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Review Article

Review of various solar cavity receivers of parabolic dish concentrators with design aspects and heat loss analysis

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ABSTRACT

In a parabolic dish system, the heat losses from the cavity receiver significantly suppress the system's efficiency and may increase its overall cost. Several existing researches have numerically and experimentally developed the different cavity receiver models by modifying their inclinations, design geometrics, and structure. The conductive loss does not occur much in the cavity receivers compared to the convective loss. So, the analysis of convective loss is more critical in the cavity receivers; however, the accurate prediction of convection loss is quite complex due to the temperature distribution near the cavity. This prime aim of the paper is to comprehensively review the existing literature related to design configurations of cavity receivers and heat loss analysis to set a platform for performance improvement via design modifications. The study emphasizes the effect of geometric parameters like the structure of cavity receivers, shape and sizes, and angle of inclinations with the ground. Structural configurations, especially the hemispherical, cylindrical, conical, and trapezoidal cavity receivers utilized for the solar dish collector (SDC), are investigated between the years 1980 to 2022. A comparison is made based on heat loss models and research outcomes. Besides, the Nusselt correlation model used for predicting heat losses is also carried out in this review by varying the effects such as inclination, aperture ratio, wind effect, etc. This review supports the solar cavity designers for experimentally investigating and simulating a new modified solar cavity receiver with minimization and accurately predicting convective losses.

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INTRODUCTION

One of the convenient and cost-effective sources of electricity formation is solar energy, which converts thermal energy into electrical energy [1]. Certain solar power technologies, mainly solar collectors, are emerging to provide thermal energy from solar radiation [2]. Such solar thermal systems are efficiently used in several applications such as chemical processing, heating process, and mainly for producing electricity. The most utilized solar-thermal techniques are solar tower/steam turbine, dish/ heat engine, and trough/steam turbine systems [3]. The solar collectors are divided into superior types by considering the radiation view, i.e., point and line focusing system. Besides, the system's tracking behavior occurs in both ways, via a single

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axis and two axes [4]. The one-axis tracking is mainly performed in Linear Fresnel reflectors and parabolic trough collectors (PTC) [5-7]. The two axes of tracking behaviors occur in collectors: solar dishes and central receiver systems [8-9]. The solar dish system, also known as Parabolic Dish Collector (PDC), is superiorly utilized in numerous thermal and electrical applications because of its optimum efficiency rate and high working temperatures over 1800K, with a maximum concentration ratio between 1000 and 5000. The solar dish-based system is commonly used in thermal power plants because it plays a prominent role in enhancing plant efficiency. Besides, in a heat engine, it helps to raise the thermodynamic fluid's temperature to 1000oC. Despite expensive and bulky systems, several types of research have been focussed on minimizing the PDC cost [10-13]. Several efforts are also made to enhance the heat transfer rate and efficiency improvement by using nanofluids and phase change materials [14-17]. Literature reported that there is an efficiency improvement of 5 – 10 % by using nanofluids in the receivers [18].

The solar dish-based engine consists of a thermal receiver, parabolic dish concentrator, and generator/heat engine [19]. The dish configuration is mainly in the form of the reflector, and the receiver is located on the dish's focus as downward facing for receiving the concentrated solar radiation. Despite the significant characteristics of thermal receivers, it may reduce the system's effectiveness due to the available losses of heat [20]. Thus, various modifications have been implemented on cavity receivers to enhance the system's efficiency, minimum optical and thermal losses, uniform wall temperature, convenient cost, better efficiency for solar absorption, etc. [20]-[22].

The primary heat losses attained in the cavity-type receivers are convection, radiation, and conduction losses [23]; similarly, the radiation and the convective losses are achieved mainly through the cavity openings of the receiver. The conduction mainly depends on the insulating material and the receiver's temperature, and compared to the other heat losses, the availability of conduction loss is minimum and conveniently calculated [24]-[25]. Besides, the radiation loss mainly depends upon the shape factors, temperature, absorptivity, and emissivity of the receiver cavity wall. Several existing researchers reported that the cavity inclination is independent of both the convective and radiative losses [26]. The convection mode heat loss mainly depends on the external wind behaviors, cavity geometrics, cavity inclinations, attainable air temperature, etc. Given cavity inclination angles, the convective losses decrease at maximum inclination [27]. The analysis of the loss of the convective mode of heat is quite complex because of specific difficulties of available velocities and temperatures in and around the cavity receiver [28]. Significant parameters such as inclination, aperture area, and wind conditions are considered the main parameter for the formation of convective losses. The accurate prediction of convective losses is quite complex because of the flow behavior near the cavity.

Numerous researchers have studied the different types of cavity receivers in solar dish systems, mainly for determining heat loss. But the modified type of receivers based on its structure is rare than the modifications in inclination effects. The main aim of the review study is to understand the various configurations of solar cavity receivers, their efficiencies, and heat losses in order to make a platform to further modify the existing cavity receivers. Several modeling approaches with Nusselt correlation to predict the system heat losses make the outcomes economically and technically practical. Besides, the system's thermal efficiency is also studied from the effect of aspect ratio, inclination, and wind conditions. The different solar collectors used for the high-temperature application are discussed based on the construction and configurations of receiver coils. Accordingly, various modes of in-depth heat transfer and heat loss analysis are discussed. The comparative analysis of different cavity receivers based on their thermal performances is also presented in this paper. The search is carried out using an online logical database from 1980 to 2022; mainly, the distributed papers are collected from accepted search engine databases such as Taylor & Francis, Wiley online library, Springer Digital Library, Elsevier, Google Scholar, Science Direct, and so on.

CONSTRUCTION OF SOLAR CAVITY RECEIVERS

In solar collector technology, receivers are considered a substantial component and significantly dominate the system's thermal performance. Two major solar receivers are cavity and evacuated metal-glass-based tube receivers [29]. In an evacuated tube-based receiver, the annulus of both metal and glass absorber is to be evacuated, which helps to suppress the loss of convective heat. Specific effects such as hydrogen penetration and glass breakage may sometimes compromise the vacuum created [30]. A cavity receiver can be several types as shown in Figure 1. Different researchers reported the cavity receivers' performances mainly based on the effect of heat loss and pumping power modes.

The cylindrical receiver with insulating nature was investigated for analyzing heat transfer performances [36]. In this, at an outlet temperature of 130oC, the efficiency is optimal at 90%. The author concludes that the receiver system with better selective nature of the coating and without a vacuum enclosure approach provides better outcomes. The four different configurations for the black body cavity receiver, such as square, semicircle, triangle, and circle, were developed and simulated to analyze the effect of thermal performance and optical efficiencies [37]. The triangular configuration promotes better performances and minimal thermal losses among different configurations. A minimal thermal loss of 20 W and better conversion efficiency of 67% was obtained. Besides, the semi-circular cavity receiver is worse than the overall utilized configurations and evacuated type tube receiver. Melchior et al. [38] have conducted a numerical analysis on cylindrical cavity-assisted tubular

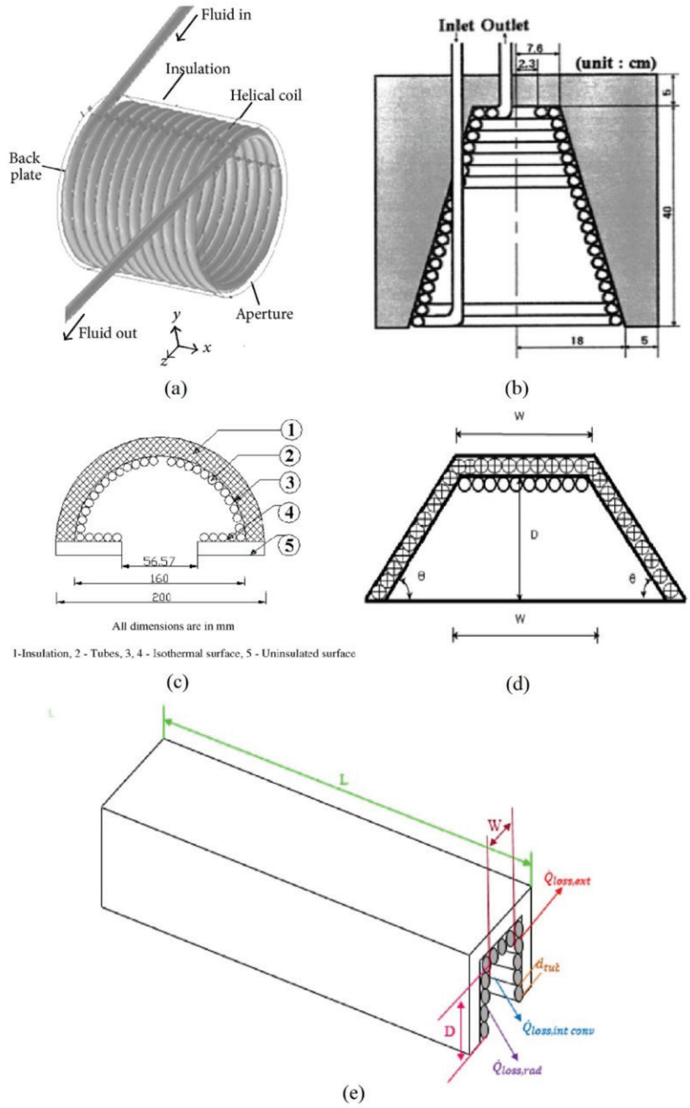


Figure 1. Different type of cavity receiver used for solar dish collector system: (a) Cylindrical [From Prakash [31], with permission from Hindawi.] (b) Conical [From Ryu and Seo [32], with permission from KSME.] (c) Hemispherical [From Kumar and Reddy [33], with permission from Elsevier.] (d) Trapezoidal [From Natarajan et al. [34], with permission from Elsevier.] (e) Rectangular [From Loni et al. [35], with permission from Elsevier.]

receivers, and validation is carried out using experimental information. In the reactor, the solar-to-thermal energy conversion efficiency is 28.55%.

Three different types of cavity receivers, namely, two and 3-plus M-type cavities and secondary reflecting cavities, were utilized by Gao et al. [39] for investigating the optical losses and the effect of absorptivity. In this, the minimal optimal losses are gained over the conventional type receiver. Besides, maximum absorptivity is achieved from a deeper cavity receiver and specular reflection. Different receiver configurations are developed, such as single or double-glazed aperture windows and V-corrugated or smooth absorber tubes [40]. The collector efficiency is maximum as 60-65% at the fluid working temperature of 125°C. At maximum fluid temperature, 500 °C, the collector efficiency was minimized at the 13.9° incidence angle. A numerical model was developed for the two inclined pins and a central tube-assisted cavity receiver. The numerical model is to be developed by the experimental data. At the mass flow rate of 0.17–0.181 kg/s and inlet temperature of 80.6–160.5 °C, the optimal collector efficiency of 34.18–48.57% is obtained [41].

Liang et al. [42] developed a novel cavity receiver with a movable cover to suppress the heat loss and overheating effect. The 3-D heat transfer model was more effective in suppressing heat loss. The heat loss drop varies from 6.36% to 13.55%. Dabiri et al. [43] developed the trapezoidal cavity receiver to determine the total heat losses in the Fresnel reflector. In this, the thermal characteristics are analyzed by considering the

Table 1. Summary of different solar receivers utilized in the existing papers

Author, Year	Cavity type	Type of solar collector	Method of study	Aim	Findings
Facao et al [46], 2011	Trapezoidal cavity receiver	Fresnel solar collector	Numerical	CFD analysis to optimize the cavity depth	Better heat transfer coefficient
Lin et al. [47], 2013	V-shaped cavity receiver	Linear Fresnel collector	Experimental and numerical	The receiver surface temperature is investigated, and predict the optical performances are using the Monte Carlo ray tracing technique	Optical efficiency=75.5%, overall heat loss coefficient= 6.25 to 7.52 W/m^2 K
Loni et al [48], 2016	Tubular cylindrical cavity receiver	Solar dish collector (SDC)	Numerical	Thermal modeling and optimization of cylindrical cavity receiver based on the aspect ratio	Maximum optical efficiency-96%
Gao et al. [39], 2015	Two-Plus and Three-Plus M-type cavity and Secondary reflecting cavity	Parabolic trough collector (PTC)	Numerical	Enhancing solar collector's thermal efficiency	Less optical losses than conventional receivers and Absorptivity higher than 90%
Liang et al. [41], 2018	Modified novel fin-assisted cavity receiver	PTC	Experimental	Enhancing the efficiency of PTC	Collector efficiency-65.25%
Liang et al. [42], 2018	Movable cover-assisted cavity receiver	PTC	Experimental and Numerical	Protection from overheating and heat loss minimization of PTC	The reduction of heat loss varied from 6.36% to 13.55%.
Dabiri et al. [43], 2018	Trapezoidal cavity receiver	Fresnel solar collector	Numerical	Evaluate the influence of tube size and cavity angle.	Total heat transfer rate= 85.2% to 91.3%
Fan et al. [44], 2018	Volumetric-based cavity receiver	PTC	Numerical	The Heat transfer analysis on PTC assisted with absorber tube and Nanofluid.	Maximum efficiency=72% at the minimum temperature
Pavlovic et al. [49], 2018	Spiral and conical	SDC	Numerical	Compare two cavity receivers (conical and spiral).	Efficiencies are better in conical design. Optical efficiency conical-85.21 Spiral-84.06.
Qiu et al. [50], 2021	Evacuated receiver using rabbit-ear mirrors and spectral-selective glass cover	PTC	Numerical	To improve the receiver efficiency	Improvement in receiver efficiency-0.30-2.72%. Thermal loss= 3.3-41.6 W/m^2 (3.1-6.1%)

effect of tube size and cavity angle. The author concludes that the effect of cavity angle increases the heat transfer rate more than the tube size. Another author developed a mathematical model for the receiver located inside the heat transfer fluid (HTF) filled twin glass tube. The receiver's performances are analyzed at temperatures 100–120 °C, and the author concludes that similar thermal performances are analyzed from both non-selective and selective-based absorber coating [44]. The appropriate receiver configuration helps to enhance the system's thermal efficiency without any vacuum enclosures and selective surface coating. By placing the receiver in the HTF-filled twin glass tube, the thermal distortion rate is minimal for cavity receivers than the tube receivers [45]. Table 1 explains the aim and the relevant finding obtained from the different solar cavity receivers.

CAVITY RECEIVER CONFIGURATIONS WITH HEAT LOSS ANALYSIS

In the high-temperature PDC, the geometry of cavity receivers plays a prominent role in enhancing its system performance. Many kinds of research utilized different cavity design models to improve thermal behaviors [51]. The thermal efficiency rate was increased by varying the rim angle [52]. Besides, the characteristics of cylindrical cavity receivers are improved by using different enclosure materials, such as graphite and Molybdenum [53].

Cylindrical Cavity Receivers

A cylindrical-shaped frustum-type receiver was developed by Siebers and Kraabel's model (1984) [54], in which the correlation analysis is carried out by considering the tilt angle of the receiver, the size of the aperture, and the surface temperature. A modified model was developed by Seo et al. [55] by using the model formed by Stine and McDonald [56]. Two different configurations of receivers, namely, dome and conical, were developed to predict the convective-based heat losses. Another Stine and McDonald modified prediction model is formulated by Leibfried and Ortjohann (1995) [57] to determine the heat losses of several geometrics of both downward and upward-facing cavities. The heat loss outcomes from the upward-facing cavity outperform the conventional Stine, McDonald, and Clausing models [58]. Several types of research were focused on determining the optical and thermal characteristics. Beltran et al. [59] developed a mathematical model for analyzing the thermal and optical behaviors of cavity receivers in a PDC system by considering the conduction and convection losses, intercept factor, and errors of solar collectors. The average errors of the emission and the radiation losses are 14%. Besides, the average error value for the remaining thermal losses and interception factor was less than 3%. The radiation flux is mainly influenced by the parameters such as system error and aspect ratio. In the parabolic dish system, the radiation flux distribution was simulated for the cavity receivers [60]. Such radiation flux was measured mainly by analyzing the aspect ratio and the system error of the receiver. The uniform radiation flux is observed at the optimal aspect ratio of 1.5, and at minimal system errors, the increasing effect of radiation flux is observed.

Karimi et al. [61] have recently developed a mathematical model for cylindrical cavity-type receivers in parabolic dish collectors. The novel approach concentrates on the internal receiver system's wall concerning non-isothermal behavior. The authors mainly aimed to investigate the intensity of solar irradiation, the mass flow rate of the fluid, and specific geometric characteristics such as aperture diameter and receiver length. The effect of the aspect ratio, the concentration of both solar irradiation, and the geometric ratio was superiorly involved in suppressing heat loss and efficiency enhancements. Yan et al. [62] developed a cavity receiver with uniform flux distribution for the discrete dish concentrator system. A discrete optimization-based model was developed by dividing the ideal parabolic generatrix into several components. In the receiver system, the flux uniformity distribution effect was optimized with the help of a genetic algorithm and ray tracing approach. Such optimized dish concentration helps with flux uniformity factor enhancement and peak flux minimization and improves optical efficiency. In addition to the thermal performances, the optical performances are to be measured by Xiao et al. [63], in which the thermal performance was solved using the Finite Volume approach, and the Monte Carlo Ray Tracing was used to solve the optical characteristics as shown in Figure 2. The thermal efficiency was increased by nearly 2.6% by adjusting the receiver's position, tilt, rime angle, etc.

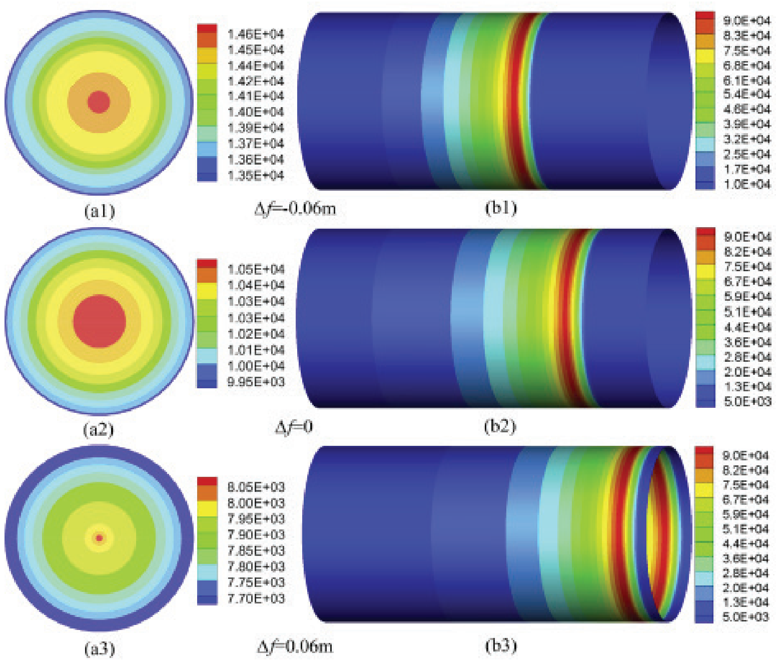


Figure 2. Solar flux contours on receiver walls at receiver position, (a1, a2, a3-botttyom walls, b1, b2, b3-side walls) [From Xiao et al. [63], with permission from Elsevier.]

Cubical, Hemispherical, and Flat Cavity Receivers

Le Quere et al. (1981) [64] conducted a numerical investigation on an open cubical cavity receiver to determine its unsteady natural laminar convection flow. Determining natural convection loss from the receivers depends mainly on the inclinations of the cavity and developed correlations for the inclinations [65]. Tan et al. [66] analyzed the heat loss from a semi-spherical cavity receiver-connected SDC system. The losses are determined from the low temperature (75oC) to the high temperature (300oC). The Nusselt correlation is formulated effectively by the aperture size and the different inclinations, and the author concludes that the loss due to convection is higher than the other losses.

Li et al. [67] have formulated an analytic model for the efficiency prediction of cavity receiver-assisted parabolic dish collectors. The analytic prediction approach, namely, Gaussian and polynomial model. The annual net thermal energy has been enhanced by optimizing the receiver size and rim angle effect. The parabolic dish system-assisted spiral cavity receiver was utilized by Pavlovic et al. [68] with several working fluids, such as water, Therminol, and air, in which both the experimental and numerical investigation took place. In this, at lower temperature conditions, water and air are outperformed; and at higher operating conditions, the contribution of therminol was efficiently involved in improving the thermal characteristics. The conical frustum cavity receiver was developed by Thirunavukkarasu et al. [69] based on energy and exergy analysis.

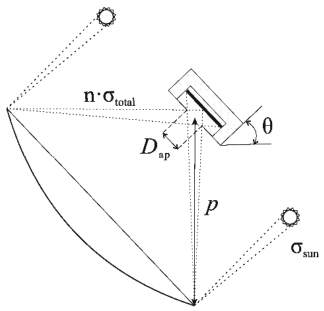
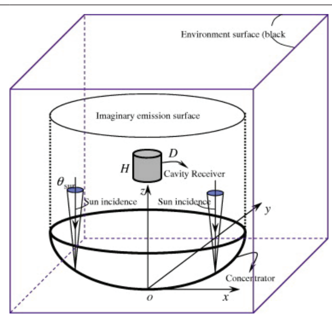
Conical Shaped Cavity Receivers

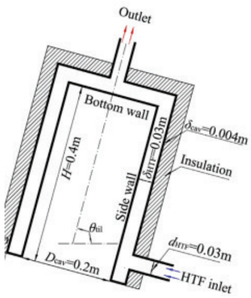
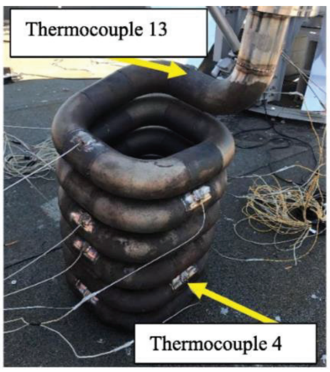
The experiment was performed under the average beam radiation of 608.17 W/m2 with the rate of mass flow of fluid at 2.5 liters per minute. As a result, the minimum overall heat loss factor was obtained at about 0.027 kW/K, and the peak thermal efficiency was 66.75% [70].In the solar collector, the surface temperature minimization is insufficient for the characteristic thermal enhancement of the receiver, an additional parameter called aspect ratio plays a significant role in thermal performance enhancement.

The influence of the velocity and incidence angle of the wind determined the forced convective heat loss. Besides, the position and orientation of the dish are also considered an impact on heat losses [71]. Recently, Venkatachalam, T. and Cheralathan.M, [70] analyzed the thermal characteristics of cubical-type cavity receivers mainly by aspect ratios 0.8, 1.0, and 1.2.

Another heat loss estimation was conducted by Craig et al. [72] for the tubular cavity receiver. The estimation is performed by varying the speed of wind and inclination angles, mainly for the natural and the forced convective losses. Due to the variations in heat losses, nearly 40 to 50% of solar power gets transferred to the HTF, while wind speed ranges from 0 to 5 m/s and 4 m/s. Regarding the parabolic dish system, the cylindrical, conical, hemispherical, and cubical receivers are categorized in Table 2.

Table 2. Survey on different cavity receiver models used for parabolic dish collector

Author, Year	Type of cavity receiver	Type of Study	Model	Findings
Beltran et al. [59],2012	cylindrical	Numerical analysis		Useful heat=9130W, Global efficiency=27.5%.
Mao et al. [60], 2014	cylindrical	Numerical investigations		The optimal receiver aspect ratio is 1.5 promotes better radiation flux.

Xiao et al. [63], 2020	cylindrical	Numerical investigations		Qcond= 65.4W, Qconv=178 W, and Qrad=187W.
Tan et al. [66], 2014	Semi-Spherical	Experimental analysis		Qcond= 450W, Qconv=25W, and Qrad=95W; at maximum temperature 150 to 300^{O}C.
Pavlovic et al. [68], 2017	Spiral cavity receiver	Experimental and numerical		Average flux value = 2.6 x 10^5 W/m2 Thermal Efficiency=34%
Thirunavukkarasu et al. [69], 2017	Hemispherical	Experimental analysis		Receiver net efficiency-24.3%
Venkatachalm and Cheralathan [70], 2015	Conical	Experimental analysis		Minimum heat loss factor= 58 W/K, Aspect ratio=0.8
Craig et al. [72], 2020	Tubular cavity receivers	Experimental and Numerical analysis		40–50% = solar power transferred to the HTF

Comparative Analysis of Different Configurations of Cavity Receivers

Three different cavity geometrics, namely, hemispherical, cubical, and spherical, were developed and compared their thermal performances with convective losses mainly by the impact of opening ratio (1, 0.5, and 0.25) [73]. The increased convective loss was attained at the maximum opening ratio for such entire receiver geometrics. Besides, minimal heat loss is obtained due to the increased inclination angle. The result also revealed increased convective loss for the hemispherical-type receivers. Solar desalination, industrial processes, electric power generation, solar-based cooling, and heating were some applications of solar in which solar concentrating technologies generated the heat for these applications. Loni R et al. [74] made a numerical comparison of a solar dish concentrator with different cavity receivers. Analysis was done by using either Behran oil or water. A numerical model was modeled to analyze the results of oil (working fluid) contributed in the receiver. A numerical model was applied to compare cylindrical, cubical, and hemispherical receivers under the same operating conditions to predict the appropriate cavity feature for a particular solar dish.

Loni et al. [75] have utilized two cavity receivers for the PDC: cubical and cylindrical. The cubical cavity receiver outperforms the cylindrical type receiver in view of thermal efficiency. Nearly 10% of increased efficiency was produced from the cubical type than the cylindrical cavity receivers. In the industrial sector, PDC applications with low working temperatures are essential. Lopez et al. [76] investigated PDC to analyze the thermal characteristics of cavity-based and flat receivers under low/medium temperatures. Conduction, re-radiation, and natural and forced convention were different kinds of detailed analyses developed for forced and natural convection. There was a significant enhancement in cavity receivers compared to flat-plat receivers. In SDC, Kalidas Murugavel et al. [77] studied the convection loss of five different shapes of cavity receivers at various locations using CFD. SolidWorks 16 was utilized to model spherical, cylindrical, flat, dome, and frustum of cone shape receivers, and the investigation was done under no wind conditions. Compared to all other cavity receivers, the spherical receiver was considered efficient in which flow velocity and temperature affected region and flow affected region was comparatively much less. Table 3 shows the comparison of different configurations of cavity receiver. While comparing the different configurations of cavity receivers, the cylindrical type receivers are less contributed to heat loss reduction. Thus several types of research aimed to enhance its thermal characteristics by the modification basis.

NUSSELT CORRELATION FOR HEAT LOSS PREDICTION

The behaviors of the natural convective-based heat transfer process are to be determined by the significant correlation called the Nusselt correlation as shown in Figure 3. It is the correlation of complex functions: tilt angle, shape, boundary conditions, Rayleigh number, Grasshof number,

Table 3. Comparative analysis of different configurations of cavity receivers

Author, year	Type of Study	Aim	Utilized cavity Geometrics	Heat losses	Findings
Kalidasa Murugavel et al [77], 2020	Numerical	Temperature variation and flow air analysis at no wind condition	Flat, dome, spherical, frustum of a cone, and cylindrical shape receivers	Convection	spherical cavity receiver is efficient
Prakash et al. [78], 2012	Numerical	Analysis of heat loss by the effect of opening ratio and inclination.	cubical, spherical, and hemispherical	Natural Convection loss	Convective loss is more in the Hemispherical cavity receiver
Loni et al [74], 2018	Numerical	Efficiency and heat loss analysis using working oils	Hemispherical, cubical, and cylindrical	Conduction, convection, and radiation	Overall efficiency is better for hemispherical cavity receiver
Loni et al [75], 2018	Experimental and Numerical	Thermal efficiency and heat gain analysis	Cubical and cylindrical	-	Thermal efficiency is better for cubical type. Cubical-65.145 Cylindrical-52.3
Lopez et al [76], 2020	Experimental and Numerical	Analysis of thermal efficiency	Flat, open cavity receivers, cavity with covers	Conduction, re-radiation, natural and forced convection	Heat losses and thermal efficiency are better for cavity receivers.

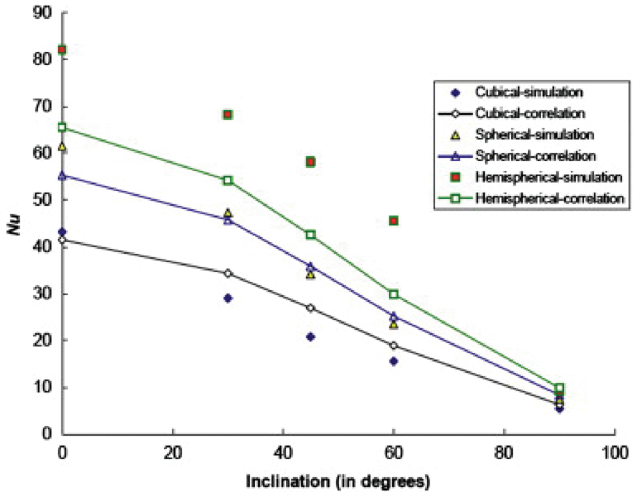


Figure 3. Nusselt number correlations and simulation analysis for different cavity receivers [From Prakash et al. [78], with permission from Elsevier.]

and aspect ratio. Calculating natural or combined convection behaviors is mainly performed using Nusselt number correlations. The flow pattern due to convection significantly affects the average and the local Nusselt numbers. But in several cases, the predicted models do not accurately match reality outcomes. Besides, the Nusselt number is maximum for three-dimensional based convective heat loss behavior than the three-dimensional model [79].

Thus, several authors have been tried to address different Nusselt correlations to agree with the investigated values. Abbassi et al. [80] developed a new convective heat loss correlation for the cylindrical cavity receiver. Such proposed correlation mainly signifies the geometric aspect ratio, cavity inclination, and temperature. The better Nusselt correlative prediction is attained when the range of Grasshof number lies between 2.6 × 105 to 1.4 × 107. The numerical investigation for convective heat loss-based Nusselt correlation was devoted by Prakash et al. [73]. In this, three different configurations, spherical, cubical, and hemispherical type open cavities, are considered, and the effect of Rayleigh number, cavity shape, opening ratio, and inclination angle are mainly considered for formulating the correlation. By considering the combined surface radiation and natural convection heat losses, Natarajan et al. [34] have developed a Nusselt correlation for a Trapezoidal cavity-type receiver in a Fresnel reflector. In this, the correlation derivation is formulated based on the non-Boussinesq numerical model, and the including parametric effects were absorber angle, surface emissivity, Grashoff number, temperature, and aspect ratio.

For various aperture sizes, inclinations, and operating temperatures, experimental-based correlations of the Nusselt number were established as a feature of the Grashof number. The e rate of heat loss convective mode is much higher in the work proposed by Tan et al. [66] relative to the existing numerical outcomes of the cavity receiver. Eames and Norton [81] have developed the direct correlation of the Nusselt number with the geometric collector's dimension and transverse inclination angle. Eames and Norton [81]. But, the proposed correlative model is suited only for a limited range of tilt angles and not for uni-cellular-based flow situations. Another, Nusselt correlation model is developed mainly for natural convective-based heat loss using the Rayleigh, Grashof, and Prandtl numbers [71]. Mainly, the proposed correlation is developed by considering the receiver's wall temperature's effect on the ambient temperature ratio, Grasshof number, etc. By considering the cylindrical cavity receiver with the size of the aperture and the tilt angle, the Nusselt correlation model was developed by Koenig and Marvin [82]. Table 4 explains the different Nusselt correlation models utilized for predicting heat losses.

EFFECT OF GEOMETRY AND ORIENTATION OF CAVITY RECEIVERS ON HEAT LOSSES

In the previous section, different shapes of solar cavity receivers are reviewed. Further, the design modification is introduced for the cavity receivers to enhance their thermal characteristics. The effects of geometry and inclination angle on heat losses are presented in Table 5.

Effect of Varying Cavity Inclination Angles

The influence of cavity inclination is shown in Figure 4. Yanping et al. [86] predicted an accurate natural convective loss from a modified cavity receiver by assuming the maximum solar flux conditions. The heat loss analysis is conducted for both insulated and non-insulated type hemispherical receivers by the inclination angle variations. The convection mode loss is minimal at the inclination angle (90o). The insulation-type receivers provide a superior heat loss; the minimal convective loss obtained from the insulation-type receiver is 12.5%, and the without insulation is 24.9%. Vikram and Reddy [87] have developed three modified-based cavity receiver configurations by varying the cavity cover emissivity, inclination angle, insulation thickness, and operating temperature. The prediction models, such as the Nusselt correlation and Artificial Neural network, determine the heat losses. At the maximum diameter ratio, the minimal heat loss of nearly 288W was obtained.

Similar to the inclination angle, the wind effect is also considered an effective parameter for solar collectors. In the parabolic dish system, another modified receiver model was developed by Reddy et al. [88]. The inclination mainly contributed to determining the thermal performances, and minimal convective loss occurred at lower wind speeds. The effects of wind speed, inclinations of receivers, the direction of the wind, receiver configuration, and the free convective heat loss are determined for the modified hemispherical cavity receiver. The cavity receiver was developed on a fully open and partially open basis, in which the author

Table 4. Survey on Nusselt correlations for heat loss prediction

Author	Nusselt correlation	Comments
Siebers, and Kraabel, [54], 1984	$Nu = 0.088Gr^{1/3}(T_w / T_\infty)^{0.18}, 10^2 \leq Gr \leq 10^5$	-Cubical cavity -Large degree of uncertainty
Leibfried and Ortjohann [57], 1995	$Nu = 0.017Gr^{1/3}(T_w / T_\infty)^{0.18}$ $(4.256 A_{ap} / A_{cav})^s h(\varphi, \varphi_{max}, \varphi_{stag})$, $h(\varphi, \varphi_{max}, \varphi_{stag})$, is the implicit function	-Cylindrical cavity -Modified Stine and Mc Donald model -Complexity due to the availability of implicit function.
Lovegrove et al. [83], 2003	$Nu = 0.04Ra^{0.44}(D_{ap} / D_{CAV})^{0.03} \Pr^{0.25}$.	-Cylindrical cavity -The correlation accounts for combining both inclination and the geometrical parameters using the characteristic length (L_C).
Yasuaki et al. [84], 1994	$Nu = 0.185Ra^{0.25}, 10^6 \leq Ra \leq 6 \times 10^{10}$, $6 \leq \Pr \leq 13{,}000, Lc = Dcav$	-Hemispherical cavity -Correlation mainly for the hemispherical receiver
Khubeiz et al. [85], 2002	Numerical Correlation: $Nu = 0.340Ra^{1/4}, 10^5 \leq Ra \leq 10^9, Lc = Dcav$ Theoretical correlation: $Nu = 0.296Ra^{1/4}, 10^5 \leq Ra \leq 10^9, Lc = Dcav$ Experimental correlation: $Nu = 0.31Ra^{1/4}, 1.7 \times 10^5 < Ra < 3.4 \times 10^5, 376 < \Pr < 1140$ $Lc = Dcav$	-Hemispherical cavity -The correlation shows good agreement by comparing theoretical, numerical, and experimental solutions.
Prakash et al. [73], 2009	$Nu = 0.21Gr_D^{(1/3)}(1 + COS\theta)^{3.02}(T_m / T_a)^{-1.5}$. $\theta -$ The inclination angle of the receiver, Tm-Mean temperature of Receiver, Ta=Ambient Temperature, Gr_D- Grasshof number with respect to the characteristic diameter	-Cylindrical receiver -The correlation helps to predict the loss due to convection at the mean temperature of receiver 100°C to 300°c. -Minimum Nusselt number is attained due to an increase in inclination.
Tan et al. [66], 2014	$Nu = 0.54(Gr_D)^{0.142}(1 + COS\theta)^{5.699}(T_m / T_a)^{-0.477.5}$ $(D_a / D)^{-0.556}$ D_a-Aperture size, D- Receiver diameter	-Modified cavity receiver -The correlation is developed when Tm/Ta ratio ranges between 1.5 and 2. -Maximum convective heat loss
Prakash et al. [78], 2012	$Nu = 0.0136(Ra_D)^{1/3}(1 + COS\theta)^{2.72}(d / D)^{0.72}$, d/D-Opening ratio	Correlation helps to predict the conventional loss of open cavity-type cubical, spherical, and hemispherical receivers.
Uzair et al. [71], 2018	$Nu = 0.0027(Gr)^{0.54}\left(\frac{T_w}{T_\infty}\right)^{2.72}(2 + 1.8Cos^3\theta)^{-3.62}$. Ta-Ambient temperature, Tw- Temperature of Cavity wall	-Conical receiver -High-temperature application.

concludes that the fully open receiver promotes more convective heat loss [89].

Effect of Varying Design and Structure

The design variation takes place in the cavity receiver, and its behavior is analyzed with the help of ASPEN HYSYS 8.4 software [8]. More attention was given to determining the surface radiation and the convection losses. The formulated Nusselt correlation is in more agreement with the other existing models. A cylindrical cavity receiver with a small opening design was developed by Kumar and Reddy [90] and the heat losses are estimated by varying the inclination angles from 0o to 90 o. The minimal losses of heat were achieved due to the modified system. Besides, the Nusselt correlation for separate and combined heat loss revealed a similar trend with the other existing heat loss models. The heat loss from the cylindrical cavity receivers from the solar dish-based system was investigated using different boundary conditions, in which three cases were adopted based on the surface treatment, such as heating at

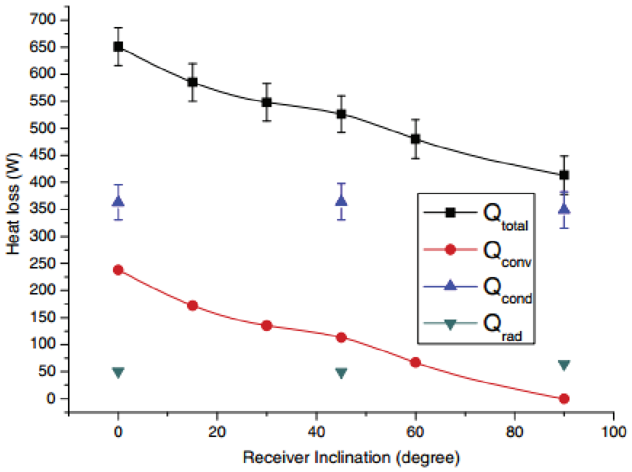
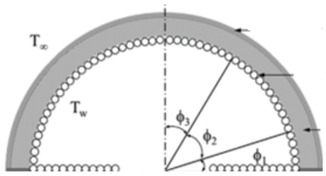
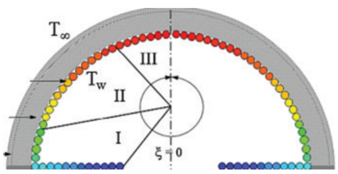
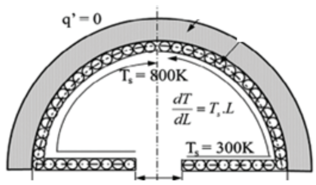
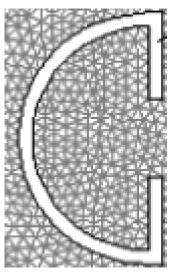


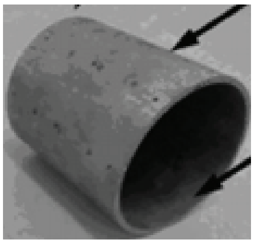
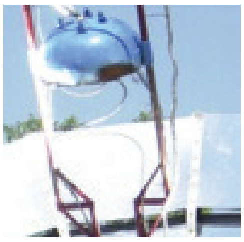
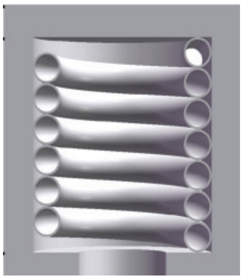
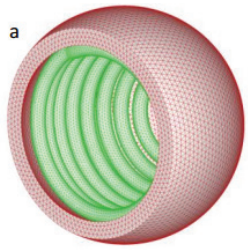
Figure 4. Heat loss analysis by varying inclination angles [From Tan et al. [66], with permission from Elsevier.]

the bottom surface, side surface, and entire surfaces. The thermal performances outperform the bottom heat-treated surface, and convective losses are minimal at the maximum inclination level [91].

An inverse design strategy was developed mainly to concentrate the cavity wall's surface temperature [92]. The heat transfer between the cavity and the working medium was analyzed mainly by the wall of the absorber model. Besides, the jet cooling approach was utilized for cooling the peak flux attained in cavity walls. Such cooling activity helps to control the surrounding temperature and reduce convective loss. However, the radiation loss was not analyzed. The solar receivers' design modifications are carried out to optimize their thermal performances. Thus, thermal performances are more optimally obtained from the modified cavity receivers than the conventional types. Reddy et al. [93], the focal image characteristics were utilized to

Table 5. Effect of Geometry and Orientation on Heat losses

Author, Year	Determined loss	Modified cavity receiver	Model and study type	Findings
Vikram et al. [86], 2015	Convection and radiation	Varying diameter ratio and inclination angle 0 to 90°	-Numerical 	Total heat loss =522 W
Reddy et al. [87], 2015	Surface Radiation and convection	Varying Receiver inclination, Aperture diameter.	Numerical 	Forced convection was less than natural convection at lower wind speeds.
Reddy et al. [88], 2015	Convection	-Hemispherical modified cavity receiver -Varying inclination angles	-Numerical 	Angle inclination-60%, heat loss is maximum
Kumar et al [89], 2010	Natural convection and radiation heat loss	-the different angles of inclinations -0-90° -cavity type with a small opening at the aperture	-Numerical 	Minimum heat loss at 90°

Wu et al. [90], 2013	Conduction, convection, and radiation	A fully open cylindrical cavity -heating of the bottom surface, side surface, and all surfaces	-Experimental and Numerical 	-Tilt angle has a minor effect on the Nusselt number correlation. -Inclination is indirectly proportional to heat loss.
Reddy [82], 2015	conduction, convection, and radiation heat losses	-Cylindrical -Aperture 0.305 m - opening radius of cavity equal to the radial distance of peak intensity	-Experimental 	Average Thermal efficiency-74%.
Zou, [94], 2017	Conduction, Convection, and Radiation	-Cylindrical The aperture was mounted at the front portion with the inside helical-shaped tube.	-Numerical 	Thermal efficiency -71.41%
Si-Quan [95], 2019	Radiation and convection.	-Spherical -cavity with Spiral copper pipes	-Numerical 	Thermal conversion efficiency varies from 81.9% to 84.4%. -Optical size 1.0~1.5.
Thirunavukkarasu et al [79], 2017	-	- $NaNO_3$ and KNO_3 phase change material	-Experimental 	The net energy efficiency of 31.4%

select the suitable absorber design, and the maximum thermal efficiency of 79.2% was achieved.

Loni et al. [94] developed an assisted organic Rankine cycle-based tubular cavity receiver-assisted solar dish system. The working fluid, namely, R141b, was utilized in the organic Rankine cycle, in which this approach enhances the system's thermal efficiency. By using the three critical geometric factors, such as cavity length, inner diameter, and the aperture diameter of the cavity receiver, a modified thermal receiver model was developed by Zou et al. [95]. The modified model consists of an aperture located in the front and an inner helical pipe. The designed model was optimized for high operating temperature conditions, and enhanced thermal efficiency was gained from such a modified design. Si-Quan et al. [96] have utilized the spherical type cavity receiver for the solar dish system. The spiral tube made of copper material in the receiver was utilized to absorb the radiation. The minimal reflection loss and the optimal optical efficiency (86.3%) were obtained by increasing the aperture ratio. At the same time, the maximum heat losses are observed by increasing the inlet temperature of HTFs. The system's thermal efficiency ranges from 81.9% to 84.4% to this contribution.

Another aspect of phase change material is also contributed in solar collectors for enhancing its radiation absorbing behaviors at irregular radiation behaviors. Thirunavukkarasu et al. [97] developed a double-layered wall-based hemispherical cavity receiver in which the eutectic mixture of KNO3 and NaNO3 is applied to the space between the two layers. Thus, this phase change activity behaves as heat transfer and the storage medium. Qiuet et al. [50] have developed heat-reflective film-coated modified receivers; meanwhile, the pair of rabbit receivers are also employed to minimize the solar rays missed by the receivers. The receiver efficiency is optimally obtained from the modified receiver system than the traditional type. The thermal loss is minimized by 3.3-41.6 W·m-1 (3.1-6.1%), and the collector efficiency is to be improved by 0.30-2.72%.

CONCLUSION

In solar dish systems, the cavity receivers are considered a significant component for collecting maximum solar flux and enhancing heat transfer rate. The convective heat loss negatively impacts the system's efficiency, so the effect of design and parameter optimization minimizes the heat losses from cavity receivers. This paper overviews and compares the design configurations of cavity receivers along with the heat loss models and prediction strategies. A modified cavity receiver can minimize heat losses at various working conditions and can be useful in utilizing solar energy effectively. Following are the concluding remarks made in this review study.

- The previous research observed that most researchers used the parabolic dish system for heat loss analysis from the solar cavity receivers. Comparing the different solar receiver configurations, the conical and the spherical receiver promotes fewer heat losses than the cylindrical type receivers.
- Several works are focussed on predicting natural convective-based heat loss. However, limited research is performed by considering the forces and the combined effect of convective heat loss.
- In the Nusselt correlation-based heat loss prediction approaches, several parameters, namely tilt angle, aperture ratio, and inclination angles, are primarily used as the optimizing parameters for heat loss reduction, but the effects of wind are rarely considered.
- Generally, the conductive loss is minimum for the cavity receivers than the convection and the radiation losses. In other words, the radiation and convection effect plays a leading role in the overall performance improvement in the solar dish system due to surface emissivity, cavity wall temperature, opening ratio, etc. However, in the overall heat loss analysis, the convective loss is highly dominated in several types of research, and the contribution of radiation loss is significantly less.
- In the modified type cavity receivers, more importance was given to the cylindrical type receivers to enhance the efficiency of their performance. At the same time, several designers developed the receivers based on design modifications by changing their dimensions. However, structural modification using different materials and additional eco-friendly components is rare. Generally, modified cylindrical-based receivers are still required for thermal performance enhancements.
- In the future, there is a need for experimental study by changing the surface area of the cavity receiver.

NOMENCLATURE

A	Area, m^2
Aap	Aperture Area, m^2
Aw	internal cavity surface area, m^2
cond	Conduction
conv	Convection
D	Diameter, m
f	focal length, m
Gr	Grashof Number
h	Height of interior convex, m
k	Thermal conductivity, W/m.K
L	Length of Cavity, m
L_c	Characteristic length, m
Nu	Nusselt Number
Nuc	Average convection heat loss Nusselt number
Nur	Average radiation heat loss Nusselt number
Nut	Average total heat loss Nusselt number
Pr	Prandtl Number
Prad	Radiation Heat Loss, W/m^2
Q	Heat, W
rad	Radiation
Ra	Rayleigh Number
T	Temperature, ^oC
Ta	Ambient temperature, ^oC
Tm	Receiver mean temperature, ^oC
Tw	Average cavity wall temperature on side, ^oC
U	Overall heat transfer coefficient, W/m^2 K

Greek symbols

ε	Emissivity
φ	Referenced angle in degrees
θ	Cavity Inclination in degrees
Δf	difference between actual receiver position and focal length f

Subscripts

PDC Parabolic Dish Collector
PTC Parabolic Trough Collector
SDC Solar Dish Collector

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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