations on effects of external wind at two different velocities 1m/s and 3 m/s in two directions (head-on and side-on) using blower assembly , no wind tests were carried out. Nusselt number correlations were proposed based on experimental and predicted data

They have reported that heat losses decrease with increase in inclination angle of receiver, increase with increase in inlet fluid temp., heat losses increase in head-on wind condition than side-on wind condition and decrease with no wind condition. The correlations for Nusselt number was developed for no-wind convective losses with a correlation coefficient of 0.98.

Prakash et al. [17] carried out experimental and numerical studies on the same cylindrical cavity receiver to identify stagnation and convective zone within the receiver. A non dimensional parameter ψ is defined to represent the values of the air temperature gradients. The values of the critical air temperature gradient corresponds to ψ of about 0.3 for all inclinations and all fluid temperatures tested. Stagnation zone occurs in regions having $\psi \leq 0.3$ while the convective zone is observed at $\psi \geq 0.3$. They have reported that at 0^o inclination, convective zone covers the entire surface area of the receiver while the percentage of convective zone is the least at 90^o inclination. At inclinations of 30^o, 45^o and 60^o, the receiver surface covered by the convective zone are 55%, 44% and 28 % respectively.

The bottom surface of the conventional cylindrical cavity receiver connot be fully covered by coiled tube during fabrication, which can induce a dead space of solar energy absorption. Fuqiang Wang et al. [18] worked on the problem of dead space of solar energy absorption which occupies about 10% of bottom surface of the receiver analysed by Prakash et al. [16-17]. Two new types of cavity receiver with bottom surface convex were put forward and analysed using Monte Carlo ray tracing method to solve the dead space and to improve the optical efficiency of cavity receiver. They have reported that cylindrical receiver with bottom surface interior covex can improve the optical efficiency and the dimensionless height of 0.875 has the highest optical efficiency.

Ashmore Mawire et al. [19] experimentally investigated the thermal performance of a cylindrical cavity receiver for an SK-14 parabolic dish concentrator. Energy and exergy analysis have been evaluated. They have reported that exergy rates and efficiencies found to be appreciably smaller than the receiver energy rates and efficiencies. The exergy factor parameter was found to be high under conditions of high solar radiation and under high operating temperatures. The heat loss factor of the receiver is determined to be around 4.6 W/K. An optical efficiency of around 52 % for parabolic dish system was determined under high solar radiation conditions.

Jianquin Zhu et al. [20] did experimental investigation on the energy and exergy performance of a coiled tube solar receiver with compressed air as heat transfer fluid under real solar radiation condition. An efficiency of 70 % and above was reported for the solar receiver, with the highest peak efficiency of 82%. The highest value of the exergy rate was around 8.8 kW and the maximum energy could reach 21.3 kW. Highest exergy efficiency was approximately 28 %. A very low value of heat loss factor (20 W/K) was achieved during the steady state operating conditions.

D. Spherical and Hemi Spherical Cavity Receiver

Kaushika and Reddy [21] carried out design, development and performance characteristics of a low cost solar steam generating system. They have represented and compared thermal performance characteristics of semi-spherical cavity and modified cavity receiver (Figure 7) applied for low cost solar paraboloidal dish system, and the modified cavity receiver was claimed to be with higher efficiency.Concentrator made of silvered polymer reflectors fitted in the aluminum frame of a satellite communication dish was used for the study.

Investigations were done on three different receivers namely, cavity, semi-cavity and modified cavity receivers. Collection efficiency of the system was analyzed for 7 years (1992 to 1998). They have reported that efficiency of modified cavity receiver was 80 to 85% whereas semi cavity was 75% and cavity receiver was 60 to 65%. Maximum efficiency may be achieved when the aperture radius is 0.035m and the A_w/A_1 (Heat transfer area of the cavity/Cavity aperture area) ratio is about 8. The reflectivity and the year wise collection efficiency at wind velocity, V = 2 m/s, $A_w/A_1 = 8$ and intensity of radiation, I_a = 850 W/m^2 investigated for 7 years shown that reflectance of mirror has reduced by 26% and collection efficiency decreased by about 23%. Semi-cavity and modified cavity receivers, thermally optimized, with the fuzzy focal image have, therefore, been investigated. Preliminary field measurements as well as performance analyses of the system, indicate a solar to steam conversion efficiency of 70 to 80% at 450°C.

Sendhil Kumar and Reddy [22] numerically investigated natural convective heat loss from cavity receiver, semi-cavity receiver and modified cavity receiver of spherical geometry. With Isothermal, pressure inlet and adiabatic boundary conditions, receiver simulation was carried out using Fluent software. Natural convection heat loss from the receiver was estimated for varying inclinations from 0° to 90°. Numerical study was performed for all the receivers at 400°C surface temperature. Influences of orientation, operating temperature and area ratio (A_w/A_1) of the modified cavity receiver on the convection heat loss have been studied. They have reported that the convection heat loss is high at 0° and decreases monotonically with increase in angle up to 90° in all three cases. The convection heat losses at 0° and 90° inclination of the modified cavity receiver are 26.03% and 25.42% of the convection heat loss of the cavity receiver, respectively. The influence of area ratio (A_w/A_1) on the convective heat loss is investigated for the modified cavity receiver, and an optimum A_w/A_1 of 8 is found for minimum natural convection heat loss. Among the three receivers, the modified cavity receiver is the preferred receiver for a fuzzy focal solar dish collector system.

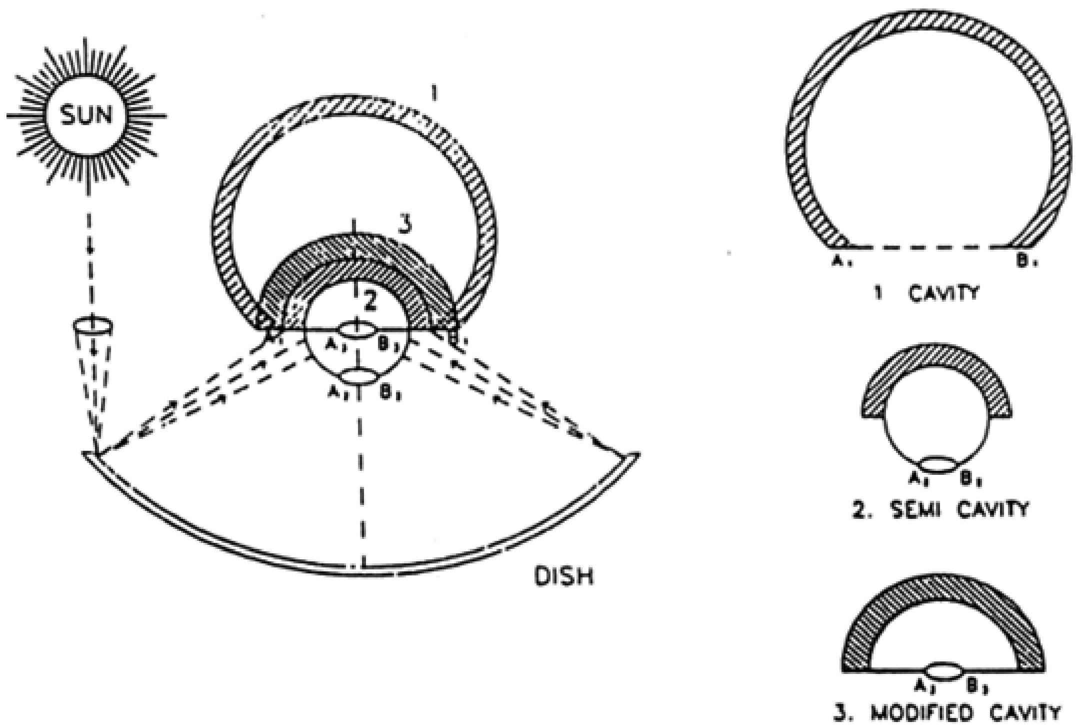

Figure 7: Cavity, semi-cavity and modified cavity receiver for solar parabolic dish concentrator

Reddy and Sendhil Kumar undertook numerical investigations on the modified cavity receiver. Study on varying area ratio was also carried out for modified cavity receiver. An improved Nusselts number correlation for determining convective loss from the modified cavity receiver was proposed.

Reddy and Sendhil Kumar [23] also undertook numerical investigations on the modified cavity receiver with two stage concentration. Numerical analysis of solar dish modified cavity receiver with Cone, CPC and Trumpet reflectors was presented. Three-dimensional modeling is carried out to estimate the convective and radiative heat loss from the receiver for different angles of inclination and operating temperatures. It was concluded in the study that by incorporating reflectors in the modified cavity receiver for second stage concentration, the natural convection heat losses are reduced by 29.23, 19.81 and 19.16%, respectively. The receiver with the trumpet reflector has shown better performance as compared to other configurations.

Fuqing Cui et al. [24] proposed an improved model of modified cavity receiver with quartz glass cover to reduce the heat loss through the aperture. A 2-D simulation model for combined natural convection and surface radiation has been developed by them. The heat transfer of the covered receiver and uncovered receiver were simulated and compared. The simulation results show that compared with the uncovered receiver, the quartz glass cover largely reduces the natural convection and surface radiation heat losses of the cavity receiver. The total heat flux of the covered receiver at 0^o inclination is only about 36% of that of the uncovered receiver.

T. Srihari Vikram et al. [25] carried out a 3-D numerical investigation to estimate heat losses from solar parabolic dish with modified cavity receiver used for three different steam generation conditions viz. sub-cooled, saturated, superheated steam. The effect of inclination of the receiver, operating temperature, emissivity of the cavity cover, insulation thickness on the total heat loss from the modified cavity receiver has been investigated. The variable wall temperature boundary conditions and insulation thicknesses are applied to match the actual conditions. The results showed that the convection heat losses are higher at 0^o inclination and found to be 400 to 500 W for superheated steam generation; 300 to 425 W for saturated steam generation and 50 to 125 W for sub-cooled steam. Nusselt number correlations have been proposed based on the numerical analysis.

Yuting Tan et al. [26] performed experiments to investigate the heat loss of semi-spherical cavity receiver applied for solar dish collector. Experiments were conducted for fluid inlet temperatures from 75°C to150°C, receiver inclination angles of 0°C (cavity aperture facing sideways), 15°C, 30°C, 45°C, 60°C and 90°C(cavity aperture facing down), and aperture size of 0.15 m, 0.2 m and 0.25 m. Experimental correlations of Nusselt number as function of Grash of number were developed for different operating temperatures, inclinations and aperture sizes.

K.S. Reddy et al. [27] carried out a 3-D numerical modeling to determine combined convection and surface radiation heat losses from a modified cavity receiver of parabolic dish collector used as mono-tube boiler for sub-cooled, saturated and superheated steam generation conditions. The forced convection heat loss from the modified cavity receiver was estimated using Nusselt number correlation developed for the modified cavity receiver. The effect of receiver inclination, operating temperature, emissivity of the cavity cover, thickness of insulation on the combined heat losses from the modified cavity receiver were investigated. It was found that the natural convection heat losses are higher at $\beta = 0°$ (receiver facing sideward) and lower at $\beta = 90°$(receiver facing down) whereas the forced convection heat loss is higher at $\beta = 90°$ and lower at $\beta = 0°$. The variation of radiation heat losses is marginal for all values of β and vary with Tw. The effect of various parameters such as receiver inclination, wind direction, wind speed and diameter ratios on forced convection heat loss from the receiver was studied.

K.S. Reddy et al. [28] carried out thermal performance analysis of 20 m^2 prototype fuzzy focal solar dish collector with modified cavity receiver. The focal image characteristics of the solar dish are determined to propose the suitable design of absorber/receiver. From theoretical analysis the maximum efficiencies of solar dish collector are found to be as 79.2% for no wind conditions and 78.2% and 77.8% for side-on and head-on winds speed of 5 m/s respectively. Latter, real time analysis of parabolic dish collector with modified cavity receiver is carried out in terms of stagnation test, time constant test and daily performance test. From stagnation test, the overall heat loss coefficient is found to be 356 W/m^2 K. Time constants values for the volume flow rate of 100 L/h are predicted as 85 s and 86 s respectively for heating and cooling, whereas for flow rate of 250 L/h, time constants are 44 s and 47 s respectively. From the daily performance tests it was found that the efficiency of the collector increases with the increase of volume flow rates. The average thermal efficiencies of the parabolic dish collector for the volume flow rate of 100 L/h and 250 L/h are found to be 69% and 74% for the average beam radiation (Ibn) of 532 W/m^2 and 641 W/m^2 respectively.

E. Conical Cavity Receiver

Nestor Hernandez et al. [29] designed and optimized a novel type of receiver (Figure 8) for a paraboloidal concentrator with 90^o rim angle by means of detailed ray tracing simulations. The radiaton from the paraboloidal concentrator arrives to the receiver sideways as well as frontally. Therefore receiver is developed in such a way to collect radiation both from below and from the sides. Both open loop and closed loop experiments were carried out to evaluate the receiver by using water as cooling fluid. The time constant, the heat removal factor, as well as the global heat loss coefficient, were obtained.

Taebeam Seo et al. [30] carried out a numerical study on heat losses from conical and dome shaped receivers (Figure 9) of solar parabolic dish system. They have concluded that dome receiver is good for lower working temperatures while conical receiver is appropriate for higher working temperatures. Reflection loss becomes important as the working temperatures decrease.

R.D. Jilte et al. [31] did numerical three dimensional studies of the combined natural convection and radiation heat loss from downward facing open cavity receiver of different shapes.

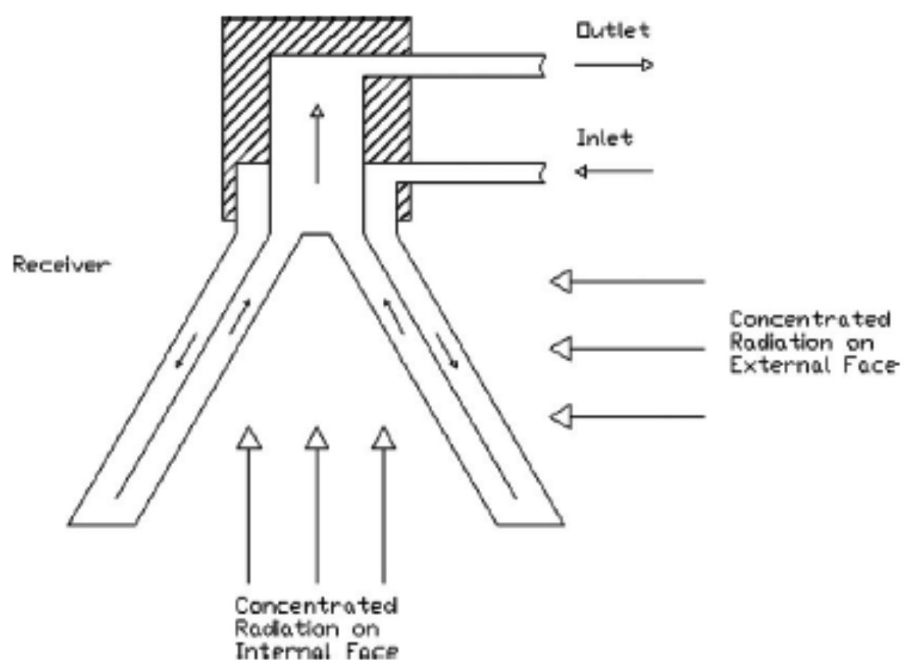

Figure 8: Conical receiver concept

The investigation was undertaken in two categories: same inner heat transfer area and aperture area (case I) and same aspect ratio and aperture area (case II). These studies were carried out for five isothermal wall temperatures (523 to 923 K in steps of 100 K). The effect of inclination was studied for seven inclinations from 0° (cavity aperture facing sideways) to 90° (cavity aperture facing down), in steps of 15°. The cavity shapes used are: cylindrical, conical (frustum of a cone), cone-cylindrical (combination of frustum of cone and cylindrical shape), dome-cylindrical (combination of hemispherical and cylindrical shape), hetro-conical, reverse-conical (frustum of a cone in the reverse orientation) and spherical. For both cases, they have concluded that conical cavity yields the lowest convective loss among the cavities investigated whereas spherical cavity results in the highest convective loss.

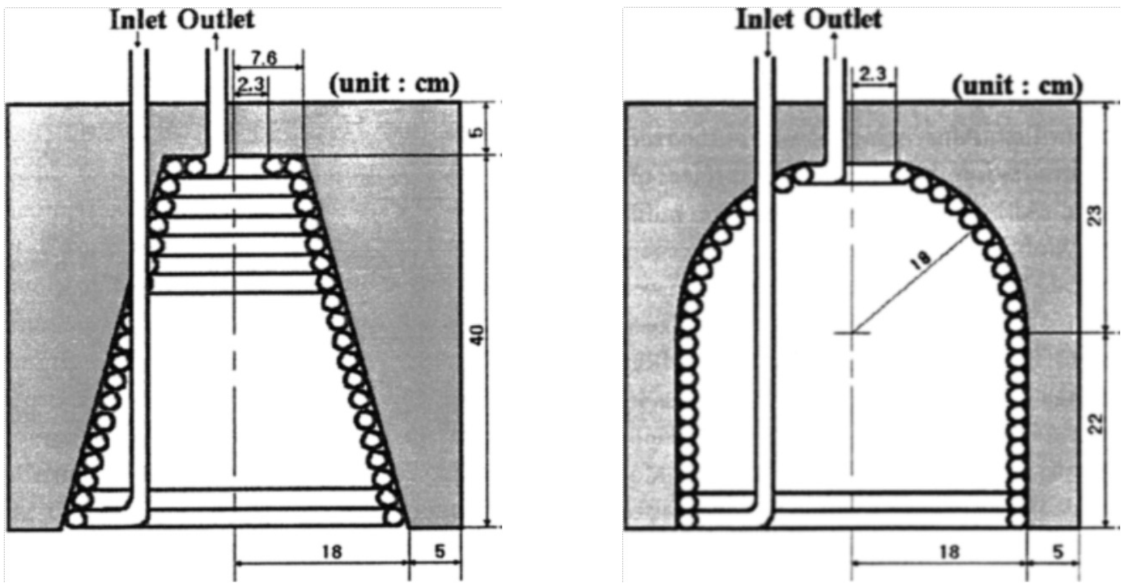

Figure 9: Conical cavity and dome cavity absorber

3. CONCLUSIONS

Four types of receivers shaped in cubical, rectangular, cylindrical, and hemispherical have been investigated extensively both experimentally and numerically. For the receivers, conduction losses are considered to be negligible and major focus had been to study convective and radiative losses. Numerous studies have been published on square, rectangular, spherical and cylindrical cavities. On the contrary, fewer studies on conical cavity receivers have been undertaken. Various correlations for free convection prediction have been proposed in the previous works.

However, each correlation has a limited range of applicability, which is inherently based on a particular cavity geometry and operating conditions used in the experiment in each of those works. Few correlations have been generated for predicting the combined free-forced convection heat loss with wind effect.

Based on reviewing the previous work on the cavity receivers, some issues that should be further researched are summarized as follows:

- In solar parabolic dish applications, the radiation heat loss by reflection could be non-negligible during low and medium temperature and must be taken into account for an overall improvement in receiver performance.
- It seems that it is necessary to investigate the emissivity and absorptivity of surface for total heat loss of receivers in solar dish systems. In most of the investigations, convection heat losses have been addressed extensively and the radiation loss effect have not been reported.
- Very few experimental work has been carried out with conical cavity receivers for solar dish systems. Optimum design features of conical cavity receivers for parabolic dish concentrators are not experimented with respect to the size and aperture opening.

Acknowledgement

The authors would like to thank the management of SRM University for encouragement extended to us for the completion of this work.

References

1. Shiva Gorjian, Barat Ghobadian, Teymour Tavakkoli Hashjin, Ahmad Banakar, 2013, "*Thermal performance of a Point-focus Solar Steam Generating System*," 21st Annual International Conference on Mechanical Engineering-ISME2013, pp. 2225-2230.
2. P. Le Quere, J. A. C. Humphrey, and F. S. Sherman, 1981, "*Numerical calculation of thermally driven two dimensional unsteady laminar flow in cavities of rectangular cross section*," Numerical Heat Transfer, Vol. 4, No. 3, pp. 249-283.
3. A. M. Clausing, 1981, "*An analysis of convective losses from cavity solar central receivers*," *Solar Energy*, Vol. 27, No. 4, pp. 295-300.
4. A. M. Clausing, 1982, "*Convective losses from cavity solar receivers-Comparisons between analytical predictions and experimental results*," *J. Sol. Energy Eng.;(United States)*, Vol. 105, No. 1.
5. Clausing, A.M., Waldvogel, J.M., Lister, L.D., 1987, "*Natural convection from isothermal cubical cavities with a variety of side-facing apertures*". ASME Journal of Heat Transfer, Vol. 109, pp. 407-412.
6. U. Leibfried and J. Ortjohann, 1995,"*Convective heat loss from upward and downward-facing cavity solar receivers: measurements and calculations*," *Journal of solar energy engineering*, Vol. 117, No. 2, pp. 75-84.
7. D. L. Siebers and J. S. Kraabel, 1984, "*Estimating convective energy losses from solar central receivers*," Sandia National Labs., Livermore, CA (USA).
8. Koenig, A.A., Marvin, M., 1981, "*Convection heat loss sensitivity in open cavity solar receivers*", Final Report, DOE Contract No: EG77-C-04-3985, Department of Energy, USA.
9. W. B. Stine and C. G. McDonald, 1989, "*Cavity receiver convective heat loss*," *International Solar Energy Society, Solar World Congress (1989, Kobe, Japon)*.
10. Ma, R.Y., 1993, "*Wind effects on convective heat loss from a cavity receiver for a parabolic concentrating solar collector*". Sandia National Laboratories Report, SAND92-7293.
11. Taumoefolau, T., Lovegrove, K., 2002, "*An experimental study of natural convection heat loss from a solar concentrator cavity receiver atvarying orientation*". In: Proceedings of 40th Conference of the Australia and New Zealand Solar Energy Society (ANZSES), Newcastle, Australia.
12. Paitoonsurikarn, S., Lovegrove, K., 2002, "*Numerical investigation of natural convection loss in cavity-type solar receivers*". In: Proceedings of 40th Conference of the Australia and New Zealand Solar Energy Society (ANZSES), Newcastle, Australia.
13. Paitoonsurikarn, S., Lovegrove, K., 2003, "*On the study of convection loss from open cavity receivers in solar paraboloidal dish applications*". In: Proceedings of 41st Conference of the Australia and New Zealand Solar Energy Society (ANZSES), Melbourne, Australia,.
14. S. Paitoonsurikarn and K. Lovegrove, 2006, "*A new correlation for predicting the free convection loss from solar dish concentrating receivers*," in *Proceedings of 44th ANZSES*, pp. 1-9.
15. Yeh, K.C., Hughes, G., Lovegrove, K., 2005, "*Modelling the convective flow in solar thermal receivers*". In: Proceedings of the 43rd Conference of the Australia and New Zealand Solar Energy Society (ANZSES), Dunedin, New Zealand.
16. Prakash, M., Kedare, S.B., Nayak, J.K., 2009, "*Investigations on heat losses from a solar cavity receiver*". Solar Energy, Vol. 83, pp. 157-170.
17. Prakash, M., Kedare, S.B., Nayak, J.K., 2010, "*Determination of stagnation and convective zones in a solar cavity receiver*", International journal of Thermal sciences, Vol. 49, pp. 680-691.
18. Fuqiang Wang,Riyi Lin, Bin Liu, Heping Tan, Yong Shuai, 2013, "*Optical efficiency analysis of cylindrical cavity receiver with bottom surface convex*", Solar Energy, Vol. 90, pp. 195-204.
19. Ashmore Mawire, Simeon H.Taole, 2014 , "*Experimental energy and exergy performance of a solar receiver for a domestic parabolic dish concentrator for teaching purposes*", Energy for Sustainable Development, Vol. 19, pp. 162-169.
20. Jianqin Zhu, Kai Wang, Hongwei Wu, Dunjin Wang, Juan Du, A.G.Olabi, 2015, "*Experimental investigation on the energy and exergy performance of a coiled tube solar receiver*", Applied energy, Vol. 156, pp. 519-527.

21. N. Kaushika and K. Reddy, 2000, "*Performance of a low cost solar paraboloidal dish steam generating system*," *Energy Conversion and Management*, Vol. 41, No. 7, pp. 713-726.
22. Sendhil Kumar, N, Reddy, K.S, 2007, "*Numerical investigation of natural convection heat loss in modified cavity receiver for fuzzy focal solardish concentrator*", Solar Energy, Vol. 81, pp. 846-855.
23. Sendhil Kumar, N, Reddy, K.S, 2008, "*Comparison of receivers for solar dish collector system*". Energy Conversion and Management, Vol. 49, pp. 812-819.
24. Fuqing Cui, Yaling He, Zedong Cheng, Yinshi Li, 2013, "*Study on combined heat loss of a dish receiver with quartz glass cover*", Applied Energy, Vol. 112, pp 690-696.
25. T. Srihari Vikram, K. S. Reddy, 2014 , "*Estimation of heat losses from modified cavity mono-tube boiler receiver of solar parabolic dish for steam generation*", Energy Procedia, 57, 371-380 2013 ISES Solar World Congress.
26. Yuting Tan, Li Zhao, Junjiang Bao, Qing Liu, 2014, "*Experimental investigation on heat loss of semi-spherical cavity receiver*", Energy Conversion and Management, Vol. 87, pp. 576-583.
27. K.S. Reddy, T. Srihari Vikram, G. Veershetty, 2015, "*Combined heat loss analysis of solar parabolic dish – modified cavity receiver for superheated steam generation*", Solar Energy, 121 pp 78-93.
28. K.S. Reddy, Sendhil Kumar Natarajan, G. Veershetty, 2015, "*Experimental performance investigation of modified cavity receiver with fuzzy focal solar dish concentrator*", Renewable Energy, Vol. 74, pp. 148-157.
29. Nestor Herna´ndez , David Riveros-Rosas,Eduardo Venegas, Ruben J. Dorantes,Armando Rojas-Morin, O.A. Jaramillo, Camilo A. Arancibia-Bulnes,Claudio A. Estrada, 2012, "*Conical receiver for a paraboloidal concentrator with large rim angle*", Solar Energy, Vol. 86, pp. 1053-106.
30. Siyoul Ryu and Taebeam Seo, 2000, "*Estimation of Heat Losses from the Receivers for Solar Energy Collecting System of Korea Institute of Energy Research*". KSME International Journal, Vol. f4, No. t, pp. f403-f411.
31. R.D. Jilte, S.B. Kedare & J.K. Nayak, 2013, "*Natural Convection and Radiation Heat Loss from Open Cavities of Different Shapes and Sizes Used with Dish Concentrator*", Mechanical Engineering Research; Vol. 3, No. 1.