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Combined heat loss analysis of trapezoidal shaped solar cooker cavity using computational approach

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ABSTRACT

The present paper focuses on computational approach to analyze the heat loss due to natural convection and radiation in a trapezoidal shaped solar cooker. Heat losses due to forced convection and radiation are considered from the top glass cover. The results are verified with standard procedure. Radiative heat loss from the cavity is found to be dominant mode which contributes around 70–80% of the total heat loss. Parametric studies regarding heat loss from the cavity are studied by varying cavity depths, heat transfer coefficients based on the wind speed above the glass surface, emissivity of the plate. Based on different parameters, flow pattern and isotherms inside the cavity have been analyzed. Results are obtained in non-dimensional forms for more generic use and correlation between the total average Nusselt number and its influencing parameters has been formulated for the considered solar cooker cavity.

1. Introduction

Solar cookers are mostly used to heat, cook food or pasteurize drink. Different types of solar cookers are available in market ranging from box type solar cooker to concentrated type solar cookers. The basic principles of solar thermal, fluid flow, heat transfer and materials apply for development of an effective solar cooker. The coated absorber plate placed in the bottom the cooker is exposed to solar flux via top transparent glass cover. Due to this, the internal surface area usually attains uniform temperature at the point of stagnation condition. Various modes of heat losses are significant in solar cooker cavity. To prevent heat loss from the cooker, the outer surface (side walls) of the cooker is covered with insulating materials. The temperature of the top wall (glass cover), cavity side walls become significant by absorbing the radiation emitted by the bottom absorber plate. As air inside solar cooker cavity heated up, some losses take place due to natural convection. Outside glass also radiates heat to atmosphere due to its high temperature. In addition, the glass cover also loses heat to the atmosphere by forced convection due to wind effects. Therefore, heat losses inside cavity are due to natural convection and radiation, while heat losses outside the cavity are due to forced convection and radiation. Analysis of these heat losses and minimization method of heat losses are key to the better performance of it.

Related heat loss analysis from cavity carried out by various researchers are reviewed. Most of the research papers have been focussed on the convective losses only (both inside and outside the solar cavity) and these losses are considered for examining the performance of the solar cooker [1,2]. Experimental techniques have been used in the past for obtaining performances of solar cooker [3–5]. Recently, analytical based approach considering both radiative and convective heat loss in cooker was found in literature [6].

Regarding heat loss in different cavities are found in literature as well. Heat loss analysis of cavity in linear Fresnel reflector cavity

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Nomenclatures

A	Area, m^2
a	Gas absorption coefficient
g	Gravitational acceleration, m/s^2
H	Height of the cavity, m
H^*	Non dimensional depth
h_{ext}	Heat transfer coefficient due to wind effect, W/m^2 K
I	Intensity, W/m^2
K	Thermal conductivity, W/m-K
Nu	Nusselt number
Q	Total heat transfer, W
q	Heat flux, W/m^2
Ra_H	Rayleigh number based on height
T	Temperature, K
T_g	Average glass temperature, K
T_p	Absorber plate temperature, K
T_∞	Atmospheric temperature, K
T^*	Non-dimensional temperature
U	Overall heat loss coefficient (W/m^2 K)
u	Velocity in x direction (m/s)
v	Velocity in y direction (m/s)
W	Width of the absorber plate, m
W_{tc}	Width of the glass cover/top cover
x,y	Cartesian coordinates

Greek Symbols

α	Thermal diffusivity, m^2/s
ρ	Density, kg/m^3
β	Thermaol expansion coefficient,K^{-1}
Ψ	Stream function
σ	Stefan-Boltzman constant,W/m^2 K^4
ε	Emissivity
ν	Kinematic viscosity (m^2/s)
∞	Atmospheric condition
Ω	Hemispherical solid angle
$\hat{s}$	Ray direction vector
$\hat{n}$	Normal pointing out of the domain

Subscripts

a	Air
c	Convection
ext	External
g	Glass
in	Incoming
r	Radiation
out	Outgoing
P	Plate
t	Total
tc	Top cover
w	Wall

has been investigated [7]. Natural convection in a square cavity with its horizontal walls subjected to different heating models by a finite difference procedure have been investigated [8,9]. Thermal performances of a solar water heating system which is dependent on a linear Fresnel receiver (LFR) as a solar energy converter has been studied experimentally and theoretically [10]. Two-dimensional numerical simulations have been performed to study natural convection in circular enclosures filled with water considering different central angles [11].

Computational approach for obtaining heat loss in case of solar cooker cavity, particularly by considering both radiative and convective heat losses inside and outside the cavity is missing in literature. With this motivation, this paper focuses on heat loss analysis of trapezoidal shaped solar cooker cavity in a computational platform. As the heat loss mechanism is complicated in solar cavity, the considered computational approach is likely to give the actual heat transfer characteristics of the solar cooker cavity. Further investigations related parametric studies of heat losses at different temperatures of the absorber plate, different height of the cooker, different emissivity and wind speed have also been considered in the solar cooker cavity. Results are obtained in non-dimensional forms. Correlation related to total average Nusselt number with respect to its influencing parameters are developed.

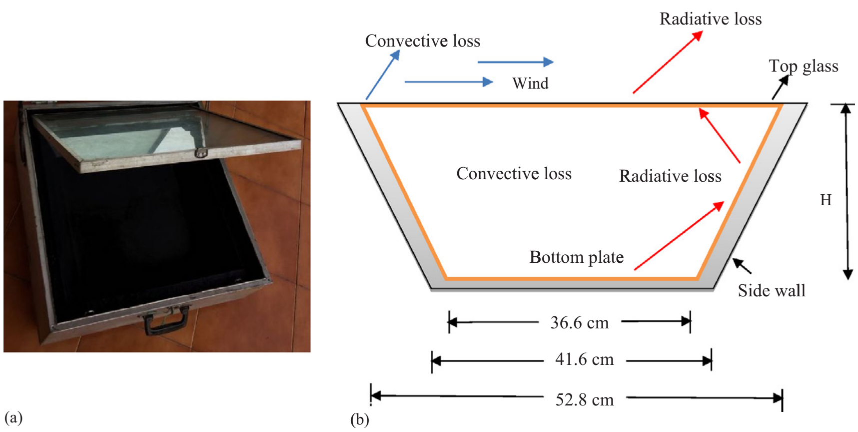

Fig. 1. (a) Photograph of the solar cooker for the present analysis (b) Schematic layout of trapezoidal cavity used for solar cooker and various modes of heat loss in it.