THESIS OF PHD DISSERTATION

Experimental examination and development of innovative Eco-friendly insulation materials for highly-efficient solar thermal collectors

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Introduction

Thermodynamics is that branch of science that deals with the thermal energy conversion into useful work. The conversion of energy from one phase to another is the most significant area of research in thermodynamics. The demand of energy is increasing rapidly in all the sectors such as agriculture, residential, commercial and industrial applications etc; that leads to the scarcity of natural resources, as well as enhance the destruction and humiliation of the natural environment in the present situation. Therefore, the examination of energy conversion procedure has changed out to be a challenging process in the recent years. The current study is focussed on the utilization of solar radiation form the efficiency evaluation of solar thermal collector.

Energy has the capability for the production of physical outcomes. Energy take place in different form i.e., open and closed system. The total is further classified into two main types: macroscopic and microscopic. The macroscopic study is based on the external flow energy, potential and kinetic energy. The microscopic approach is based on the internal energy that are mainly focus on the moment of the molecular structure and is classified as sensible heat, latent heat, chemical and nuclear energy. The energy that are based on the phase change are refer to as latent change whereas the rise in temperature of fluid is defined as sensible heat. The sensible heat takes place in various form such as molecular rotation and translation, electron translation, molecular vibration and nuclear spin. The difference of energy in initial and final stage defined as energy change in system

The main driver of the nation's economic growth and wealth creation is energy, and the availability of resources strongly correlates with economic activity. Because of the considerable developments in contemporary technology, the world's energy consumption is steadily rising. The quest for energy sources is sparked by this. The most accessible and limitless source of energy is solar energy. The conversion of solar energy into heat energy, which is incredibly helpful for thermal applications, is one of the productive methods to use

solar energy. Due to its scientific feasibility and the economic allure of using solar energy, SWH has grown to be a well-liked form of solar energy.

Heat is produced when solar light hits the surface of the collector. Solar energy losses originate from irreversible heat transfer between the sun and the collection, between the collector and the surrounding air, and inside the collector itself. Thus, research into energy conversion techniques has greatly increased in importance in recent years. The design parameters of solar water heating systems are therefore expected to be improved by scientific organisations by reevaluating and regenerating energy conversion technologies that are both efficient and affordable. The present non-conventional energy methodologies based on the first rule of thermodynamics are insufficient to quantify these losses since energy assessment is just a measure of quantity. However, employing the second law of thermodynamics to change the solar system's design criteria and operational procedures provides a solid foundation for an amazing resolution. Therefore, in order to expand the use of solar energy for home, agricultural, industrial, and commercial purposes, it is required to explore the thermohydraulic performance based on both quality and quantity of energy.

There are many researchers that have investigated the thermal performance of the SWHS by providing the obstacle inside the absorber tube. The introduce of these obstacle technologies enhance the thermal performance of the system with good design and proper installation of these obstacle. The motivation of this study is to provide the thermal performance of the system by using the delta-shape obstacle inside the observer tube. After the experimental examination it was conclude that the heat losses are also one of the major concerns for lower the thermal performance of the system. Therefore, additionally a experimental study is also conducted by using the ecofriendly thermal insulating materials (rice husk, coco-peat, stubble fibre and nitrile rubber) for absorbing the heat from solar radiation on the sunshine hours and release this heat during the off-sunshine hours.

 # Thesis Point:

- **1st Thesis point: CRITIC-COPRAS MCDM optimization approach applies on non-perforated delta obstacles.**

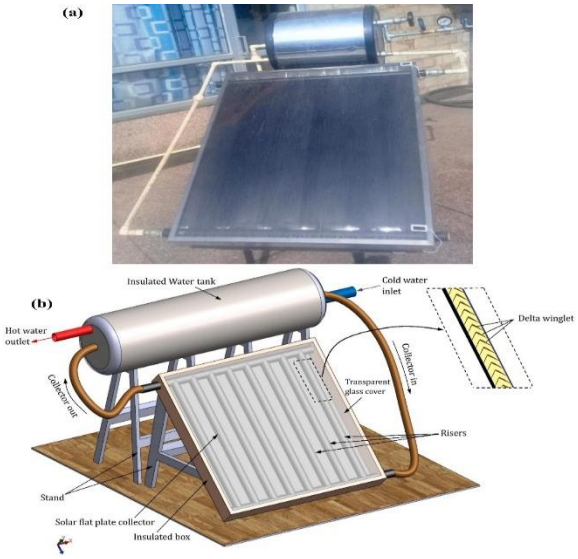
This study reports on the performance of delta-shaped obstacles in a solar water heating system (SWHS) through experimental analysis and optimization. The influence of different parameter combinations such as Reynolds number (200, 600, 1000, 1400, 1800), pitch ratio (0.5, 1, 1.5), blockage ratio (0.15, 0.20, 0.25), and angle of attack (45°) on Nusselt number, friction factor and thermo-hydraulic performance of SWHS were analyzed. For the combination of Reynolds number=1800 and pitch ratio = 0.5, the Nusselt number remains highest for 0.25 of blockage ratio, whereas the friction factor remains lowest for a blockage ratio of 0.15. The maximum thermo-hydraulic efficiency was achieved using Reynolds number=200, pitch ratio=0.5, and blockage ratio=0.20. The obtained results were intensely dependent on parameter combinations without any pronounced trend. Therefore, criteria importance through inter-criteria correlation (CRITIC) and complex proportional assessment (COPRAS) approach was implemented to find optimal design alternative. The results of the hybrid CRITIC-COPRAS approach showed that the combination of Reynolds number=1800, pitch ratio=0.5, blockage ratio=0.20, and angle of attack=45° is the best alternative for maximum thermal enhancement in SWHS. The sensitivity analysis proves the robustness of the results that the first-ranked alternative is the most dominant in all scenarios.

Related articles of the 1st thesis point:

Rohit Khargotra, Raj Kumar, Kovács András, Gusztáv Fekete, Tej Singh, (2022). Thermo-hydraulic characterization and design optimization of delta-shaped obstacles in solar water heating system using CRITIC-COPRAS approach. Energy. 2022 Dec 15; 261:125236. **D1 [I. F= 9].**

- **2nd Thesis point: AHP-ARAS MCDM optimization approach applies on perforated delta obstacles Overview of integrated AHP-ARAS method.**

The influence of Reynolds number (400, 800, 1200), angle of attack (15°, 30°, 45°), and pitch ratio (0.5, 1, 1.5, 2.0) on the friction factor, Nusselt number, and thermo-hydraulic performance was investigated and optimized. The combination of Reynolds number = 1200, angle of attack = 45°, and pitch ratio = 1 yielded the most significant Nusselt number (90.55). In contrast, the combination of Reynolds number = 1200, angle of attack = 15°, and pitch ratio = 0.5 yielded the lowest friction factor (0.38). The largest thermo-hydraulic efficiency (2.75) was obtained using Reynolds number = 400, angle of attack = 45°, and pitch ratio = 1. Since no single SWHS design alternative can meet all desired performance criteria, selecting the best among SWHS design alternatives is not easy. Therefore, a hybrid multi-criteria decision-making approach called AHP (*analytic hierarchy process*)-ARAS (additive ratio assessment) was implemented, suggesting the SWHS design alternative having the angle of attack = 45°, Reynolds number = 1200, and pitch ratio = 1 satisfies the preset performance criteria.



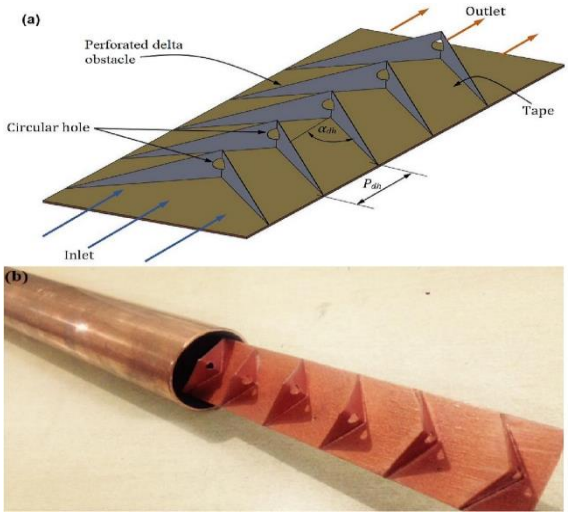


Fig. 2. (a) Real and (b) Schematic view of SWHS. Fig. 3. Perforated obstacle design (a) Schematic, (b) Real.

Related articles of the 2nd thesis point:

Rohit Khargotra, Raj Kumar, Ashutosh Sharma, Tej Singh, **(2023).** Design and performance optimization of solar water heating system with perforated obstacle using hybrid multi-criteria decision-making approach. Journal of Energy Storage. 2023 Jul 1; 63:107099. **D1 [I. F= 9.4]**

- **3rd Thesis point: Experimental examination of eco-friendly insulating materials to analyse their impact on heat transfer characteristics.**

The conventional solar flat plate collector commonly uses rock wool or other insulating materials to lower thermal losses. These inorganic materials are one of the significant concerns to the industry and the environment. Thus, reducing these inorganic materials and utilizing the naturally occurring biodegradable materials available in abundance and without any environmental hazards to the system is imperative. The current research presents agricultural waste as an insulating material for S-FPC fabrication. The novelty of this current research work is the utilization of rice husk, stubble fibre, coco-peat, and nitrile rubber as an insulating material for the fabrication of S-FPC. Experimentation is performed with insulating thicknesses of 50 mm and 70 mm. The optimum temperature is attaining 50-53˚C with an average thermal efficiency of 64-66% by using rice husk as the insulating material with a thickness of 70 mm.

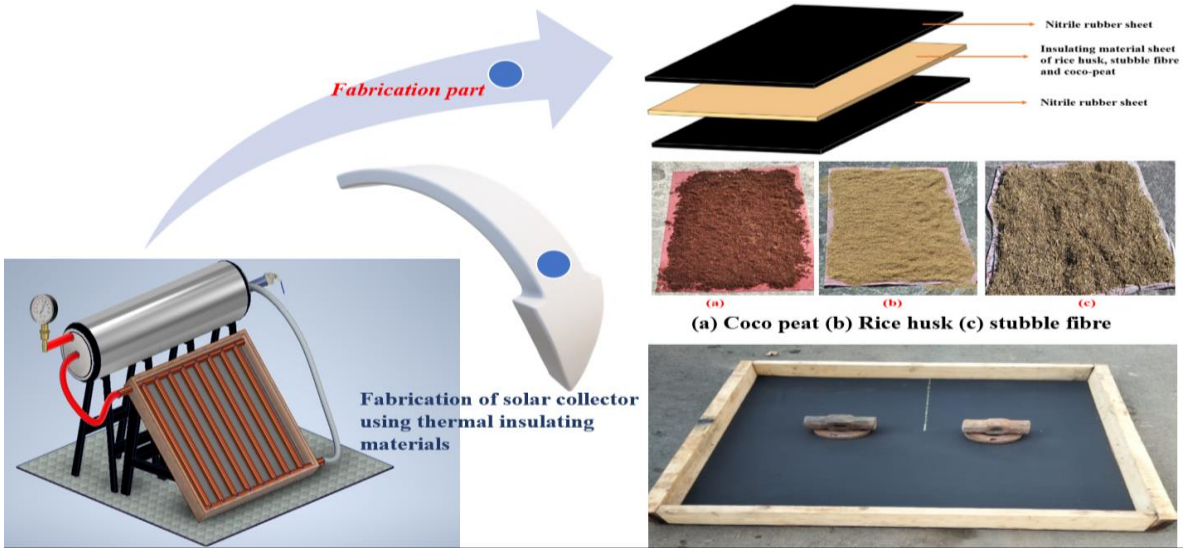


Fig. 4. Schematic representation of S-FPC using thermal insulating materials.

Related articles of the 3rd thesis point:

Rohit Khargotra*, Alam T, Thu K, András K, Siddiqui TU, Singh T. Influence of heat enhancement technique on the thermal performance of solar water heater for sustainable built environment. Start-of-the-art review. Sustainable Energy Technologies and Assessments. 2023 Jun 1; 57:103293. **Q1 [I. F= 8]**

Rohit Khargotra, Kumar, R., Kovács, A. et al. Techno-economic analysis of solar thermal collector for sustainable built environment. J Therm Anal Calorim 149, 1175–1184 (2024). **Q1 [I. F= 4.4]**

Rohit Khargotra* *Tabish Alam,* Kovács András, Tej Singh. **Indigenous solar thermal collector for hill climates: An experimental study of eco-friendly insulating materials.** Results in Engineering. 2023 Dec 16:101681. **Q2 [I. F= 5]**