Effect of Opening Ratio and Operating Temperature on Heat Losses for Cavity Receiver of Solar Concentrator

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ABSTRACT
In this paper effect of opening ratio and operating temperature on convective and radiative losses from cavity receiver of solar concentrators are presented. Convective and radiative losses for specified cavity receiver are estimated by MATLAB programming and effect of the various parameters such as cavity temperature, cavity orientation and opening ratio of cavity is studied. Radiation losses are analyzed for operating temperature in range of 150 ^{o}C to 350 ^{o}C and opening ratio of 0.2 to 0.5. Convective losses are investigated for operating temperature in range of 150 ^{o}C to 350 ^{o}C, inclination angle from 0 to 90^{o}, and opening ratio of 0.2 to 0.5. Radiation losses and convective losses increase as operating temperature of cavity receiver increases and decreases with decrease in temperature. Radiation losses also increase with increase in openingt ratio from 0.2 to 0.5. The convective losses are more for sidewise facing cavity (0^{o} inclination angle) and less for downward facing cavity (90^{o} inclination angle). As opening ratio increases, the convective loss also increases and decreases with decrease in opening ratio.

Keywords
Opening ratio, Convection loss, Cavity receiver, Radiation loss.

1. INTRODUCTION
In solar energy thermal systems, heat loss mechanisms can significantly reduce the efficiency and consequently the cost effectiveness. It is therefore vital to fully understand the nature of these heat loss mechanisms. Cavities can be classified into two types namely closed cavity and open cavity (one side of the cavity called the aperture is open to the atmosphere). The open cavity heat transfer has been widely analyzed due to its applications in many fields of practical interest like solar concentrator systems, solar passive architecture. Among the heat transfer mechanisms from open cavities, the buoyancy driven heat transfer plays a major role. The phenomenon is dependent on various factors such as the geometrical shape of the cavity, inclination angle, wall boundary conditions, the aspect ratio and the opening ratio thus making it difficult to estimate.

The performances of cavity receiver of solar concentrator are studied by various authors. Harris and Lenz [1] have presented six loss mechanisms for the concentrating solar collector system with cavity receiver. These loss mechanisms were losses due to reflection from reflector, spoilage losses from the cavity, losses due to shadowing, reflection and thermal radiation losses from the cavity, convective and conductive losses from the cavity. Stine and Mc Donald [2] developed the correlation for convective losses experimentally using full size cavity receiver by considering effect of cavity temperature, tilt and geometry.Clausing [3] has developed analytical model to estimate convective losses. Clausing analyzed cavity receiver and suggested that buoyancy effect plays important role and wind velocity also affects convective losses. N. Sendhil Kumar [4] has been reported studies on combined convection and radiation from hemispherical solar cavities for the comparison of different cavities. T. Taumoefolau [5] has investigated the natural convection heat loss from a electrically heated model solar concentrator cavity receiver between the inclination -90 degree to 90 degree for different opening ratio. Leibfriend and Ortijohann [6] have studied convective heat loss from upward and downward facing spherical and hemispherical receivers for different aperture diameters. Kedare [7] had designed and set-up 'ARUN 160'dish concentrator of 160 m^{2} with cylindrical solar cavity receiver and studied performance of system.

Koenig and Marvin [8] studied dish receiver to estimate convective losses and the results are compared with all available models for convective heat losses. M. Prakash [9] has done numerical study of convection loss for open cavity receivers considering the different parameters of cavity receiver.Barahate S.D [10] studied the thermal analysis of cylindrical cavity receiver for medium temperature range for different orientation of cavity receiver.

In this paper spherical cavity receiver specified below is analyzed to investigate radiative and convective losses by MATLAB programming. Radiation losses are estimated for operating temperature up to 350 ^{o}C and for opening ratio of 0.2 to 0.5. Convective losses are studied for operating temperature up to 350 ^{o}C and inclination angle from 0^{o} (Horizontal position of cavity) to 90^{o} (Downward position of cavity) and opening ratio of 0.2 to 0.5.

2. METHODOLOGY AND MATHEMATICAL MODEL
The spherical cavity receiver is analyzed in this work with following details

Cavity material: Copper

Receiver Diameter(D) = 385 mm

Aperture diameter (d)= 96.25 mm

Operating Temperature Range: 150^{o}c to 350^{o}C

Thermal conductivity of copper = 385 W/mk

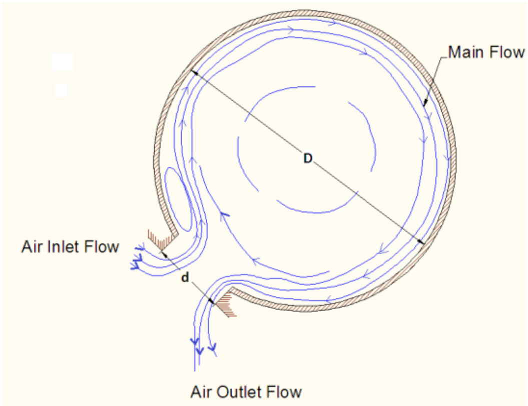

Fig.1 Spherical cavity receiver

The Convection loss can be find out by using the following equations for spherical cavity.

$$Q_{convec} = hA_w(T_w - T_a) \quad (1)$$

$$Nu = \frac{hD}{K} \quad (2)$$

The following correlation is used for finding the Nusselt number which is used by M. Prakash et.al. [9].

$$Nu = 0.0136(Ra)^{1/3}(1+\cos\theta)^{2.72}\left(\frac{d}{D}\right)^{0.72} \quad (3)$$

$$Ra = \frac{g\beta\Delta TD^3}{\nu^2}\Pr \quad (4)$$

The Radiation loss can be calculated by using the following equation for spherical cavity.

$$Q_{rad} = \in A_1\sigma\left(T_w^{\ 4} - T_a^{\ 4}\right) \quad (5)$$

Where, $\in$ = Equivalent emissivity of surface.

A_1 = Area of cavity opening in m^2.

σ = Stefan- Boltzmann constant in W/m^2k^4

3. RESULTS AND DISCUSSION

Effects of various parameters on radiation and convection losses for spherical cavity receiver are studied by using MATLAB programming. The effect of inclination angle, geometry, temperature and opening ratio are studied.

3.1 Convection losses

The convection losses from cavity receiver are studied and presented for effect of various parameters i.e. temperature, orientation, opening ratio (d/D).

3.1.1 Effect of operating temperature of cavity and cavity orientation

Fig.2 shows effect of cavity surface temperature on convection loss. Convection loss is calculated using the correlation developed by M. Prakash. The convection losses increase linearly with the cavity surface temperature. This is because convection loss is directly proportional to the difference between cavity surface temperature and ambient temperature. Fig.3 shows plot of convective loss (W) versus cavity inclination angle for different for different orientation of cavity. The convective losses are more for sidewise facing cavity (0^o inclination) and less for downward facing cavities (90^o inclination). The decreased natural convective heat loss as the receiver is tilted downward is due to a larger portion of the receiver volume being in the stagnant zone, where convective currents are virtually non-existent and air temperature is high, and a smaller portion being in the convective zone,where significant air currents exist. In the present analysis, correlation of M. Prakash is used to estimate convective losses from spherical cavity receiver.

3.1.2 Effect of Opening ratio

Fig.4 Shows effect of opening ratio on convection loss from cavity receiver. Opening ratio is varied from 0.2 to 0.5. It is clear from this plot that convection loss increases with increase in opening ratio of cavity receiver. As opening of the receiver increases, the surface area, through which convection loss occurs, increases. Since, more surface is available for convection to take place, convection loss increases with increase in opening ratio. For low values of opening ratio, the surface available for convection loss will be less and hence the convection loss will be less. This variation is also observed for radiation loss with opening ratio. As opening ratio increases, radiation loss and convection loss increases. So, opening ratio of cavity receiver should be such that it gives moderate or less values of both radiation loss and convection loss.

3.2 Radiation Losses

The radiation losses are studied for different cavity surface temperature and opening ratio (d/D) of the cavity receiver.

3.2.1 Effect of cavity receiver surface temperature and opening ratio (d/D)

Fig.5 shows variation of radiative loss from cavity receiver with cavity surface temperature.In the cavity receiver radiative losses occur through small aperture area and due to reflection and thermal emission. Therefore it depends upon reflectivity, emissivity, view factor and temperature of hot parts and ambient temperature. At low temperatures, losses due to emission are small and only reflection losses are significant and at high temperatures both reflection and thermal emission becomes significant. Radiation losses become dominant at higher temperature because radiation losses are directly proportional to fourth power of absolute temperature.

Fig 6 shows effect of opening ratio of cavity on radiation loss from receiver. Opening ratio is varied from 0.2 to 0.5. Radiation loss is higher for low values of opening ratio and it increases with increase in opening ratio. As we know, radiation losses are through the cavity opening. So, larger diameter opening will facilitate more radiation loss. Therefore radiation losses are increases with increase in opening ratio. The less radiation losses are obtained for opening ratio 0.2, while the high radiation losses are obtained for opening ratio 0.5. The radiation losses are remains constant for different inclination angle of cavity.

3.3 Comparison Of Convective And Radiative Losses

Fig.7 shows the comparison of convective loss with cavity temperature obtained experimentally [6] and from present correlation calculated data for spherical cavity receiver. The radiation losses are increased with increase in cavity temperature. The calculated data shows nearly good agreement with the experimental data of spherical cavity by Leibfried and Ortjohan [6]. Fig.8 shows the variation of convective loss with cavity inclination. This plot gives the comparison of calculated results of convective losses with the experimental data of spherical cavity which also shows the nearly good agreement of convective losses for cavity receiver.

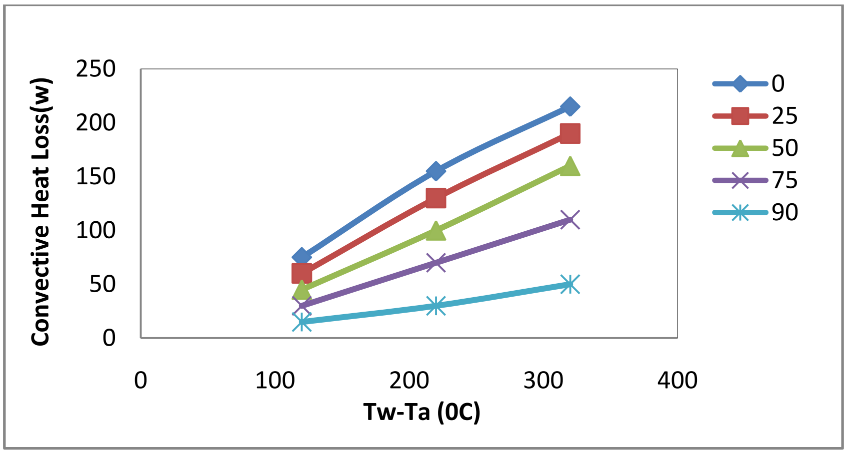

Fig 2: Effect of temperature of cavity receiver on convection loss.

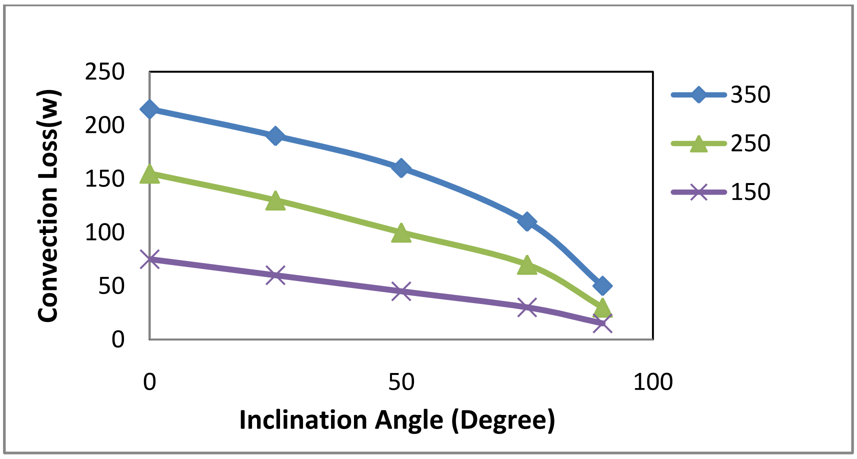

Fig 3: Effect of inclination angle of receiver on convection loss.

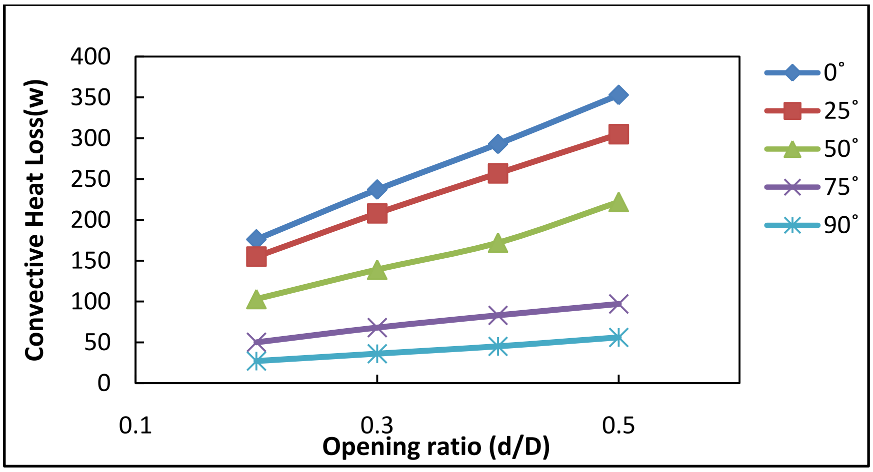

Fig 4: Effect of opening ratio of receiver on convection loss.

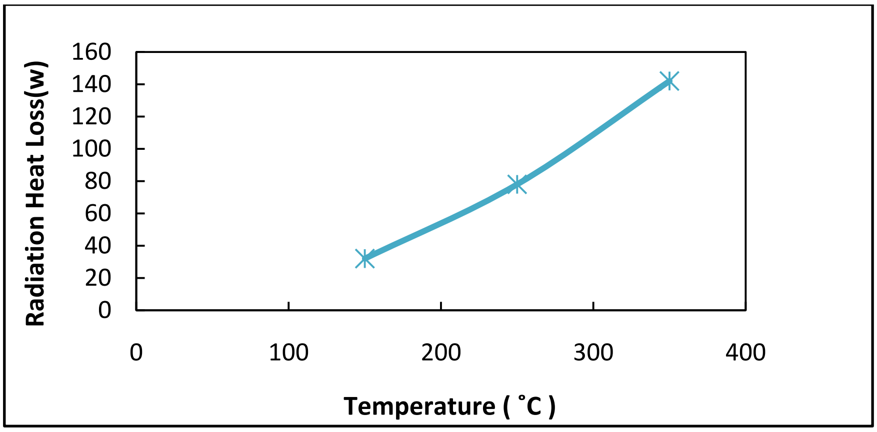

Fig 5: Variation of radiation loss with cavity receiver temperature

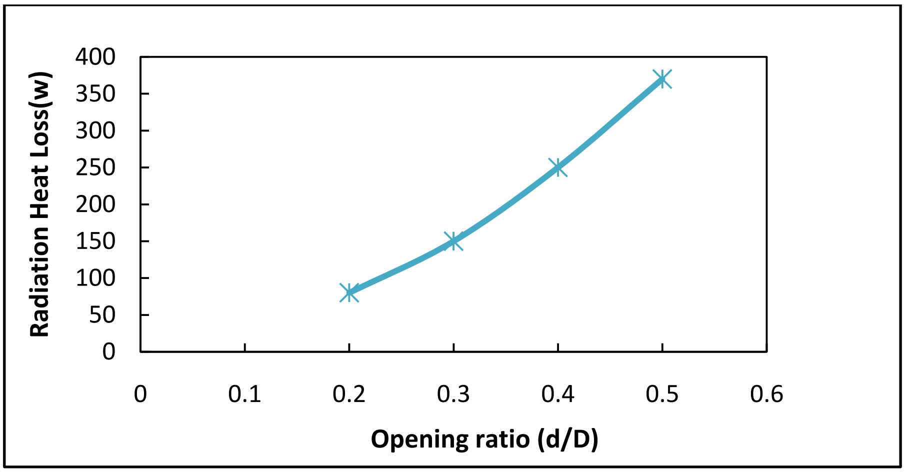

Fig6: Variation of radiation loss with opening ratio of receiver

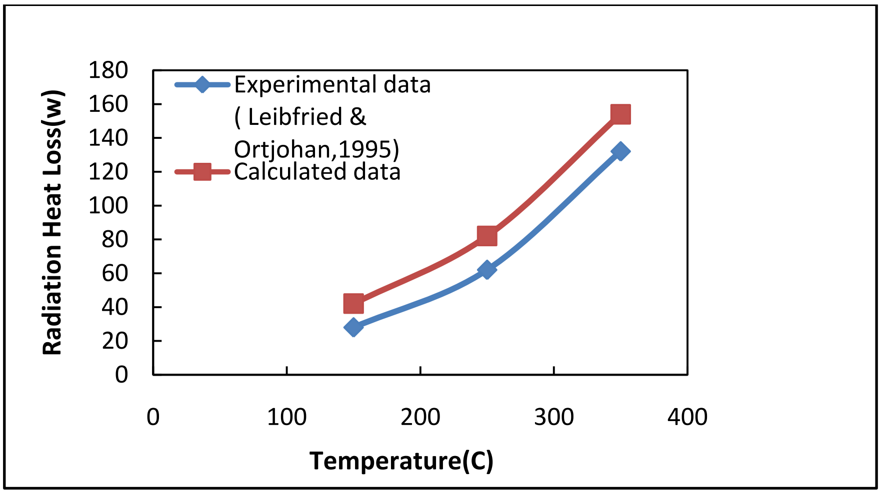

Fig 7: Radiation loss with cavity receiver temperature

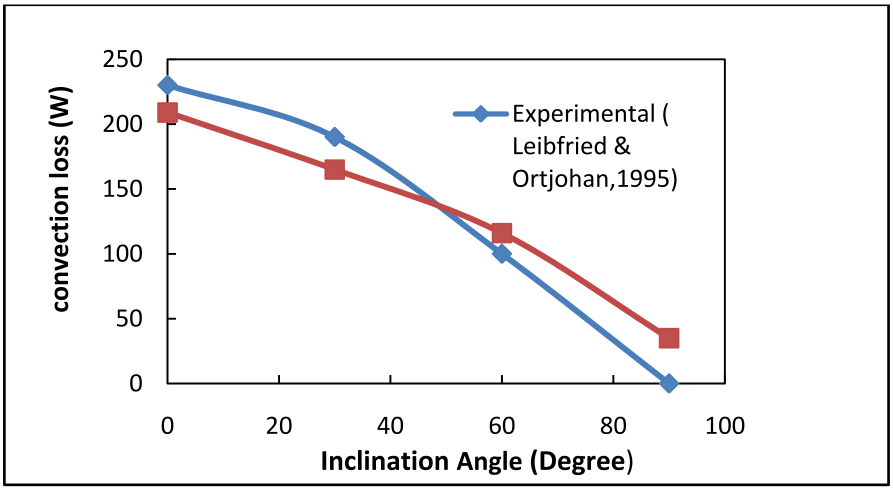

Fig 8: Convection loss with cavity inclination angle.

4. CONCLUSIONS

Radiation loss increases as the receiver's operating temperature and opening ratio increases. The radiation losses remain constant during rotation of cavity receiver from 0^o to 90^o as they are independent of cavity inclination. Convective loss increases with increase in cavity temperature. Convective loss decreases with increase in cavity inclination. It is minimum for downward facing cavity receiver and maximum for horizontal facing cavity receiver during the rotation of cavity receiver from 0^o to 90^o. As opening ratio increases, convective losses increase and decreases with decrease in opening ratio. The effect of cavity surface temperature shows that a convective loss increases with increase in cavity operating temperature and decreases with decrease in temperature. Radiation and convective losses are compared with the practical data of Leibfried and Ortjohan [6] and found good agreement with this data.

5. REFERENCES

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