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Investigation of thermo-hydraulic performance of concentrated solar air-heater with internal multiple-fin array

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HIGHLIGHTS

- An internal multiple-fin array arrangement of solar air heater is proposed.
- Simple efficiency test confirms preliminary thermal feature of the arrangement.
- A mathematical model of heat transfer processes was build.
- Calculation showed optimum of thermo-hydraulic efficiency against the volume flux.
- Optimal duct amounts for the receiver were found.

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ABSTRACT

This study presents a thermo-hydraulic analysis of a solar air heater with an internal multiple-fin array. A preliminary simple test was carried out to confirm the efficiency enhancement of the proposed arrangement.

A mathematical model of heat transfer processes was proposed.

A thermo-hydraulic efficiency test was used to find the best fin arrangement of the receiver. For an applied set of ducts, calculations were carried out to find the thermo-hydraulic efficiency of the collector against the volumetric air flux. As a comparison, a smooth pipe arrangement was used.

Calculation results of the mathematical model showed an existing optimum of thermo-hydraulic efficiency against the volume flux, fin thickness and duct width. If there is no limitation of the air speed, proposed half-pipe finned technology enables a 14% efficiency improvement in relation to the smooth pipe arrangement of the solar collector with black paint and double glass envelope, and 3.3% for the solar collector with selective layer and single glass envelope. If 5 m/s speed limit of air in piping system is assumed, proposed half-pipe finned technology enables a 13% efficiency improvement in relation to the smooth pipe arrangement of the solar collector with black paint and double glass envelope, and 11% for the solar collector with selective layer and single glass envelope.

Proposed multiple fin-array technology enables to decrease the demanded air flux of 7–10 times in comparison to the smooth pipe arrangement of the absorber. Even with the flux decreased, the efficiency of internal multiple-fin array arrangement is higher than the one available for smooth pipe arrangement.

The solution could be applied in solar space heating with rock bed storage systems or in solar dryers.

1. Introduction

1.1. Concentrating solar air collectors

Solar concentrators are usually used in solar power plants or industry, mainly to produce high-temperature process heat. As an operation medium in concentration collectors, oil, glycol, water, phase change fluids, or less frequently gases, are used. Concentrating collectors for liquid are heated up to 400 °C. A higher temperature level is very useful for thermal electricity generation, process heat application, desalination, chemical conversion of fuels, detoxification [1]. Concentrating collectors for air heating are rarely used. Main applications are: drying, thermal conversion, solar air space heating. The research on high-thermal solar air space heating is developed by the authors.

Concentrating solar air collectors are most commonly used in warm climate countries, where only the direct component of solar radiation is used. Nevertheless, it does not exclude their use in

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Nomenclature

A	area, m^2
A_{ff}	free flow area, m^2
C	concentration ratio, –
C_p	specific heat of air, J/kg K
D	diameter, m
D_h	substitutive hydraulic diameter, m
E	fin efficiency, –
h	heat transfer coefficient, W/m^2 K
I	irradiation, W/m^2
K	thermal conductivity, W/m K
L	length, m
p	pressure, Pa
P_{wet}	perimeter wetted, m
P_{blow}	power input of blower, W
T	temperature, K (or °C)
Q	heat, W
V	volumetric flux, m^3/s
W	width, m
α	absorptivity of receiver, –
ζ	local loss coefficient, –
ν	kinematic viscosity, m^2/s
δ	thickness
ε	emissivity
ρ	density of air, kg/m^3 or mirror layer reflectivity, –
ξ	linear loss coefficient, –
η	thermal efficiency, –
τ	transparent transmittance, –
χ	optical efficiency of concentrator, –
Gr	Grashof number, –
Nu	Nusselt number, –
Pr	Prandtl number, –
Re	Reynolds number, –
A/V	friction of heat transfer area per unit of exchanger volume, m^2/m^3

Subscripts

a	air
al	aluminium
amb	ambient
b	beam (radiation) on sloped collector front
br	back radiated
e	envelope glass
f	finned
fr	front radiated
fs	air flow in channels
g	glass envelope
gp	outside of glass envelope
h	hydraulic
ig	inner glass pipe
igr	radiative (heat transfer coefficient) of inner glass
in	inlet
L	loss
m	mirror layer or medium
m	medium
mr	mounting ring
og	outer glass pipe
ogc	convective (heat transfer coefficient) of outer glass pipe
ogr	radiative (heat transfer coefficient) of outer glass pipe
out	outlet
r	receiver
rr	radiative (heat transfer coefficient) of receiver
rc	convective (heat transfer coefficient) of receiver
t	thermal
t-h	thermo-hydraulic
u	useful
uf	not finned

other parts of the world, which is proven by a successful research on a concentrating collector, conducted by Madessa et al. in Trondheim (Norway) [2]. The research concerned a concentrating parabolic collector which heated the air even up to 300 °C. In the United Kingdom, where the sunlight is also low, the research of v-trough solar concentrator for water desalination applications was conducted [3]. Swedish researchers presented a photovoltaic system with a concentrator [4] and a photovoltaic/thermal hybrid with a concentrator [5].

A typical linear concentrating collector applied in the solar air heating is presented in Fig. 1. The concentrator based on cylindrical, parabolic or conical profile focuses the beam radiation onto a receiver. The heat loss is minimized by a glass envelope placed around the receiver. Various types of internal receiver arrangements have been used.

The research with an applied linear parabolic receiver was conducted by Li and Wang [6], with N_2 as a working medium. A small diameter of the receiver and vacuum insulation were applied. The stagnation temperature was about 600 °C. The highest efficiency 0.44 was achieved for the flow of 0.0023 kg/s and the outlet temperature 358 °C. Togrul et al. [7] described an air collector with a conical concentrator. A pipe absorber covered with black paint and another one with selective coating were tested. First tests were carried out in the conditions of natural convection. The efficiency for the absorber covered with black paint was maximally 0.12, and the highest air temperature on the outlet was 150 °C. The results for the absorber with selective coating were minimally better. Consecutive tests in the same set-up [8] were carried out for the air speed of approximately 6 m/s. For the painted absorber, the process efficiency was 0.50 and for the other one 0.53. Youa et al. [9] reported a trough solar collector of the direct steam generation tested for air heating up to 350 °C, but its efficiency was not calculated.

The idea of performance enhancement described in this paper is enlarging the heat exchange surface inside the receiver. The

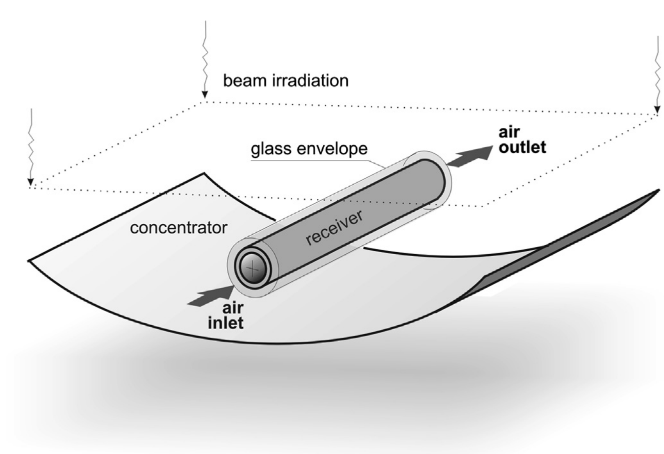

Fig. 1. Concentrating solar collector with cylindrical receiver as an air heater.