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Design, developing and testing of a solar air collector

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ABSTRACT

The flat-plate collectors have an important place among applications of solar energy system. The paper describes the design and testing of a solar air collector in order to develop more efficient and cost effective energy process. In the design of solar collector the energy and exergy analysis were used to establish the appropriate components and the optimum working parameters. Experiments according to the ASHRAE Standard 93-86 and European Standard EN 12975 2006 on the solar air collector were performed.

1. Introduction

The flat-plate collectors as diabatic radiative heat exchangers transforming solar radiant energy into heat, which is transferred to the working fluid have an important place among applications of solar energy system. The used working fluids are: water, organic fluids and air. The air collectors are Generally used for the heating or preheating of air in air conditioning and drying applications. The design, construction materials and construction methods for solar air heaters have been slowly developed compared to liquid-based collectors. The efficiency of air collectors is lower because of low thermal capacity of air and low absorber-to-air heat transfer coefficient. The most important advantages for air-type collectors include: no freezing or pressure problems; generally lower construction cost [1], and no heat exchanger for direct heating of a space.
There are two main types of air collectors with several different design features each: the conventional air collectors with an absorber plate being over or /and underflown by the working fluid, and the collectors with an absorber matrix in which the working fluid flows through the absorber-matrix.
The major heat losses of the collector are from the front cover (glass cover), because the sides and the back of the collector can be insulated adequately, while the front face must be exposed to solar radiation and exposed to the ambient temperature. To minimize heat losses from the front cover of the collector and to maximize heat extraction from the absorber can be done by forcing air to flow over the front glass cover (preheat the air) before passing through the absorber.

2. Design future of a solar air collector

To increase thermal efficiencies, heat has to be transferred efficiently from the absorber to the flowing air. Therefore, many configurations of the absorber plate have been designed to improve the heat transfer for the air flow in the passage.
Choundhury et al. [2] proposed to modify the simple absorber fat plate for a corrugated absorber. Garg et al. [3] introduced the absorber plate with fins attached.. Gunnewiek and Kutscher proposed the use of transpiration.
There has been significant interest in packed-bed solar air heaters because of some exclusive advantages of such systems over conventional systems. A packed-bed matrix absorbs the solar radiation "in depth" and has a higher ratio of heat transfer area to volume and high heat transfer capability, resulting in a relatively low absorber temperature. This will decrease the heat losses from the absorber to ambient air and, hence, result in an increase in the thermal efficiency of the heater. However, there is a substantial increase in pressure drop and, consequently, a higher mechanical (ultimately electrical) power requirement to move the air. Mohamad [4] suggested a porous absorber plate, Swartman and Ogunade [5] and Kolb et al. [6] proposed a solid matrix. Sharma et al. [7] reported that absorbers having a bed packed with slit-and-expanded aluminium foil matrix wire-screen matrix,

hollow spheres and crushed glass matrices have been used. Mishra and Sharma [7] tested the performance of solar air heater with iron-chips, aluminium-chips and pebbles packing. Hastani et al. (1985) reported those solar air heaters in which semi-transparent materials like glass beads or glass tubes had higher efficiency of energy collection in comparison to a usual flat-plate collector. Yildiz proposed incorporation of aluminium wool packing on a second perforated plate, which may serve to extend the heat transfer surface and induce convection of air through the collector. Demirel and Kunc [8] tested a solar air heaters with packed air flow passage filled with Raschig rings and found that the packing increased the thermal efficiency considerably. This is mainly because the packing breaks the resistance film underneath the plate and causes a better radial dispersion. Porous media forms an extensive area for heat transfer, where the volumetric heat transfer coefficient is very high. Hence, using a porous absorber will enhance heat transfer from the absorber to the airstream. In the design of this type of collector, which combines double air passage and porous media, care should be taken to minimize pressure drop. However, the thermal efficiency of this type of collector is significantly higher than the thermal efficiency of conventional air heaters. The thermal efficiency of the suggested collector exceeds 75% under normal operating conditions. The pressure drop is not so significant if high porous medium is used and careful design of U-return section is considered.

All the absorber plates proposed deal with clean new materials, implying high costs on the production of the very special absorber plates. Henden et al. [9] mentioned that the main barrier for large-scale introduction of thermal solar systems is the high cost compared with conventional heating systems. The costs of the collector gain more importance, and the need of less expensive collectors is evident.

The amount of solar-energy absorbed by a solar-energy air heater depends largely on [7]:

- the level of insolation and the solar collector orientation;
- the absorptance of the absorber surface;
- the transmittance of the cover material.

The ***absorber material,*** in addition to having a high absorptance of the incident radiation, should also have a low emissivity, good thermal conductivity and should be stable thermally under the temperature regimes encountered during operation and stagnation. It should also be durable, have a low weight per unit area and, most importantly, be cheap. Black-coated metal sheets (for example, corrugated galvanised iron sheets) are used frequently as absorbers due to their ease of use, availability and relatively low cost. Other absorber materials in use include black plastic sheets, black-painted rocks, charcoal and ash. The use of selective absorbing surfaces may not be justified economically for low cost drying operations. A major consideration in the choice of materials for the construction of solar-energy air heaters for crop/wood drying operations would be their cost and local accessibility.

The transmittance of the ***cover material*** is also an important parameter that affects the amount of solar-energy absorbed by a collector. A good cover material should have a high transmittance in the visible range of the electromagnetic spectrum and a low transmittance to infrared radiation in order to trap effectively the re-radiated heat from the absorber plate.

Other qualities of a good cover material include low heat absorptivity, stability at the operating and stagnation temperatures, resistance to breakage, durability under adverse weather conditions and low cost. Glass has been used very widely as a cover material due to its high transmittance to visible light, low transmittance to infrared radiation and stability to high temperatures. Its high cost, low shatter resistance and relatively high weight per unit area (which increases the cost of supporting structures) have necessitated the need for alternative cover materials. Plastics are being used increasingly, their major limitations being their relatively low stability at higher collector operating temperatures and their low durability under weather conditions, particularly degradation under ultra-violet radiation. However, some plastics have been treated to overcome at least some of these shortcomings. Some plastic covers show high transmittance to visible light and equally low transmittance to infrared. Plastics weigh about 10% for the same area of glass.

Knowing the main disadvantage of the air-type solar collectors, low absorber-to-air heat transfer coefficient, a significant attention was paid to the packed-bed/porous solar air heaters because of some exclusive advantages of such systems over conventional systems.

3. Investigation of the solar air collector

The investigation of the laboratory air solar collector has involved: setting of solar collector power and average intensity of radiation from solar simulator; estimation of collecting area, air flow rate (the air fan selection); test set up; apparatus adjustments; collector testing by varying absorber design and operating conditions. The solar simulator was developed in agreement with the standards set by ASHRAE [10]. As it has the function of the sun it is important that the spectral radiation emitted matches as closely as possible the characteristics of the natural radiation incident on the Earth's surface. The

conditions set by ASHRAE that must be met during the design of solar simulators in collector testing are the following:

- the spectral radiation distribution of the simulator shall match that of natural sunlight on a surface at an inclination of 37° under air mass 1.5 conditions and an irradiance of 958 W/m^2;
- the intensity at the surface of a collector under test shall be greater than 630W/m^2;
- variation of irradiance over a grid of dimensions smaller than 15 cm shall be less than 10%;
- changes of light intensity at different input voltages should not affect the nature of the relative spectral distribution;
- the air speed across the collector shall be less than 4.5 m/s;
- the light reaching the surface of the collector should be sufficiently collimated to ensure that at least 90% of radiation reaching a point should have emanated from a region subtending less than 20° from that point.

The experimental tests were performed according to ASHRAE Standard 93-86 and European Standard EN 12975-2 2006 [11]. The collector is composed of basically the same elements present in a conventional flat plate air solar collector (fig. 1). The case is constructed from galvanized iron plate of 1.5 mm thickness.

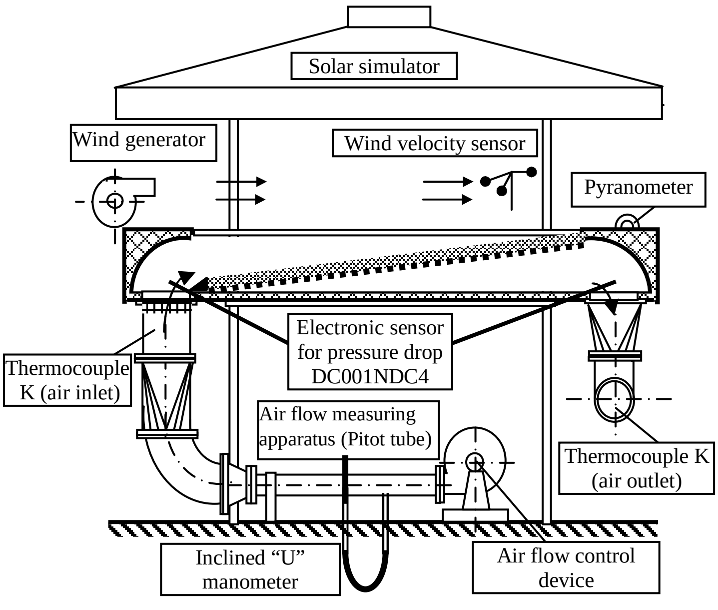

Fig. 1. Schematic diagram of the air solar collector with solar simulator.

To minimize the heat losses through the collector walls the case was insulated with extruded polyurethane foam plate with a thickness of 50 mm, thermal resistance R_D=0.9m^{2}K/W, and thermal conductivity λ_D=0.033W/mK.

The fan was chosen taking into consideration its overall efficiency, power consumption and characteristic pressure-flow rate. The solar simulator set-up consists of 20 x 400W dimmable metal halide lamps of Philips MSR type. To reduce the pressure losses of the air stream at collector entrance and exit due to the flow direction changes, joints of proper shape were constructed. In order to obtain a uniform flow velocity at the collector inlet it was designed a flow straightner and placed inside the diffuser and also wire screens and honeycomb flow straightner were placed in the right place downstream the diffuser. The aperture area of the cover was A_c=1.8m^2.

The incident radiation was measured by means of a pyranometer with an accuracy of about ±3% and it was found I=637W/m^2. At the collector entrance and exit were placed thermo-couples type K (Chromel-Alumel) connected to the FLUKE 52 K/J THERMOMETER on which could be read the air temperatures and the temperature difference. The pressure drop of the air passing through the collector was measured with an electronic sensor type DC001NDC4, a sensitive sensor to measure low pressure difference. The air flow rate was measured using a Pitot tube and an inclined "U" type manometer. The air flow rate of the fan was adjusted by a sliding plate placed at the air inlet. The velocity of the wind over the cover was measured with the DANTEC 54 N10 Flow Analyser. As collector cover, were tested a single glass plate (low iron glass) and a polyethylene sheet. The materials tested as absorber was polyurethane foam, plastic fabric and metal sheet.

4. Results and discussions

The experimental results show the expected increase of collector power with the air mass flow rate for all absorber types (fig. 2, 3, 4). Among all tested absorbers that made of two painted plastic fabric sheets present the biggest collector power. The polyethylene sheet used as cover is more efficient than glass. This can be explained by a lower reflectance value or a better effective product transmittance–absorptance of polyethylene. The collector power rises with the increase of the air mass flow rate with no extremum point. The air temperature decreases rapidly with the air mass flow rate. Using a solar simulator, which has the function of the sun, the exergy analysis applied for the entire collector installation allows establishing the appropriate component and the optimum working parameters of the solar collector. The solar collector developed on the basis of this analysis can operate either in open or close circuit.

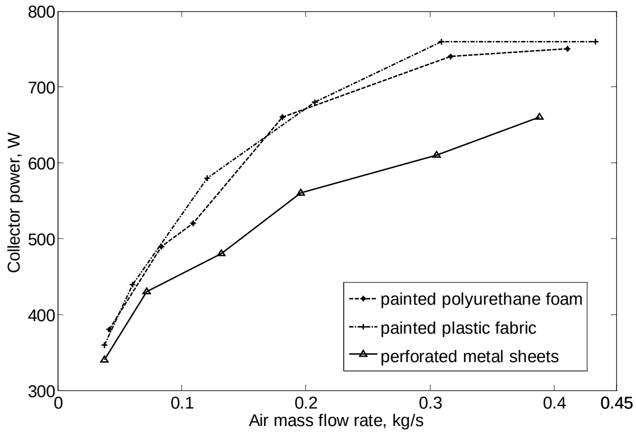

Fig. 2. Collector power versus air mass flow rate for different absorbers and glass as cover.

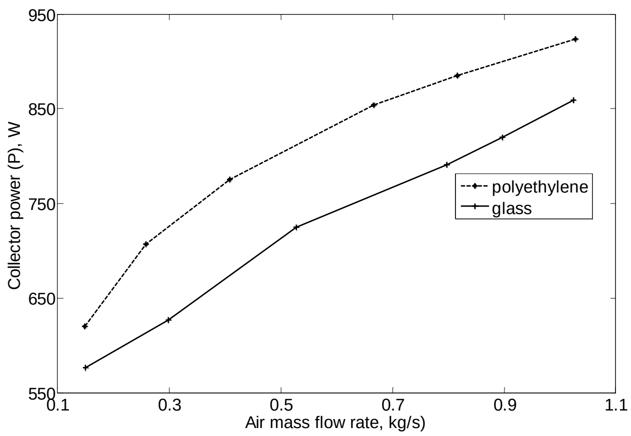

Fig. 3. Collector power versus air mass flow rate for an absorber made of painted plastic fabric and two different covers (glass and polyethylene).

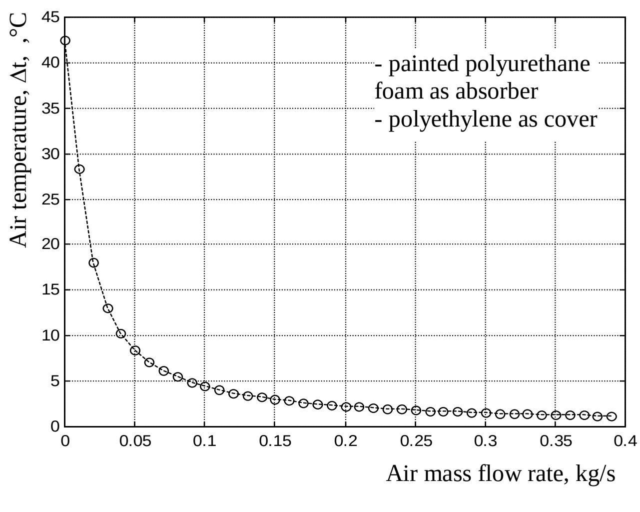

Fig. 3. Air temperature variation with mass flow rate.

The air solar collector performance can be enhanced by the following ways: use of a good thermal. insulation to reduce the heat losses; use of a cover with high transmittance and low absorptance and thermal conductivity; use of a low cost absorber with high absorptions and thermal conductivity; constructing of a flow duct with low pressure losses and use of a fan with a proper power-flow rate characteristic.

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Proiectarea, construcția şi testarea unui colector solar cu aer

În lucrare sunt prezentate proiectarea şi testarea unui colector solar cu aer folosit la uscarea lemnului în scopul realizării unui colector mai eficient din punct de vedere energetic şi mai ieftin. A fost preferată testarea în laborator, folosind un simulator solar. Testele au fost realizate conform Standardului american ASHARE Standard 93-77 şi Standardului european BS EN 12975-2:2006. S-au realizat experimente pentru trei tipuri de materiale pentru absorber şi două tipuri de materiale pentru învelitoare, pentru diferite debite de aer prin colector.