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Analysis of advanced thermal insulation alternatives for a solar collector with PCM and nanomaterials

Analiza unor soluții avansate de izolare termică pentru un colector solar cu materiale cu schimbare de fază și nanomateriale

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Abstract. *Maximizing the quantity of heat delivered to the air is one of the difficulties dealt with by solar collectors used for air heating. In order to increase the quantity of heat delivered by the phase change materials with integrated nano materials, a thermal insulation solution is investigated in this work to reduce losses to the adjacent regions. A mobile insulating blanket that is fully mechanized is the solution. The time of day or the season determines where to set the insulating blanket.*

Key words: *aerogel; thermal insulation; solar collector*

1. Introduction

The construction industry is one of the largest energy consumers, accounting for over forty-five percent of total worldwide consumption of energy [1]. Furthermore, CO2 emissions around the world are increasing year after year, and global warming threats are becoming more serious each year. Greenhouse gas emissions are a direct result of rapid industrialization and urbanization. The utilization of renewable energy sources to provide indoor comfort and low energy consumption ought to be considered in such a scenario. Because of its abundance and accessibility, solar thermal energy is regarded as one of the most viable renewable energy sources [2]. The solar collector is one of the most widely deployed low-cost solar energy capture devices.

Solar water collectors are already a common solution for residential hot water and heating, whereas air solar collectors are used to warm fresh air, dry or heat the air inside a space. Employing a solar air collector instead of a solar water collector reduces expenses, has a reduced environmental impact, and eliminates the risk of freezing. Furthermore, by employing air solar collectors, outlet temperatures of up to 65 °C can be achieved, making them appropriate for a wide range of building applications [3-5].

Transpired solar collectors (TSC) are typically installed on large scale structures, such as industrial, office, or multi-family residential buildings, for ventilation and room heating during cold periods, and hot air from the system is typically bypassed during warmer periods [6-8]. Using PCMs in solar collectors can boost o operating hours and thermal stability while integrating nanoparticles in PCMs may also enhance thermal behavior related to the melting and solidification process and shorten the phase change period, resulting in a number of overall advantages. This novel type of materials are called nePCMs. The authors suggest a novel system: a transpired solar collector with nano-enhanced phase-changing materials and dynamic insulation. Throughout the day, the dynamic insulation is placed to the interior space, thus, during the coldest months of the year, the air is preheated as it passes over the transpired plate, which has a higher heat transfer rate due to the lobed perforations, and excess heat is stored in the highly efficient nePCMs. Inside, warm air is introduced. The dynamic insulation shifts to the exterior during the night, shielding the nePCMs, which can now transfer heat to the interior.

This paper focuses on insulating materials that can be used as dynamic insulation because the requirements they must meet are both thermal- in terms of the coefficient of thermal conductivity-, mechanical due to the fact that the insulating material is circulated by a roller, and also the mechanical properties and water absorption.

2. Methodology

Figure 1 depicts the novel solar collector system built by the team. The solar collector is constructed of perforated metal plates, a grid-type system in which nePCMs stored in spherical plastic recipients will be positioned.

Fig. 1. Solar collector with nePCMs

A moving roller on which the dynamic insulation will be shifted based on the time of day is placed on the top of the experimental stand. The challenges in developing this experimental stand included selecting the best phase change material for Romania's climatic conditions, selecting the right Nano material and the concentration with which it will be mixed with the phase change material, as well as selecting the type of insulation that will be carried by the mobile system.

To investigate the optimal solution in terms of thermal insulation, three types of material were analyzed: an Armacell Armaflex blanket (glass fiber polymer composite), an aerogel blanket and a ceramic fiber blanket.

A KERN ABJ 220 – 4NM analytical balance- Figure 2- with single cell technology was used to determine the density of the materials.

Fig. 2. Analytical balance

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The mechanical strength of materials is essential for the design of structures and components to ensure their safety and durability. There are several properties and parameters that characterize the mechanical strength of materials, the most important of which is tensile strength. This material property refers to its ability to resist tensile forces (stretching). This is measured by determining the maximum breaking stress of the material- Figure 3.

Water absorption represents the property of porous materials to absorb and retain water in open pores. It is calculated as the difference between the mass of water-saturated material (m2) and the mass of dry material (m1). The higher the open porosity and the finer the pores, the higher the water absorption. In capillary pores with a diameter between (1-10) μm, water penetrates by capillary rise, and in those with a diameter smaller than 1 μm by pressure. This is an important property of materials and can vary significantly between different types of materials. Water absorption can have a significant impact on the performance and durability of materials in various applications.

Fig. 3. Hegevald & Pesche machine

Thermal conductivity testing is an important part of evaluating the thermal performance of materials [9]. The majority of thermal conductivity testing equipment involves putting samples of certain size into a system consisting of a hot plate heated by an electrical resistance and a plate cooled, in most cases, by mains water. Thus, a temperature differential is maintained between the two opposite sides of the monitored material sample, and thermal conductivity is indirectly estimated by measuring the heat flow transported through the material under the respective conditions.

Thermal conductivity was measured using a P.A.Hilton H111N equipment for the materials under consideration. The tests were carried out on an experimental stand recognized by the Romanian National Accreditation Body (RENAR) at the Centre of the Department of Thermal Sciences, part of the Technical University of Civil Engineering Bucharest. The EA Multilateral Agreement (EA MLA) is a signed agreement between EA members that recognizes and respects the equivalence of the signing states' accreditation systems [10].

3. Results

From each type of material, a specific sample was cut to the dimensions required to be tested in each individual case. The materials under consideration have the following densities:

1. *Ceramic fiber blanket*
Mass, m = 18.4 g
Volume, V = (10 x 10 x 1.96) cm3 = 196 cm3
Density 0.094 g/cm3

2. *Glass fiber polymer composite*
Mass, m = 4.1 g
Volume, V = (10 x 10 x 0.7) cm3 = 70 cm3
Density, 0.0585 g/cm3

3. *Aerogel blanket*
Mass, m = 6.6 g
Volume, V = 10 x 10 x 0.7 = 70 cm3
Density, 0.094 g/cm3

The insulating materials used in this project were tested to tensile strength, and the results obtained are presented in the following. Figure 4 shows the appearance of the materials before and after tensile testing.

1. *Ceramic fiber blanket*
Initial length, Li = 100 mm
Final length, Lf = 115 mm
Section, S = (40 x 19) mm2 = 760 mm2
Maximum force = 2 daN
Tensile strength, ft = 0.026 N/mm2
Elongation, ε = 15%

2. *Glass fiber polymer composite*
Initial length, Li = 100 mm
Final length, Lf = 160 mm
Section, S = (40 x 7) mm2 = 280 mm2
Maximum force = 6 daN
Tensile strength, ft = 0.214 N/mm2
Elongation, ε = 60%

3. *Aerogel blanket*
Initial length, Li = 100 mm
Final length, Lf = 120 mm
Section, S = (40 x 7) mm2= 280 mm2
Maximum force = 18 daN
Tensile strength, ft = 0.643 N/mm2
Elongation, ε = 20%

The materials tested in this project have the following water absorption values:

1. *Ceramic fiber blanket*
Mass of dry material, m1 = 6.7 g
Mass of material saturated with water, m2 = 42.7 g
Mass absorption, Am = 537.3%

2. *Glass fiber polymer composite*
Mass of dry material, m1 = 0.5 g
Mass of material saturated with water, m2 = 0.6 g
Mass absorption, Am = 20%

3. *Aerogel blanket*
Mass of dry material, m1 = 0.6 g
Mass of material saturated with water, m2 = 0.6 g
It does not absorb water.

Fig. 4. Tested materials before and after tensile strength testing

The thermal conductivity ranges between 0.0323...0.0545 W/(mK) for the analyzed solutions. The lower the thermal conductivity, the lower the heat flow to the areas adjacent to the solar collector. In this regard, the best option is represented by the *aerogel blanket* having the lowest value. The highest value was obtained for *Glass fiber polymer composite.*

4. Conclusions

The most efficient material to be implemented in the solar collector with nePCMs and dynamic insulation (on rolls) in order to improve the energy efficiency by reducing the number of operating hours and operating costs is the aerogel blanket.

The aerogel blanket achieved the best results in the tests carried out, having the highest tensile strength, 0.643 N/mm2, not participating in the absorption of water vapor process and also having the lowest value of the coefficient of thermal conductivity, 0.0323 W/(mK).

The optimal solar collector insulation solution will be implemented in the experimental stand and the research team will carry out tests and will report the performance in operation in further research.

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