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Experimental investigation of concentrated solar air-heater with internal multiple-fin array

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This paper presents the results of experimental validation of energy conversion in a concentrated solar air-heater with internal multiple-fin array. A novel high temperature solar air heater was proposed to convert solar energy to heat for space heating in climatic conditions of Poland.

The aim of the study was to verify the previously created mathematical model of heat transfer processes. The collector's performance was analysed experimentally against the reduced temperature difference. During the experiments, an electrical air heater was used to change the air temperature at the inlet of the receiver according to the test demands. Additionally, two daily performance evaluation tests were done. During the tests the all-day measured data was collected automatically and recorded at 1-min intervals. Hourly and daily thermal efficiency was calculated. Validation of the model showed its correctness and proved that the model can be accepted.

1. Introduction

At present, a wide range of scientific research worldwide concerns issues connected with renewable energy sources including solar collectors. It is the result of widespread green actions involving both industry as well as constructing single-family detached houses. Most research is devoted to flat plate collectors in which the working substance is water or glycol. Air collectors are less frequently studied, mainly due to lower efficiency of energy conversion, obtained temperatures and possibility of application of heat storage containers in case of liquid installations. Flat plate air collectors are most commonly applied in drying installations. The conducted research concerns, inter alia, the influence of using cheap materials such as, for example, plastic bubble wrap as insulation [1], modification of absorbents' shapes and flows [2,3] and the influence of alternative solar solutions on the process' efficiency [4] and its evaluation [5].

The mentioned low efficiency of air collectors is the basis for designing constructions which enlarge the agent's twirling and heat exchange surface by, for instance, using fins. Even the use of a constructionally simple absorber which is undulated with a zigzag shape [6] allows to achieve higher air temperature in comparison with a collector with a flat absorber. Another type of action is mounting additional elements in the form of fins assembled at an angle on the surface of a flat absorber [7].

Most commonly, the operational medium in concentrating solar collectors is oil, glycol, water or other liquids. The collectors themselves are used in electricity production installations and for industrial processes [8], to support the processes of desalination [9], in solar thermochemical hydrogen production [10], or in simple solar cookers [11].

Concentrating solar air collectors are not very common. There are only few scientific papers concerning concentrating solar collectors applied for air heating. Madessa et al. [12] concerned a concentrating parabolic dish, which heated the sucked up ambient air up to even 300 °C. Various air flows and two different absorbers were researched. The first of them was of honeycomb construction and the flow of 4 m/s reached the efficiency of 0.60. However, the absorber filled with fibrous wire mesh with the same flow reached 0.81. Additionally, Togrul et al. research on an air collector with a conical concentrator [13,14] is known. A pipe absorber covered with black paint, and then another, with selective coating, were tested. First tests [13] were carried out in conditions of natural convection. The process 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 only slightly better. Consecutive tests in the same set-up [14] were carried out for the air speed of approximately 6 m/s. For the first of

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Nomenclature

A	area, m^2
C_p	specific heat of air, J/kg K
I	irradiation, W/m^2
L	length, m
T	temperature, K (or °C)
U	extended uncertainties, –
V	volumetric flux, m^3/s
W	width, m

Subscripts

amb	ambient
ap	aperture
b	beam (radiation) on sloped collector front
c	combined
d	daily or diffused (radiation)
in	inlet
m	model
out	outlet
t	thermal or total (radiation)

Greek symbols

δ	deviation, %
ρ	density of air, kg/m^3
η	efficiency, –

the absorbers (with paint) the process efficiency was 0.50, whereas for the second one it was 0.53. Afterwards, wire mesh with various number of folds in the packing was inserted into the absorbers. For 14 folds in the absorber covered with black paint the process efficiency was 0.80, whereas for the absorber with selective coating it was 0.84. Also Zheng et al. [15] has conducted an experimental test of a novel multi-surface trough solar concentrator. They tested three receivers with different geometry of air flow channels, filled with black thin wire mesh. The variable parameter was the air flow rate. The test showed that daily average efficiency can reach about 0.6 at a certain air flow rate. The highest reached temperature can be over 140 °C. Jamal-Abad et al. [16] investigated heat transfer in tubular solar air-heater filled with a porous medium. The results showed that the collector heat removal factor enhances when the porous media shape parameter increases.

Other researchers [17] conducted experimental and simulation studies of a system made from 10 linked compound parabolic concentrators with a U-shaped copper tube heat exchanger installed inside. During a sunny day, with air volume flow rate between 6.8 and 7.1 m^3/h, the temperature of the air at the outlet was over 200 °C. The efficiency of the tested system was up to 0.5. Nitrogen instead of air was used to do research on the influence of the flow change of a working medium on the efficiency of a linear concentrating collector by Li et al. [18]. Subsequent research with nitrogen as a working medium was conducted with the use of an absorber of a small diameter. Its stagnation temperature was 600 °C. The highest outlet temperature of nitrogen was 463 °C for the flow of 0.0012 kg/s with the efficiency of 0.28. The highest efficiency, 0.44, was achieved for the flow of 0.0023 kg/s and outlet temperature of 358 °C.

The efficiency in concentrating collectors is enhanced by enlarging the heat exchange surface inside the absorber. One of the methods is to use wire mesh, as was done in the abovementioned solutions: [15], [12] [14], and [16]. Another way is to apply fins on or inside the absorber, which can be seen in case of the following

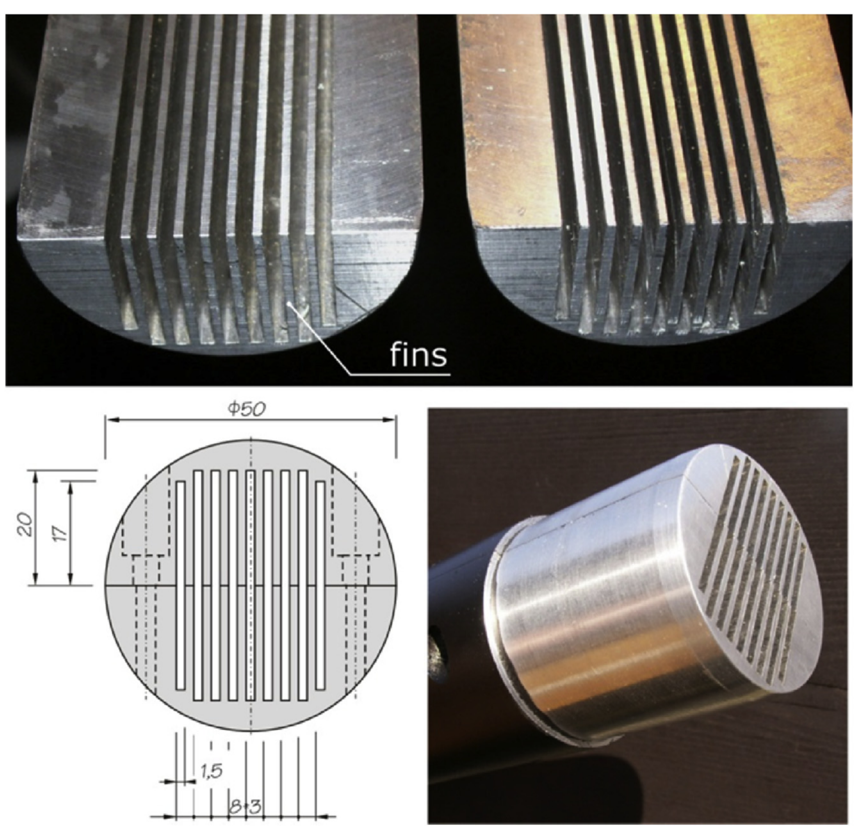

Fig. 1. Absorber with internal multiple-fin array.