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Effect of wind speed and direction on convective heat losses from solar parabolic dish modified cavity receiver

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Abstract

The performance of solar parabolic dish collector is significantly influenced by heat losses due to wind speed and direction. In this article, investigation of convective heat losses from the modified cavity receiver of solar parabolic dish collector is carried out numerically by considering the wind direction, wind speed, receiver configuration and receiver orientation. The effect of wind on the receiver in various directions ($\varphi = -90°$ to $90°$), wide range of operating wind speeds ($V = 0$–10 m/s), receiver inclinations ($\beta = 0$–$90°$) and varying surface temperature on convective heat loss from the receiver are studied. Velocity vectors, velocity contours, temperature contours are presented to show the effect of wind on the heat loss from the modified cavity receiver. The forced convection is found to have similar trend of free convection heat loss at lower wind speed. However at higher wind speed, such a pattern is not observed. At lower wind speeds say less than critical wind speed (<2.5 m/s), the forced convection heat loss is lower than natural convection heat loss for lower receiver inclinations and wind direction ranging between $-90°$ and $0°$. The forced convection heat loss is more significant than free convection heat loss above 5 m/s for all φ and β values. For side-on winds, at higher wind speeds above 5 m/s, irrespective of receiver inclination, the variation of forced convection heat loss is marginal (less than 5%). The maximum forced convection heat loss occurs for partly open receivers (receiver aperture diameter ratio, $R_{AD} = 0.4$ and 0.6) at $\varphi = 0$ (side-on wind) for all receiver inclinations and at $\varphi = 30°$ for $R_{AD} = 0.8$ and 1. The receiver inclination has less effect on heat loss from the receiver for $V > 2.5$ m/s due to side-on wind. The highest convection heat loss occurs for fully open ($R_{AD} = 1$) receiver as compared to partly open ($R_{AD} < 1$) modified cavity receiver. Nusselt number correlation is proposed to calculate combined convection heat losses from the receiver as a function of receiver inclination, wind direction, wind velocity and aperture diameter ratio.

Keywords: Solar parabolic dish collector; Modified cavity receiver; Combined convection heat losses; Nusselt number correlations; Numerical analysis

1. Introduction

The parabolic dish collector is one of the most efficient technologies for utilization of solar energy to produce high temperature heat. Solar parabolic dish collector is operated under different weather conditions and tracking sun continuously for efficient energy conversion. The cavity receivers are preferred in parabolic dish collector system for converting concentrated solar energy to heat due to nominal heat losses. Several trade-off strategies have been discussed for design of various components such as parabolic dish collector, receiver and transport medium/system (Kaushika, 1991). The knowledge of heat loss from the receiver is one of the prime requirements for efficient design of the receiver of parabolic dish. As receiver experiences high

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Nomenclature

A	Area, m^2
C_p	specific heat capacity at constant pressure, J/(kg K)
d	opening diameter of the modified cavity receiver, m
D_i	diameter of the modified cavity receiver, m
D_ω	cross-diffusion
g	acceleration due to gravity, m/s^2
Gr	Grashof number
G_k	generation of k, kg/(m s^3)
G_ω	generation of ω, kg/(m s^3)
h	convection heat transfer coefficient, W/(m^2 K)
k	turbulent kinetic energy, m^2/s^2
k_f	thermal conductivity, W/m K
Nu	Nusselt number
P	pressure, Pa
q_{cv}	Heat loss from the receiver surface, W/m^2
Q_{loss}	Wall heat loss, W
R_{AD}	Aperture diameter ratio
Re	Reynolds number
S	source term
T	temperature, K
u	velocity component, m/s
V	wind speed, m/s
x, y, z	cartesian coordinates
Y_k	dissipation of k, N/m^2
Y_ω	dissipation of ω, N/m^2

Greek symbols

β	receiver inclination, deg
δ_{ij}	Kronecker delta function
φ	incident angle of the wind in horizontal plane, deg
μ	dynamic viscosity, kg/ms
μ_t	turbulent eddy viscosity, kg/ms
ρ	density, kg/m^3
σ_T	effective Prandtl number for T
Γ_k	effective diffusivity of k
Γ_ω	effective diffusivity of ω
ω	specific dissipation rate, s^{-1}

Suffix

a	ambient
aw	area weighted average
b	bulk
i, j, k	direction components
s	surface
t	total/combined

temperature and operates in an open atmosphere, all the modes of heat transfer play a major role. Conduction heat losses from the receiver can be reduced by covering proper insulation over the receiver. The radiative loss depends on the receiver wall temperature, shape factor and emissivity/absorptivity of the receiver surface. The convective heat loss depends on the receiver geometry, surface temperature, ambient conditions and receiver orientation. An accurate estimation of heat losses from the receiver under actual conditions is very important to develop an efficient solar dish collector. Several researchers have proposed different shapes and sizes of the cavity receivers for parabolic dish collector. Wu et al. (2010) presented an extensive review on cavity receivers for solar thermal applications and also presented results on cavities used in electronic cooling devices, building, etc. Numerical and experimental investigations were carried out to estimate the natural convection and forced convection heat losses from cavity receiver of parabolic dish collector system. Kumar and Reddy (2008) performed numerical investigations on natural convection heat loss from three types of cavity receivers of a fuzzy focal solar dish concentrator for various inclinations of the receivers and area ratios with uniform surface temperature of 673 K. It was reported that the convection heat losses from the modified cavity receiver were lower than the other type of receivers considered and it was found that the minimum heat loss occurs for an area ratio of 8. The modified cavity receiver is the preferred receiver for the fuzzy focal solar parabolic dish collector among cavity, semi-cavity and modified cavity receivers. Reddy and Kumar (2008) carried out 2-D numerical studies to determine the influence of operating temperature, emissivity of the surface, orientation and the geometry on combined natural convection and surface radiation from a modified cavity receiver of solar parabolic dish collector. It was observed that convective loss is significantly influenced by the receiver orientation and the radiation heat loss is considerably influenced by the area ratios. An improved 3-D numerical model was proposed by Reddy and Kumar (2009) to investigate the natural convection heat loss accurately from the modified cavity receiver. The 3-D model can be used for an accurate estimation of natural convection heat loss from the modified cavity receiver of fuzzy focal solar dish concentrator. Vikram and Reddy (2014, 2015) performed combined natural convection and surface radiation heat losses from modified cavity receiver of solar parabolic dish collector considering three different temperature profiles instead of isothermal wall temperature for receiver surface.

Cui et al. (2013) analysed the combined natural convection and surface radiation heat loss from the hemispherical cavity receiver with a quartz glass cover for the dish