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# EXPERIMENTAL INVESTIGATION OF HEAT LOSSES FROM CYLINDRICAL CAVITY RECEIVER

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**Abstract**
Heat loss is the most significant element reducing the overall efficiency of a solar concentrator's cavity receiver. Heat losses are measured experimentally and numerically on a cylinder with a hollow diameter of 0.35 meters, an aperture of 0.55 meters, and a wind skirt. Experiments were conducted to assess both total and convective losses at cavity angles of 0 $^o$, 25 $^o$, 50 $^o$, 75 $^o$, and 90 $^o$. The experimental apparatus's main component is a cylinder-shaped hollow receiver insulated with glass wool. This receiver aims to limit the quantity of heat lost due to convection. A numerical investigation of the connective heat losses that occurred in the absence of wind was performed using the CFD tool. A comparison of the numerical and experimental results found good agreement, with the highest difference being 13%. When the inclination angle into the cavity receiver increases from 0$^o$ to 90$^o$, convection and total losses decrease. It is conceivable to detect an increase in both total and convective losses when the cavity's operating temperature rises. Furthermore, M. Prakash's convective losses are compared to the current results. M. Prakash's convective loss model provides the forecast closest to matching experimental and numerical data.
***Keywords***: Cylindrical cavity receiver, Heat losses, Temperature effect

## 1. Introduction

The primary functioning of the cavity receiver in terms of its heat resistance is important for better performance. The majority of the studies investigated various methods for reducing losses, the majority of which involved experimenting with various cavity receiver shapes. T. Taumoefolau et al. [1] conducted an experiment to investigate the convection losses that result from using a cylindrical cavity receiver. In addition to that, they carried out numerical analyses by using CFD software. They discovered that the findings were consistent with the findings of previous research. Harris and Lenz [2] conducted research on the reason behind the energy loss that occurs in cavity receivers. They investigated how the numerous cavity shapes affected the system's effectiveness and discovered that the differences were negligible across the board. Stine and McDonald [3] conducted a series of experiments to investigate how the direction of the cavity, the operating temperature, and the aperture size all influenced the amount of heat lost through convection. In addition to this, they devised a correlation that took into account the influence of cavity inclination, geometry, and temperature. U. Leibfried and Ortjohann [4] conducted research on the convection heat losses. For both they investigated the influence that opening ratios and cavity operating temperatures had on the amount of convective heat lost from the cavities. A.M. Clausing [5] presented an analytical model that may be used to investigate the receiver in terms of the convective loss. Both the importance of bringing warm air into the cavity receiver and the impact of wind on convective losses may be seen to be demonstrated by the same model. M. Prakash [6] carried out an investigation in order to make a comparison between the convective heat losses of three cavity receivers that were all the same. In order to determine the convective losses, a CFD simulation was run to explore the impact of opening ratios at various cavity receiver operating temperatures and to build a universal correlation for cavity designs. This was done in order to establish a universal correlation for cavity designs. Koenig and Marvin [7] developed an empirical connection for the model of convection heat losses. This connection took into consideration the high temperature of the cavity receiver, which ranged from 550 to 900 O C. In [8] conducted an investigation of convective losses through the use of experimental study with a square hole in a hollow receiver. In [10] conducted research on an isothermal cubical cavity that had an inclination ranging from -90 degrees to +90 degrees. They performed a series of experiments and discovered that each one produced very different nusselt numbers. V. C. Shewale and colleagues [14, 15] conducted experiments and computational evaluations of spherical cavity receivers for a variety of angles of the cavity in the receiver and temperatures.

Researchers have investigated heat losses while taking the various cavity receiver designs into account. After a great deal of inquiry and investigation, there was not much found out about the cylindrical cavity receiver. It has also been pointed out that M.Prakash [6] is the only researcher who has analysed the heat losses of a cylindrical cavity receiver with a wind skirt. Due to this fact, it is important to do research on the cylindrical cavity receiver with a bigger opening diameter than cavity diameter. In this investigation, heat losses are evaluated in a cylindrical hollow with a diameter of 0.35 metres, an aperture diameter.

## 2. The Mathematical Modelling and Experimental Design

### 2.1 Details of the cavity receiver

This experiment used a cylindrical cavity receiver, the front of which is depicted in Figure 1. The aperture diameter is 0.55 meters with a wind skirt, and the internal diameter of the cavity receiver is 0.35 meters. The copper coil contains 46 turns. The inside diameter of this copper tube is 0.0012 meters. In order to lessen heat loss, 150 millimeters of glass wool was used to insulate the exterior of the hollow. A little copper disc acts as a seal on the rear of the hollow receiver.

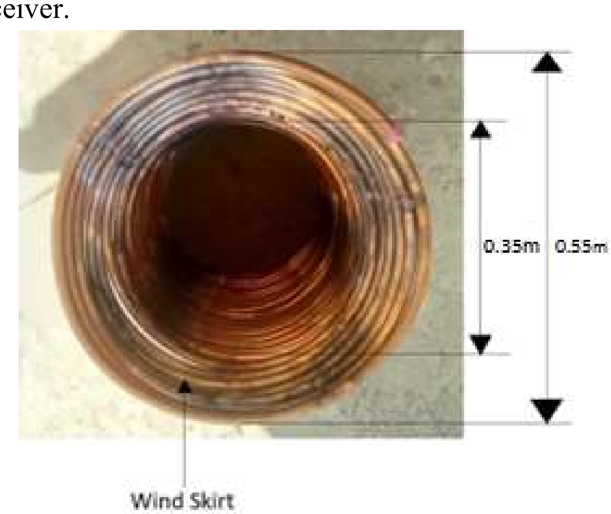


**Fig. 1.** A lateral view of a cylinder-shaped cavity receiver

## 2.2 The experimental set up:

The experimental apparatus represented in Figure.2 is utilized in the performance of low-temperature experiments, which are carried out at temperatures ranging from 60 to 80 O C. A cylindrical cavity receiver that is mounted on a stand and can be tilted to any one of five distinct angles is the most important part of the equipment (0, 25, 50, 75, and 90 degrees with respect to the horizontal). Using a pump with a quarter of horsepower, hot water is drawn from a storage tank that has a capacity of 140 litres and pumped into the hollow tubes. Several thermocouples of the K type are utilized in order to monitor the temperatures of the cavity surface, the fluid's entry point, and the fluid's exit point respectively. The experimental setup's rotameter and all of the K-type thermocouples will need to be calibrated in the laboratory before any measurements can be taken with them. Rotameter readings for mass flow rate at 60 kg/hr are only off by 3.5%, while thermocouple readings in the range of 60 °C to 80 °C are only off by 0.75%

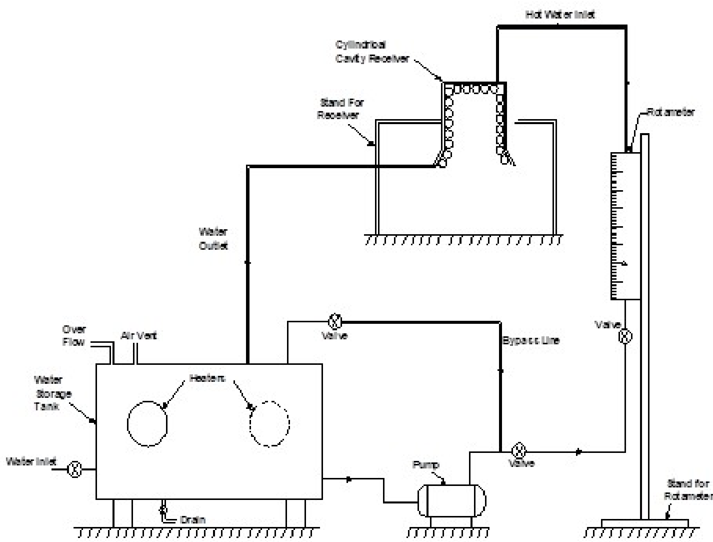


**Fig. 2 :** A diagram of the apparatus used in the experiment

While keeping the flow of hot water at a constant 60 kg/hr, we consider the temperature of the fluid every ten seconds. After the system has reached a point of equilibrium, measurements are carried out, and calculations are made regarding heat losses.

## 2.3 Mathematical Modeling:

The symbol "I" represents the energy balance of a cylindrical cavity receiver, where the three forms of heat loss are denoted by the terms "conduction loss," "convection loss," and "radiation loss," respectively. Conduction losses are caused by the receiver's outer layer, whereas the receiver's opening causes convection and radiation losses.

How much heat is wasted in a cavity receiver can be calculated with the help of the energy balance equation provided by,

$$Q_{tot} = Q_{cond} + Q_{convec} + Q_{rad} \quad \text{(i)}$$

Where $Q_{tot}$ , $Q_{cond}$, $Q_{convec}$, and $Q_{rad}$ are the total, conduction, convection and radiation heat loss for cavity inclination angle θ respectively.

The following equation can be used to calculate total heat losses.

$$Q_{tot} = m\, C_p\, (T_{fi}\text{-}T_{fo}) \quad \text{(ii)}$$

Water mass flow rate (m), specific heat (Cp), and inlet and outlet temperatures (Tfi and Tfo) are used in the equation.

To measure the conductivity loss, the entrance to the hollow receiver was covered with an insulating wooden plate and then sealed off. Experiments are carried out with temperatures of 60 $^{O}$ C, 70 $^{O}$ C, and 80 $^{O}$ C being introduced into the cavity at an angle of ninety degrees. Therefore, in order to calculate the amount of conduction loss, the following equation was utilized.

$$Q_{cond/opening\ closed} = m\, C_p\, (T_{fi}\text{-}T_{fo}) \quad \text{(iii)}$$

Using the following equation, we were able to determine the amount of radiation that was lost potentially.

$$Q_{rad/therotically} = \sigma\, \epsilon\, A_{op}\, (T_m^4\text{-}\ T_a^4) \quad \text{(iv)}$$

Where $\epsilon$ is the emissivity and $A_{op}$ is the opening area of the cavity receiver.

Therefore, the convective heat losses are calculated by using the following equation.

$$Q_{conv} = Q_{tot} - Q_{rad} - Q_{cond} \quad \text{(v)}$$

**3. The Numerical Analysis**

The findings of numerical analysis for a receiver with a cylindrical cavity are presented in the study. The cavity receiver model is depicted in figure 3, and it consists of a cubical enclosure that has dimensions that are ten times higher than the diameter of the cavity, and it surrounds the space that is outside of the cavity receiver to prevent air passage into the cavity. In this research, we investigated the possibility of grid independence by employing two distinct grid sizes: a fine grid for the cubical enclosure and a coarse grid for the cylindrical cavity receiver. Comparatively, the circular enclosure has around 0.5 million hexahedral cells, and the cylindrical cavity receiver contains approximately 2.1 million tetrahedral cells. Because of the low temperatures used for the tests, the Boussinesq approximation was used to come up with a close estimate of the properties of the air. For this investigation, we will assume that the temperature of the cavity's exterior wall is isothermal, while the temperature of the enclosure's inside walls will be kept at room temperature.

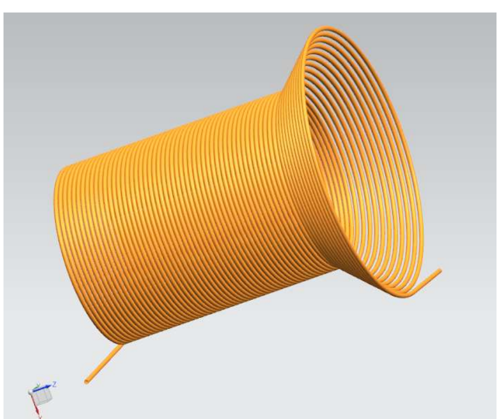

**Fig. 3:** An illustration of a cavity receiver model

## 4. Results and Discussion

### 4.1. Experimental Results

#### 4.1.1. Total heat loss for no wind condition

Temperatures of 60, 70, and 80 $^{O}$ Fahrenheit are tested at various inclination angles of 0, 25, 50, 75, and 90 $^{O}$ in the cavity receiver to measure total and convective heat losses in still air. Here are some pictures showing how the overall heat loss and convective heat loss of an angled cavity receiver change with time.

Heat loss owing to conduction, convection, radiation, and total heat loss is shown experimentally in Figure 4 for the 80 $^{O}$ C operating temperature of the cavity receiver. However, the cavity receiver's convection and total losses decrease from 0 to 90 degrees of inclination, while the conduction and radiation losses stay the same.

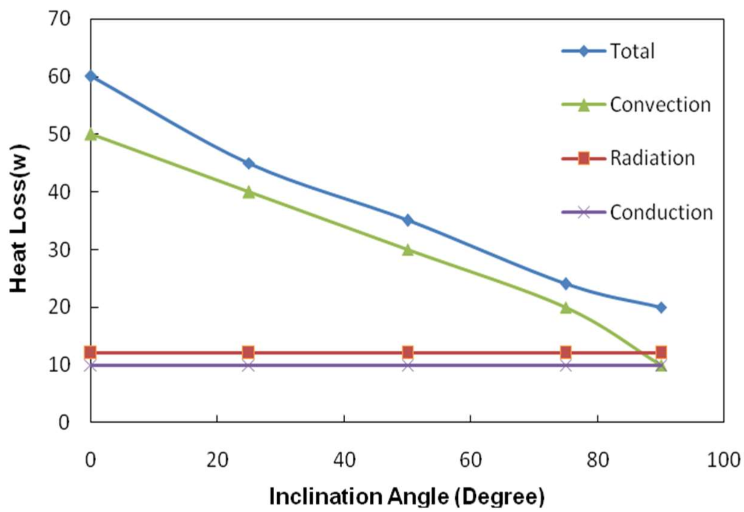


**Fig.4:** Heat loss compared to inclination angle at a cavity temperature of 800 $^{O}$ C

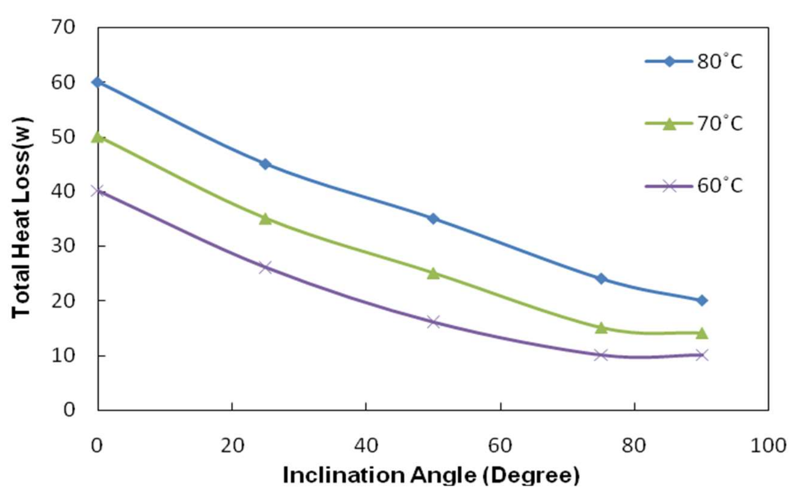


**Fig.5:** The ratio of the total heat loss to the inclination angle

### 4.1.2. The convection heat loss:

Figure 6 shows that, even when there is no wind, the quantity of convective heat loss varies with the rise of inclination for a particular cavity receiver's operating temperature. Specifically, we found that the convective losses of the cavity receiver are most significant at an inclination of 0 $^{O}$ and are minimal at an inclination of 90 degrees. There will be less heat dissipation due to convection if a more significant fraction of the cavity receiver is in the stagnation zone and a smaller fraction is in the convective zone. It was also discovered that, despite being minimal at a 90 $^{O}$ angle, convection losses do not cancel out completely.

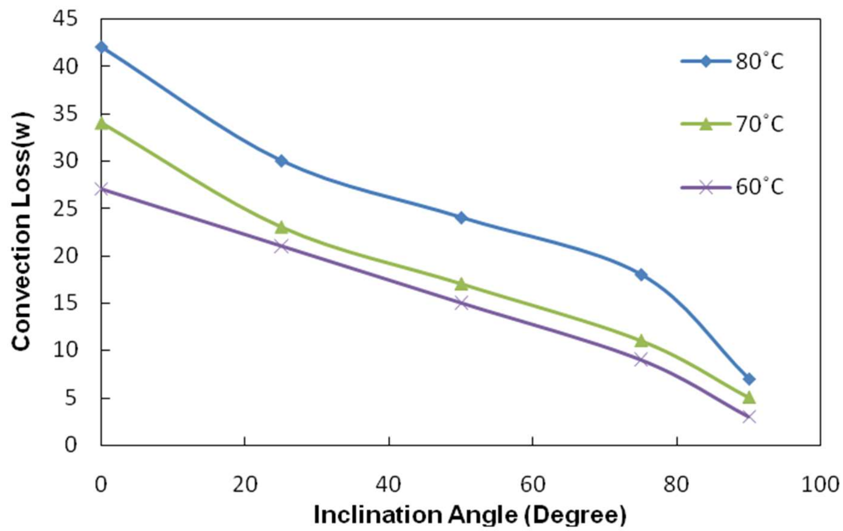


**Fig.6:** Heat loss due to convection in comparison to angle of inclination

### 4.2. Comparisons between numerical results, experimental results, and prior research:

The numerically estimated convective losses for conditions with no wind accord quite well with the experimental heat losses. This was discovered through experimentation. According to the findings of this study, the cavity receiver experiences the fewest losses at an inclination angle of ninety degrees. In contrast, it experiences the most losses at an inclination angle of zero degrees.

Comparisons are made between the numerical findings and the results of past study correlation for the cavity receiver's convection heat losses at temperatures of 70 and 80 $^{O}$ C. Figure 7 depicts the cavity's convective losses at 70 $^{O}$ C, while Figure 8 depicts same losses at 80 $^{O}$ C.

The numerical calculations and the experimental data correspond well with one another, with a maximum variance of 13% over all angles of the cavity receiver. This holds for all temperatures that were investigated. Compared to the results of computational and experimental research, the M. Prakash model [6] predicts significantly higher side convective losses.

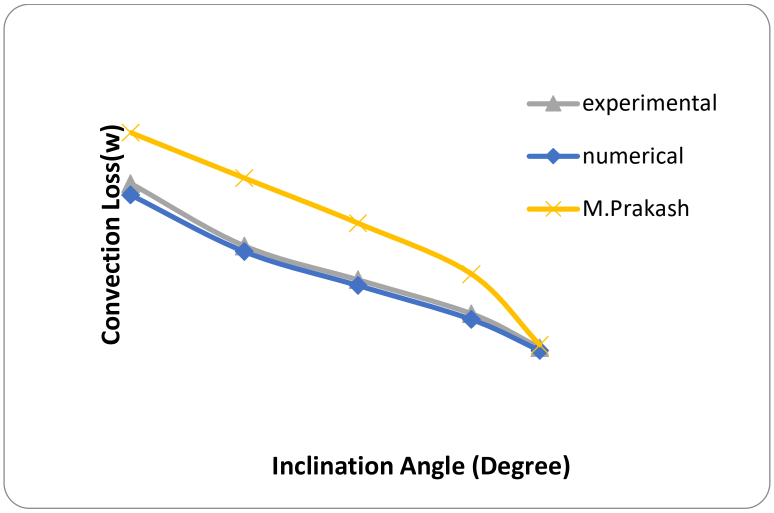


**Fig.7:** Convection heat loss comparison at 70 $^{0}$C

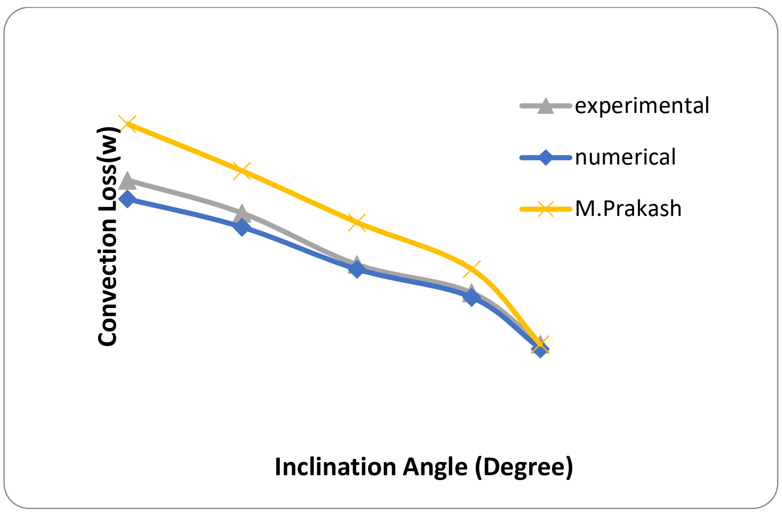


**Fig.8:** Convection heat loss comparison at 80 $^{0}$C

Between 0 and 25 $^{O}$ of cavity inclination, the M. Prakash model [6] has a more excellent range of convection loss variations. However, between 25 and 90 $^{O}$ of cavity inclination, there is significantly less variance noted, and the two data sets are quite compatible. The link of the M. Prakash model [6] with computational and experimental results reveals that the convective losses are at their lowest for a 90° angle of the cavity receiver. This finding supports the hypothesis that the M. Prakash model [6] is accurate.

## 5. Conclusions

This study will include an experimental and numerical investigation of total and convective heat losses. Our current heat loss examination is between 60 and 80 degrees Celsius. The quantity of heat lost owing to convection and radiation is calculated in relation to the temperature and angle of inclination of the fluid entering the cylindrical cavity receiver. When a wind skirt is present, the opening of the copper tubing used in the cavity receiver's construction is bigger than the diameter of the cavity. A reasonable agreement was discovered to exist between the results obtained from experiments and those obtained from numerical simulations over a wide range of inclination angles of the cavity receiver. In the absence of wind, a cavity receiver will experience the largest amount of heat loss at an inclination angle of 0 degrees, and the least amount of heat loss at an inclination angle of 90 degrees. Furthermore, an increase in the mean temperature of the cavity receiver correlates with an increase in the heat losses of the cavity receiver. This is something that needs to be looked at more.

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