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NUMERICAL SIMULATION OF SOLAR RECEIVER

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Abstract

The parabolic concentrator reflects the direct incident solar radiation onto a receiver mounted above the dish at its focal point. The conversion of concentrated solar radiation to heat takes place in receiver. The heat transfer characteristics of the receiver changes during the rotation of the receiver which affects thermal performance. The working temperature may also influence the thermal performance and overall efficiency of the dish-Stirling solar electricity generating system.

A heat transfer and flow simulation is performed for four different solar cavity receiver's viz.: cylindrical, conical, dome and spherical receivers at various receiver inclinations at constant temperature. The receivers are designed such that they have same surface area and aperture. It is observed that convective heat loss decreases as the inclination changes from 0^0 to 90^0. Among these receivers, the convective heat loss is least for conical receiver followed by dome, spherical and cylindrical receivers

1. Introduction

A central receiver system (CRS) is another concept for a high temperature solar concentrator that aims at the collection of large amounts of highly concentrated solar energy without requiring a piping. In this concept it is expected to achieve economy-of scale benefits, because systems with several 100 000 m2 of reflector surface area can focus to a single receiver approaching several 100 MW of power and thus use conventional power plant technology for the power cycle. Fig. 1 shows the Schematic diagram of the dish solar concentrator/cavity receiver system.

There are two different receiver designs in CRSs, the external and the cavity design. In cavity receivers, the heat absorbing elements are located inside of an insulated cavity. The focal spot of the heliostat field coincides with the aperture of the cavity. In external receivers the heat transferring surfaces are exposed to the ambient and are located directly in the focal point of the heliostat field. Cavity receivers offer the benefit of lower heat losses but generally constrain the direction of the incoming radiation and thus impact the heliostat field arrangement. They also restrict the benefits of selective absorber surfaces when they may become available in the future and are generally costlier. External receivers allow for an easier scale-up to higher power levels. In particular, cylindrical designs offer a flexible design of surround heliostat fields. However, in contrast to cavity receivers, the maximum concentration of the heliostat field that could be exploited is limited by the material constraints of the heat absorbing elements, because they are located directly in the focal point. The Fig. 2 and 3 shows the Stream Lines in Downward and Upward Facing Tilted Cavity Receiver

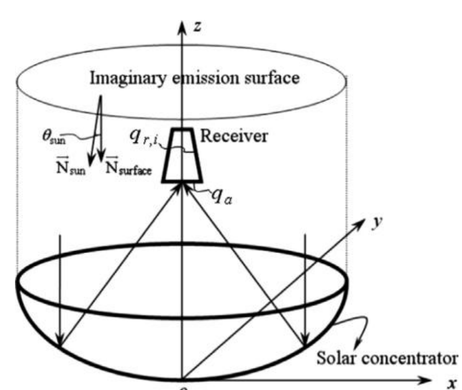


Fig. 1 Schematic diagram of the dish solar concentrator/cavity receiver system

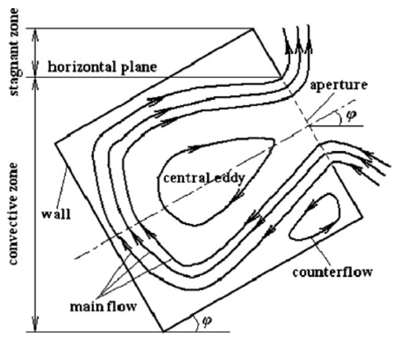


Fig. 2 Stream Lines in Downward Facing Tilted Cavity Receiver

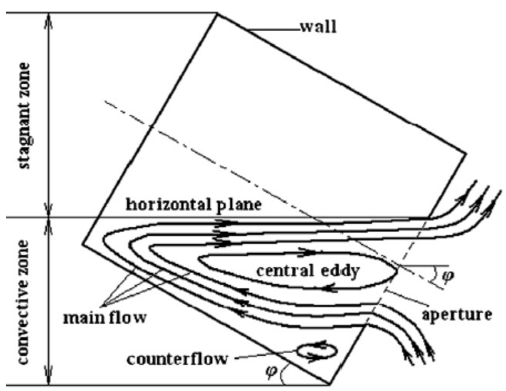


Fig. 3 Stream Lines in Upward Facing Tilted Cavity Receiver

The important energy loss for the receiver originates from convection and radiation heat transfer to the surroundings. These losses depend on the design of the receiver, whether it is a cavity or external receiver, its heated (or aperture) area, and its operating temperature. Additional factors include the local wind velocity, ambient temperature, and the orientation of the receiver.

Studies have been made on the combined radiation, free and forced-convection losses from large surfaces, and tilted cavities. Siebers et al. (1982) have performed experiments on large vertical surfaces in horizontal f low, and their data are being used to predict losses from external receivers. Clausing (1981) has developed a method for predicting the natural convective loss from cavity receivers. A summary of these studies may be found in Siebers and Kraabel (1984). Radiation and convection losses are primarily functions of the size of the receiver and the operating temperature of the system. For most currently conceived central receiver system designs, the receiver operates at a constant temperature. Therefore, the rate of energy being lost from the receiver is essentially constant throughout the day (and year) and the percentage loss increases in the morning and evening.

Numerical studies of cavity receiver convective losses are very limited. Numerical investigations on the convective heat transfer in open cavities have been reported in literature (Le Quere et al., 1981, Penot, 1982, Chan and Tien, 1985, Skok et al., 1991). Though the solar cavity receiver is essentially an open cavity, the studies carried out on open cavities cannot be directly extended to the case of solar cavity receivers

The heat losses from the receiver include three contributions: conductive heat loss from the receiver walls and radiative and convective heat losses through the receiver aperture. Among these contributions, natural convective heat loss contributes a significant fraction of energy loss. The natural convective heat loss in the receiver is an important factor for determining the performance of a fuzzy the overall focal solar dish concentrator. In order to improve system efficiency, natural convection characteristics need to be studied extensively. The main objectives of this work to predict the convective heat loss from the different receiver is shown in Fig.4.

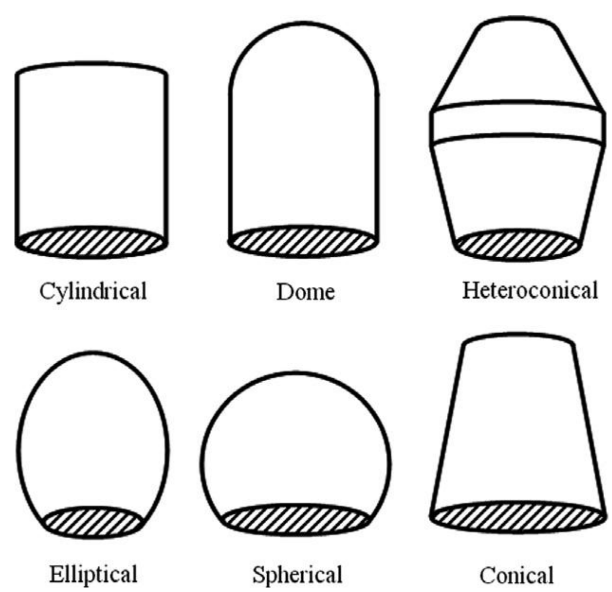


Fig. 4 Six classical cavity geometries

2. Geometric Model of the Receiver

Geometric model of solar receiver is created in ANSYS Design Modeller 13.0. Initially for validating the CFD results the geometric model is considered from Taumoefolau [16] as shown in Fig.5and 6.

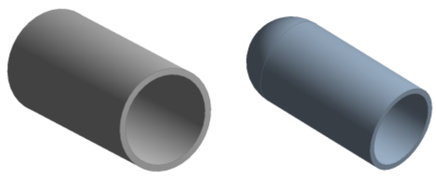


Fig. 5 Geometric Model of cylindrical dome receiver

Initially cylindrical geometry of cylindrical receiver is created as shown in Fig.7. For CFD analysis, the receiver is assumed to be placed in a sufficiently large enclosure with walls at ambient temperature. Due to the symmetrical flow geometry with respect to the middle vertical plane, the computational extent comprises only one half of the physical domain. The size of the enclosure was determined in a preliminary study such that it showed negligible effect on fluid and heat flows in the vicinity of the receiver. It was found that the diameter and height of the enclosure should be approximately twenty times the diameter of the receiver to achieve this

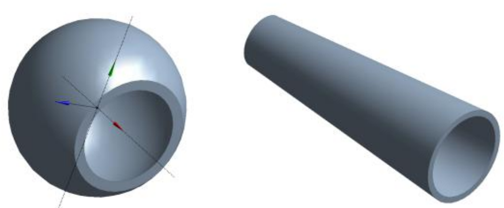
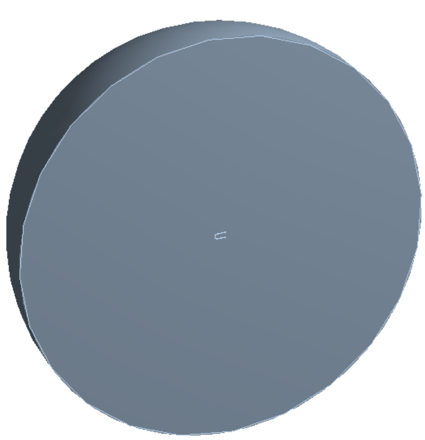


Fig. 6 Geometric Model of spherical and conical receiver



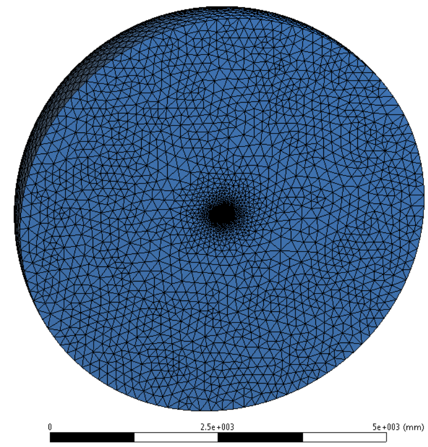


Fig. 7 CFD Domain of dome receiver

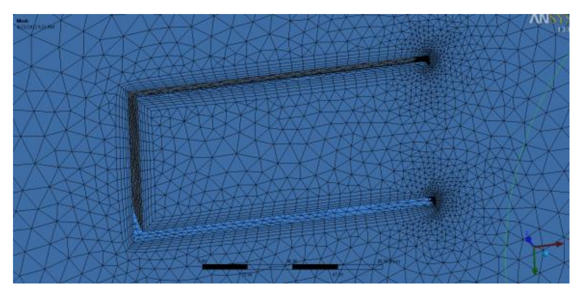


Fig. 8 Boundary layer Mesh close to cylindrical receiver wall

For boundary conditions, the cylindrical enclosure wall was set to ambient temperature of 27°C. The receiver's cavity and outer walls were assumed to be isothermal and adiabatic, respectively. The cavity wall temperature for each receiver was set as follows:

- For the model receiver, the average experimental values of cavity wall temperature data of 450°C is used for the cylindrical section, similar setup is used for all the receivers.

3. RESULTS AND DISCUSSIONS

The results obtained in this simulation study are presented and discussed in this section. Temperature contours of the cylindrical receiver at surface temperature of 450^0 C for inclinations of 0^0, 30^0, 60^0, and 90^0 are shown in Fig. 9. Red color represents the stagnation zone that has high temperature within the cavity where as blue color represents the convective zone that is near ambient temperature. The zone boundary is the separation of red and yellow colors. Most of the receiver locations have air temperature gradients at 0^0 inclination (receiver facing sideways) of the cavity hence little stagnation zone exists for this particular orientation.

As the inclination of the receiver increases from 0^0 to 30^0 the stagnation zone size increases. A direct consequence of this is the decrease in convective heat loss as shown in fig 11. The convective heat loss values are calculated using FLUENT reporting options. As the inclination of the receiver increased to 90^0 (facing side ways) the stagnation zone size further increases. The convective heat loss is minimum at 90^0 inclination of the receiver as shown in Fig10.

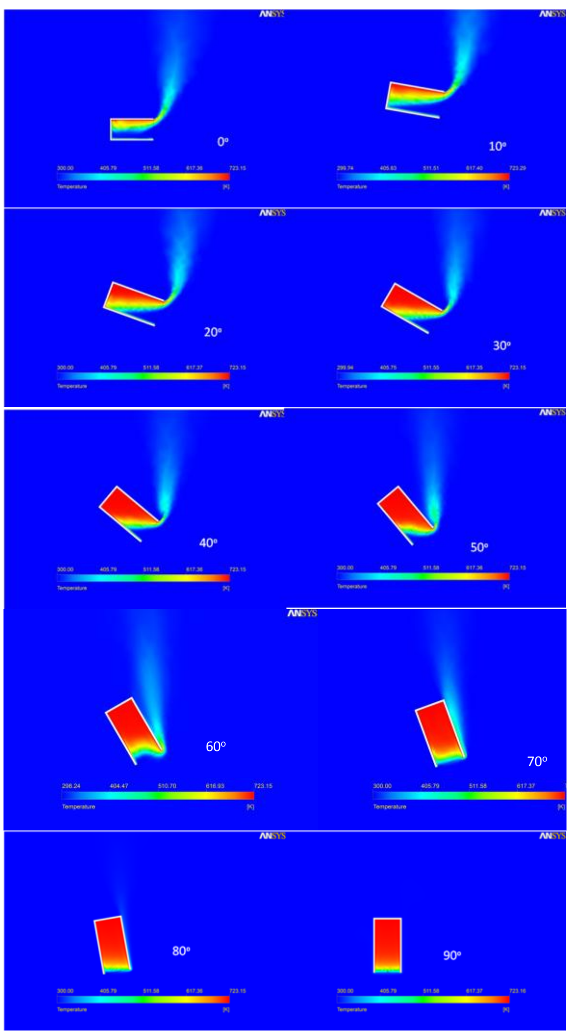


Fig. 9 Cylindrical receiver Temperature contours at inclination 0-90°

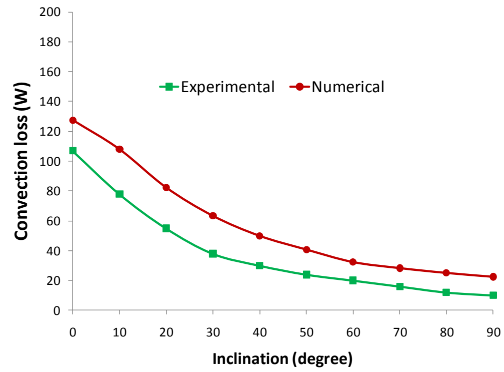


Fig. 10 Comparison of Experimental and Numerical values for cylindrical receivers

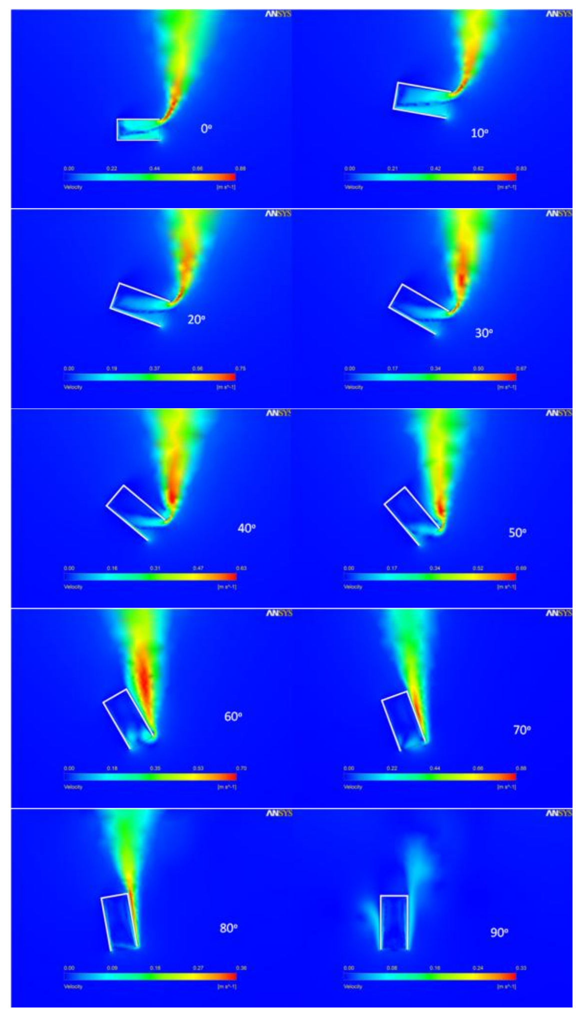


Fig. 11 Cylindrical receiver Velocity contours at inclination 0-90°

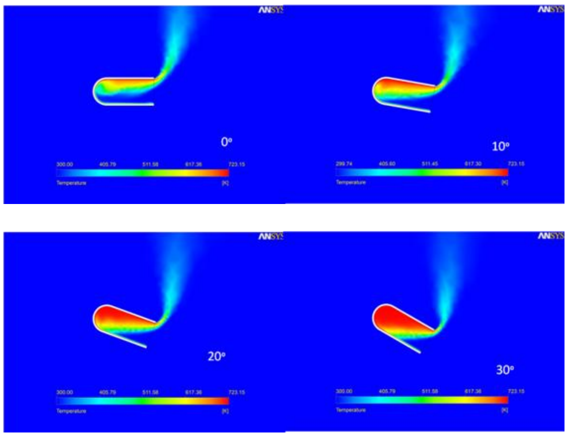


Fig. 12 Dome receiver Temperature contours at inclination 0-30^o

Fig12 to 13 shows the temperature contours of the dome receiver for various inclinations at 450^0 C. It is observed that the inclination of the receiver increases from 0^0 to 90^0 of the receiver, the stagnation zone increases whereas the convective zone decreases. Hence the convective heat loss decreases as the orientation of the receiver changes from 0^0 to 90^0

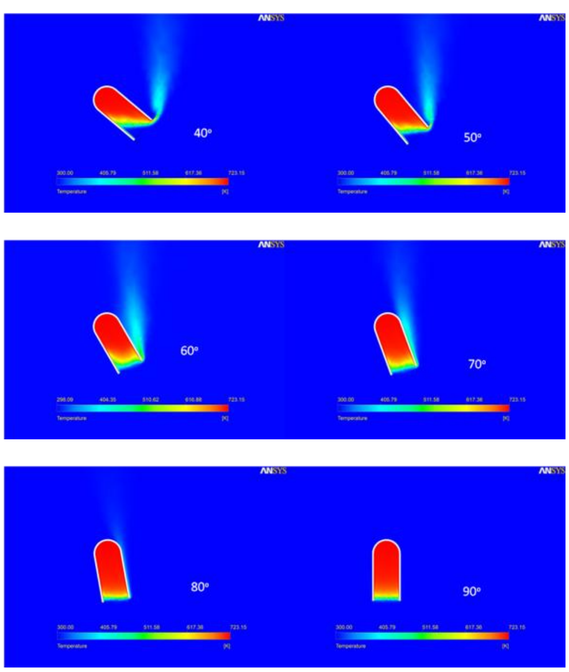


Fig. 13 Dome receiver Temperature contours at inclination 40-90^o

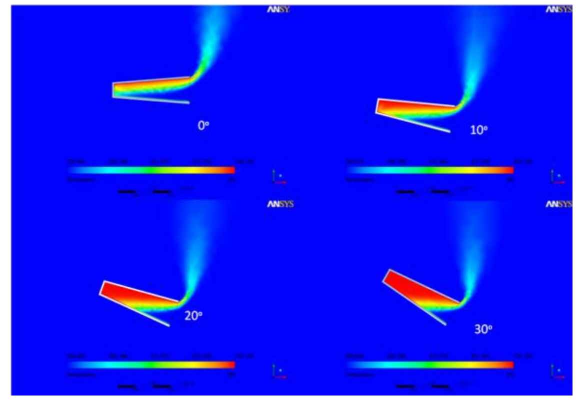


Fig. 14 Conical receiver Temperature contours at inclination 0-30^o

Fig. 14 to 15 shows the temperature contours of the conical receiver for various inclinations at 450^0 C. It is observed that at 0^0 inclination the convective heat loss is maximum. The convective heat loss reduces to minimum as the orientation is increased to 90^0. The stagnation zone increases within the receiver in both cases as the inclination of the receiver increases from 0^0 to 90^0. The direct consequence of increase in stagnant zone is decreased in convective heat loss as the orientation changes from 0^0 to 90^0.

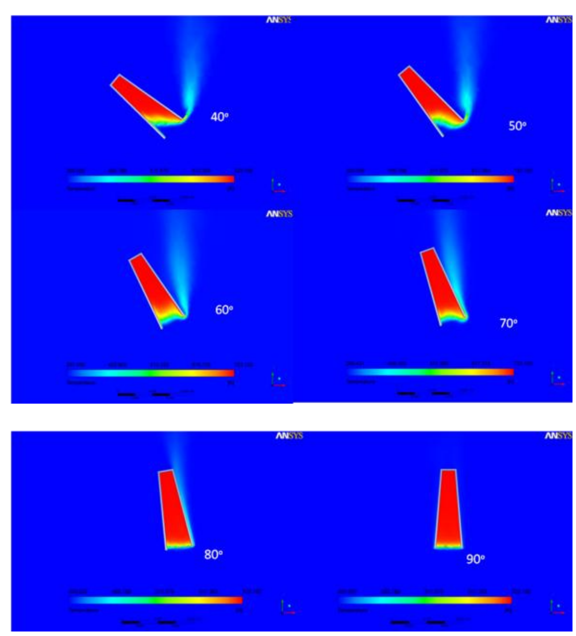


Fig. 15 Conical receiver Temperature contours at inclination 40-90^o

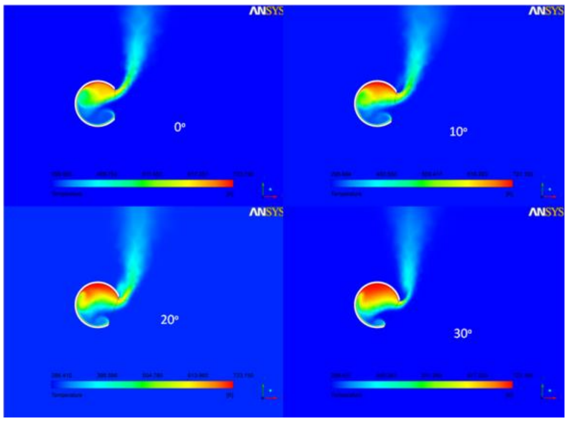


Fig. 16 Spherical receiver Temperature contours at inclination 0-30°

Fig. 16 to 15 shows the temperature contours of the spherical receiver for various inclinations at 450^0 C. It is observed that the maximum convective heat loss occurs at 0^0 inclination. It is observed that the convective heat loss is minimum as the orientation changes to 90^0.

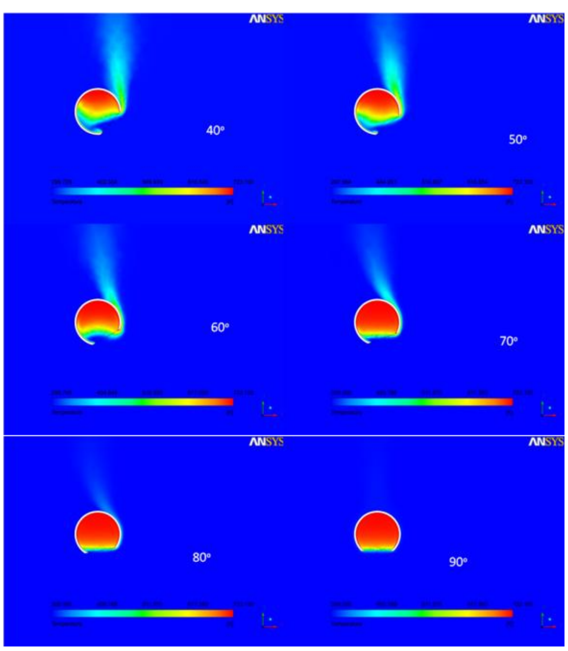


Fig. 17 Spherical receiver Temperature contours at inclination 40-90°

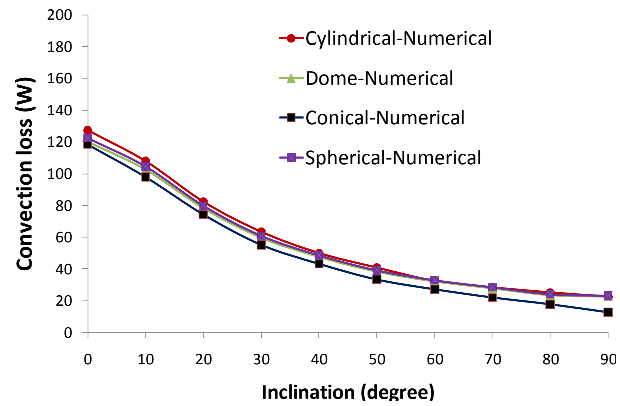


Fig. 18 Convection Heat loss comparison

Fig.18 shows Comparison of convective heat loss with different inclinations among cylindrical, conical, dome and spherical receivers at 450^0C. The receivers are designed such that they have same surface area and aperture. It is observed that convective heat loss decreases as the inclination changes from 0^0 to 90^0. Among these receivers, the convective heat loss is least for conical receiver followed by dome, spherical and cylindrical receivers.

4. CONCLUSIONS

The results of a numerical study of the problem of natural convection in cavity receivers of solar parabolic dish collector have been presented in this thesis. The effect of cavity geometry, inclination, receiver temperature through the aperture of solar cavity receiver has been numerically investigated using CFD package FLUENT 13.0. Modeling and thermal performance characteristics of the solar dish collector system are presented.

The comparison of convective heat loss with different inclinations among cylindrical, conical, dome and spherical receivers at temperature 450^0C is presented. The receivers are designed such that they have same surface area and aperture. It is observed that convective heat loss decreases as the inclination changes from 0^0 to 90^0. Among these receivers, the convective heat loss is least for conical receiver followed by dome, spherical and cylindrical receivers.

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