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Energy and exergy analysis of all-glass evacuated solar collector tubes with coaxial fluid conduit

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Abstract

In this research work, all-glass evacuated solar collector tubes with coaxial fluid conduit for T-type and H-type models with forced convection flow have been modeled. These models are based on an analytical solution of energy balance equations for various components of the collector's tube. On comparison, the results obtained in this work show good agreement with the results of previous research. The effects of changing the working fluid and the properties of the delivery tube and absorber tube on the working fluid temperature distribution in the collector tube have been investigated. Also the effect of the mass flow rate, solar radiation intensity, inlet temperature, ambient temperature, and optical efficiency and the length of collector tube on the outlet temperature of the fluid, energy efficiency and exergy efficiency in both models, have been studied. The results show that the changing delivery tube thermal conductivity and emission coefficients have no effect on the outlet temperature of the collector tube, but using selective coating absorber tube, increases collector tube outlet temperature for both models. The results also illustrate that in the H-type model the outlet flow temperature and exergy efficiency for both air and carbon dioxide as working fluid is greater than the T-type model.

Keywords: All-glass evacuated tube; T-type; H-type; Energy efficiency; Exergy; Forced convection

1. Introduction

Evacuated tube solar collectors are simple devices in which the energy of the sun is captured by an absorbing tube and used to heat fluid. They have shown that the combination of a selective surface and an effective convection suppressor can result in good performance at high temperatures. Similar to flat-plate collectors, they collect both direct and diffuse radiations (Kalogirou, 2013), but the vacuum space decreases convection and conduction losses, so the collector can operate at higher temperatures than flat-plate collectors. Classification of evacuated solar collector tubes is illustrated in Fig. 1. All-glass solar collector tubes with coaxial fluid conduit are a kind of evacuated tube solar collectors in which the individual collector's tube consists of two concentric cylindrical glass tubes and a delivery tube (coaxial fluid conduit). The outer tube, or cover tube, is transparent, and the inner tube, or absorbers tube, has a selective coating on its outer surface. The cover and the absorber tubes are sealed together at one end with the annular space between the tubes evacuated to eliminate convection losses from the absorber tube. The heat transfer medium, which can be either air or a liquid, is introduced

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Nomenclature

A	area (m^2)
c_p	specific heat capacity ($J\ kg^{-1}\ K^{-1}$)
D	diameter (m)
$\dot{E}$	exergy (W)
F_R	collector tube heat removal factor
F'	collector tube efficiency factor
f	coefficient of friction
h_c	convection heat transfer coefficient ($W\ K^{-1}\ m^{-2}$)
h_r	radiative heat transfer coefficient ($W\ K^{-1}\ m^{-2}$)
IR	exergy loss and destruction (W)
k	thermal conductivity ($W\ m^{-1}\ K^{-1}$)
L	length of the collector tube (m)
$\dot{m}$	mass flow rate ($kg\ s^{-1}$)
N	number of collector tube
Nu	Nusselt number
P	pressure (pa)
Pe	perimeter (m)
Pr	Prandtl number
Q	heat transfer rate (W)
q''	heat flux ($W\ m^{-2}$)
Re	Reynolds number
s	solar radiation intensity ($W\ m^{-2}$)
T	temperature (k)
U	overall heat transfer coefficient ($W\ K^{-1}\ m^{-2}$)
$V_{average}$	average velocity ($m\ s^{-1}$)
V_∞	wind velocity ($m\ s^{-1}$)
$\dot{W}_{fan}$	fan power (W)
x	axial co-ordinate along the flow direction

Greek symbols

α	absorptance
τ	transmittance
ε	emittance
$(\alpha\tau)$	optical efficiency (effective product transmit tance–absorptance)
σ	Stefan–Boltzmann constant ($5.67 \times 10^{-8}\ W\ m^{-2}\ K^{-4}$)
Δ	difference in pressure or temperature
ρ	density ($kg\ m^{-3}$)
η_E	second law efficiency
η_{fan}	fan efficiency
η_{th}	first law efficiency

Subscripts

a	ambient
$dest$	exergy destruction
i	cover tube inside surface
in	inlet fluid to the collector tube
$loss$	exergy loss
o	cover tube outside surface
$optical$	optical efficiency
$o-a$	from cover tube outside surface to ambient
out	outlet fluid from the collector tube
p	absorber tube
$p-a$	from absorber tube to ambient
$p-\mathrm{i}$	from absorber tube to cover tube inside surface
$useful$	useful exergy gain
$useful, net$	actual useful exergy gain
w	delivery tube
wi	delivery tube inside surface
wo	delivery tube outside surface
1	inlet working fluid
$p-1$	from absorber tube to inlet working fluid
$1-wi$	from inlet working fluid to delivery tube inside surface
$1-wo$	from inlet working fluid to delivery tube outside surface
2	outlet working fluid
$p-2$	from absorber tube to outlet working fluid
$2-wi$	from outlet working fluid to delivery tube inside surface
$2-wo$	from outlet working fluid to delivery tube outside surface
$p-wo$	from absorber tube to delivery tube outside surface

into the collector tube by the use of another tube, the delivery tube, inserted inside the absorber tube. The absorbed heat is conducted through the inner glass tube (absorber tube) and then removed by a fluid in direct contact with the inner glass tube. This solar energy heating technology could be employed to heat or condition the air for buildings or process heat applications; also they can be used for industrial purposes. Fig. 2 shows a typical operational scheme of the all-glass solar collector tubes with coaxial fluid conduit system investigated in this study. With the importance of the use of solar energy sources in mind, all-glass evacuated tube solar collectors have been attractive ideas for heating of buildings and industrial applications, which have been investigated by many researchers theoretically and experimentally.

Eberlein (1976) studied the analysis and performance predictions of evacuated tubular solar collectors using air as the working fluid. In that study, he found that the collector tubes have a very low loss coefficient because of the combination of a low emittance selective surface, and the evacuated cover system. Also, results showed that the theoretical performance of a collector array using air as the heat transfer medium is not expected to be much less than the performance of an array using a liquid, when operated