ENERGY, EXERGY AND ECONOMIC ANALYSIS OF NANO-ENHANCED PHASE CHANGE MATERIALS INTEGRATED SOLAR PHOTOVOLTAIC THERMAL SYSTEMS

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We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Solar Panel (PV) adalah salah satu teknologi solar yang paling menonjol bagi menghasilkan tenaga elektrik, tetapi hanya 5-20% tenaga suria ditukar kepada elektrik, manakala tenaga yang selebihnya terbazir. Suhu sel suria memainkan peranan penting dalam pengurangan kecekapan sistem PV, dimana kecekapan sistem PV berkurangan dengan peningkatan suhu sel suria. Sistem terma solar panel (PVT) adalah sebagai bahagian yang memainkan peranan penting dalam sistem aplikasi suria yang mengintegrasikan solar panel (PV) dan pengumpulan haba solar dalam satu unit untuk menghasilkan tenaga daripada sinaran suria berkala dan menyelesaikan isu kepanasan melebihi had sistem PV pada tahap tertentu. Namun, sistem PVT tidak mampu menyimpan tenaga haba; sedangkan tenaga elektrik boleh disimpan menggunakan teknologi yang diperakui iaitu bateri elektrokimia. Bahan perubahan fasa (PCM) ialah bahan penyimpanan haba pendam yang boleh digunakan untuk pengawalan suhu sistem PV serta bahan ini boleh menyimpan tenaga haba sistem PVT yang boleh digunakan kelak apabila tiada suria. Tetapi, PCM ini mempunyai sifat termofizik yang rendah dan boleh dipertingkat menggunakan bahan nano partikel yang berbeza; PCM yang digabungkan dengan bahan nano partikel dikenali sebagai nano partikel PCM (NePCM). Prestasi sistem PVT bergantung kepada analisis tenaga, biasanya pengurangan tenaga yang berlaku dalam sistem boleh dikenal pasti menggunakan analisis eksergi, oleh itu analisis tenaga, eksergi dan ekonomi diperlukan untuk meningkatkan kecekapan sistem dari perspektif prestasi dan kos. Oleh itu, objektif utama kajian ini ialah; a) menghasilkan komposit PW/TiO_2 dan yang bercirikan binari PW/TiO_2-Gr; b) mengklasifikasikan ciri-ciri termofizik NePCM; c) menganalisis prestasi sistem PVT menggunakan pendekatan 3E, dan d) mensimulasikan prestasi sistem PVT bersepadu PCM dan NePCM. Kajian ini mencadangkan penyelesaian kepada masalah ini dengan merangka komposit perduaan TiO_2 dan TiO_2:Gr (1wt% TiO_2: 0.1, 0.5, 1 dan 2 wt% Graphene (Gr)) lilin Parafin (PW) dipertingkat. Spektrum Inframerah Transformasi Fourier (FT-IR), Spektrometer Ultralembayung (UV-Vis), Analisis Termo-Gravimetrik (TGA), Kalorimeter Pengimbasan Berbeza (DSC), Penganalisis Sifat Terma (TEMPOS) dan Mikroskop Elektron Pengimbasan Pelepasan Medan (FESEM) telah digunakan untuk analisis ermofizik. Haba pendam dan pengaliran haba bagi komposit perduaan PW/TiO_2-Gr didapati 10.02%, dan 179% lebih tinggi daripada PW asas. Spektrum FT-IR tidak menunjukkan reaksi kimia antara PW dan nano partikel. TGA mengesahkan bahawa kestabilan haba dalam penyepaduan TiO_2-Gr ke dalam PW. Penghantaran cahaya kepada komposit yang disediakan telah dikurangkan sebanyak 58.30% berbanding PW asas. Dalam kajian ini, penyerapan aliran serpentin dicadangkan sebagai pengumpul haba untuk sistem PVT yang membolehkan pengekstrakan tenaga haba yang cekap. Sistem PVT yang dicipta adalah untuk kajian pada tiga kadar aliran jisim yang berbeza (0.3, 0.5, dan 0.7 liter seminit (LPM)) dan seterusnya kajian simulasi ke atas sistem PVT bersepadu NePCM juga telah dijalankan pada ketiga-tiga kadar aliran ini. Hasilnya, tekno-ekonomi menunjukkan kos tenaga, nilai terkini bersih dan masa pembayaran balik masing-masing 0.30 MYR/kWh, 127.22 MYR dan 8.82 tahun. Pada kadar aliran optimum 0.3 LPM, telah dipastikan bahawa kecekapan tenaga keseluruhan sistem PVT, PVT-PCM, dan PVT-NePCM ialah 80.49%, 82.45% dan 83.65%, masing-masing. Bagaimanapun, kecekapan eksergi keseluruhan sebanyak 6.19%, 8.03% dan 8.45% masing-masing direkodkan untuk sistem PVT, PVT-PCM dan PVT-NePCM. Kepentingan penyelidikan ini menyumbang ke arah matlamat pembangunan mampan (SDG), selari dengan pelbagai aplikasi seperti keperluan isi rumah atau dalam industri seperti air pra-kepanasan.

ABSTRACT

Solar photovoltaic (PV) is one of the most prominent solar technology that produces electrical energy. However, only 5-20% of solar energy is converted into electricity depending upon the PV technology; the remaining energy is wasted. The temperature of solar cells plays an important role in the PV systems' efficiency. The efficiency of PV systems decreases with an increase in solar cells' temperature. Photovoltaic thermal (PVT) systems are budding as an essential part of the solar application systems, which integrates photovoltaic (PV) and solar thermal collector in a single unit to produce thermal energy and electrical energy from intermittent solar radiation and solves the issue of overheating of PV systems at a certain extent. However, PVT systems cannot store thermal energy, and the electrical energy can be stored using well-established technology, i.e., electrochemical batteries. Phase change materials (PCMs) are latent heat storage materials which can be used for temperature regulation in PV systems and as thermal energy storage materials in PVT systems which can be used later in the absence of solar energy. Nevertheless, these PCMs suffer from low thermophysical properties and can be improved by incorporating different nanomaterials and known as nano-enhanced PCMs (NePCMs). The PVT system's performances are dependent on energy analysis. The energy reduction occurring in the systems can often be detected using exergy analysis. Thus, energy, exergy and economic analysis are needed to enhance the system efficiency from a performance and cost perspective. Therefore, this study's main objectives are: (a) to formulate PW/TiO_2 and PW/TiO_2-Gr binary composites; b) To characterize the thermophysical behaviour of NePCMs; c) to analyse the performance of the PVT system using the 3E approach; d) to simulate the performance of PCM and NePCMs integrated PVT system. The present study proposes the solution to the problem by formulating the TiO_2 and TiO_2:Gr binary composite (1wt% TiO_2: 0.1, 0.5, 1 and 2 wt% of Graphene (Gr)) enhanced Paraffin wax (PW). Fourier transform infrared spectroscopy (FT-IR), Ultraviolet-visible spectrometer (UV-Vis), Thermogravimetric analyzer (TGA), Differential scanning calorimeter (DSC), Thermal property analyzer (TEMPOS) and Field emission scanning electron microscopy (FESEM) were used for material characterizations and thermophysical analysis. The latent heat and thermal conductivity of the PW/TiO_2-Gr binary composites were found to be 10.02% and 179% higher than base PW respectively. The FT-IR spectra showed no chemical interaction between the PW and the nanoparticles. The TGA analysis confirmed improved thermal stability by the integration of the TiO_2-Gr into PW. The light transmission of the prepared composite was reduced by 58.30% as compared to the base PW. In the present study, a serpentine flow absorber is proposed as a thermal collector for the PVT system that allows efficient extraction of heat energy. The designed PVT system was studied at three different mass flow rates (0.3, 0.5, and 0.7 litres per minute (LPM)). Techno-economic results showed levelized cost of energy, net present worth and payback time as 0.30 MYR/kWh, 127.22 MYR and 8.82 years respectively. Further, the NePCM-integrated PVT system simulation was also carried out at these three flow rates. At the optimal flow rate of 0.3LPM, it was determined that the overall energy efficiency of the PVT, PVT-PCM, and PVT-NePCM systems was 80.49%, 82.45%, and 83.65%, respectively. However, overall exergy efficiencies of 6.19%, 8.03%, and 8.45% were recorded for the PVT, PVT-PCM, and PVT-NePCM systems, respectively. The significance of current research contributes towards sustainable development goals (SDGs) number 7 and number 13, along with many applications for household purposes or in industries like preheated water.

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