THERMAL PERFORMANCE OF BACKFLOW SOLAR AIR HEATING WITH INTEGRATED NANOPARTICLE ENHANCED PCM ABSORBER STORAGE SYSTEM

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To the memory of my mother, my father, who would have been glad to see me at this moment.

To my wife and beloved children, Sarah, Malak, Lyan, Hussein for their love and support.

To my brothers and my sisters for their support and encouragement

To all my family members and friends for their love and support

To science,

enlightening us

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ABSTRACT

The present study has been executed to clarify the advantage of using latent thermal storage integrated with a back pass solar air heater (SAH). The purpose of this study is to design, fabricate and evaluate the performance of SAH with integrated nanoparticles enhanced phase change material (PCM) absorber storage system. Three different SAH configurations have been designed and studied; without thermal storage, with thermal storage using paraffin wax as a PCM and with thermal storage using Al_2O_3-paraffin wax. A three-dimensional Navier-Stokes equation coupled with the energy balance equation is solved using the computational fluid dynamics (CFD) software program to implement numerical computations. The numerical analysis is conducted to determine the optimum collector dimensions in terms of length (L), width (W) and depth of air flow channel (H_{ch}) at air mass flow rate of 0.03 kg/s and solar irradiance of 1000 W/m^2. Results obtained from the numerical analysis indicate that the collector dimensions of (L = 1.8 m, W = 0.7 m, H_{ch} = 0.07 m) which are the best design. The numerical results show that the SAH with Al_2O_3-paraffin wax have the thermal efficiency ranged between 73 % and 78 % with air temperature difference from 25 °C to 46.6 °C when the solar irradiance of 1000 W/m^2 at the air mass flow rates of 0.03 kg/s and 0.06 kg/s, respectively. The experimental setup is constructed using these optimum dimensions for each configuration and validated using the numerical results. All configurations are fabricated and tested outdoor under the Iraq climatic conditions according to ASHRAE standard tests at different air mass flow rates. The two steps method is used to prepare the mixture of nanoparticles with PCM and ultrasonic device is used to suspend the nanoparticles in the PCM. The experimental results show that the SAH with Al_2O_3-paraffin wax has the highest daily performance and thermal efficiency followed by SAH with pure paraffin wax and SAH without storage. Moreover, the discharging time in the SAH with pure paraffin wax of heat stored took 5.5, 5, 4.5 and 4 hours at the air mass flow rate 0.03, 0.04, 0.05 and 0.06 kg/s, respectively. As for the SAH with Al_2O_3-paraffin

wax, the discharge time are 5, 4.5, 4 and 3.5 hours at the air mass flow rates of 0.03, 0.04, 0.05 and 0.06 kg/s, respectively. The experimental results also show that increment in the thermal conductivity of PCM with the dispersion 1wt. % Al_2O_3 which led to raise the outlet air temperature and thermal efficiency of the SAH compared to SAH with pure paraffin wax. In addition, good agreement are obtained when comparing between the numerical and experimental results. It was the average differences in percentage on outlet air temperatures obtained in the numerical and experimental results from 2.11 % to 2.47 % and on the thermal efficiency from 2.70% to 3.50 %, respectively.

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ABSTRAK

Kajian ini telah dilaksanakan untuk menjelaskan kelebihan menggunakan storan terma laten yang disepadukan dengan pemanas udara suria (SAH) aliran belakang. Tujuan kajian ini adalah untuk merekabentuk, membina dan menilai prestasi SAH dengan sistem storan laten bersepadu berdasarkan sistem penyerapan thermal material berubah fasa yang telah ditambah nanopartikel terpadu (PCM). Tiga konfigurasi SAH yang berbeza telah direka dan dipelajari; tanpa penyimpanan termal, dengan sistem simpanan termal menggunakan lilin parafin sebagai PCM dan dengan penyimpanan haba menggunakan Al_2O_3-lilin parafin. Persamaan Navier-Stokes tiga dimensi disertakan dengan persamaan imbangan tenaga telah diselesaikan menggunakan program perisian dinamik bendalir (CFD) untuk melaksanakan perhitungan berangka. Analisis berangka telah dijalankan untuk menentukan dimensi pengumpul optimum dari segi panjang (L), lebar (W) dan kedalaman saluran aliran udara (H_{ch}) pada kadar aliran jisim udara 0.03 kg/s dan sinar matahari 1000 W/m^2. Keputusan yang diperoleh daripada analisis berangka menunjukkan bahawa dimensi pengumpul (L = 1.8 m, W = 0.7 m, H_{ch} = 0.07 m) mempunyai reka bentuk terbaik. Keputusan berangka menunjukkan bahawa SAH dengan Al_2O_3-lilin parafin mempunyai kecekapan haba berkisar antara 73 % dan 78 % dengan perbezaan suhu udara dari 25 °C hingga 46.6 °C apabila sinar matahari 1000 W/m^2 pada kadar aliran jisim udara daripada 0.03 kg/s dan 0.06 kg/s. Persediaan eksperimen dibina menggunakan dimensi optimum untuk setiap konfigurasi dan telah disahkan menggunakan kaedah analisa berangka. Semua konfigurasi dibuat dan diuji di bawah keadaan iklim Iraq menurut ujian standard ASHRAE pada kadar aliran jisim udara yang berlainan. Kaedah dua langkah digunakan untuk menyediakan campuran nanopartikel dengan PCM dan peranti ultrasonik digunakan untuk mengampai nanopartikel dalam PCM. Keputusan eksperimen menunjukkan bahawa SAH dengan Al_2O_3-lilin parafin mempunyai prestasi harian yang paling tinggi dan kecekapan terma diikuti oleh SAH dengan lilin paraffin tulen dan SAH tanpa penyimpanan.

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Selain itu, masa pelepasan haba pendam di SAH dengan lilin parafin tulen yang disimpan mengambil 5.5, 5, 4.5 dan 4 jam pada kadar aliran jisim udara 0.03, 0.04, 0.05 dan 0.06 kg/s. Bagi lilin SAH dengan Al_2O_3-lilin Parafin, masa pelepasan adalah 5, 4.5, 4 dan 3.5 jam pada kadar aliran jisim udara masing-masing 0.03, 0.04, 0.05 dan 0.06 kg/s. Keputusan percubaan juga menunjukkan bahawa peningkatan dalam kekonduksian terma PCM dengan pengampaian 1wt. % Al_2O_3 yang menyebabkan peningkatan suhu udara dan kecekapan haba SAH berbanding dengan SAH dengan lilin parafin tulen. Di samping itu, persetujuan yang baik diperoleh apabila membandingkan antara keputusan berangka dan eksperimen. Secara umumnya, perbezaan purata peratusan pada suhu udara keluar yang didapati dalam keputusan berangka dan eksperimen iaitu dari nilai 2.11 % hingga 2.47 % dan perbezaan pada kecekapan terma dari nilai 2.70 % hingga 3.50 %.

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LIST OF SYMBOLS AND ABBREVIATIONS

I	-	Global Solar Irradiance (W/m^2)
I_T	-	Solar Irradiance on the Tilt Surface (W/m^2)
h_{conv}	-	Convection Heat Transfer Coefficient (W/m^2 K)
h_{rad}	-	Radiation Heat Transfer Coefficient (W/m^2 K)
h_{cond}	-	Conduction Heat Transfer Coefficient (W/m^2 K)
T_{out}	-	Output Temperature (°C)
T_{in}	-	Inlet Temperature (°C)
T_{amb}	-	Ambient Temperature (°C)
T_p	-	Absorber Plate Surface Temperature (°C)
T_g	-	Glass Cover Surface Temperature (°C)
T_{sky}	-	Sky Temperature (°C)
T_m	-	Mean Temperature (°C)
T_b	-	Bottom Temperature (°C)
T_{PCM}	-	PCM Temperature (°C)
$T_{out,t}$	-	Outlet Temperature at the Time (°C)
$T_{in,init}$	-	Outlet Temperature When Solar Radiation is Interrupted (°C)
k	-	Thermal Conductivity (W/m K)
U_L	-	Overall Heat Loss Coefficient (kJ/kg K)
U_t	-	Top Heat Loss Coefficient (kJ/kg K)
U_b	-	Bottom Heat Loss Coefficient (kJ/kg K)
U_e	-	Edges Heat Loss Coefficient (kJ/kg K)
S	-	The Absorbed Solar Irradiance by a Collector (W)

C_p	-	Specific Heat Capacity (kJ/kg K)
Q_u	-	Useful Energy of Collector (W)
Q_{st}	-	Stored Thermal Energy of Collector (W)
$\dot{m}_{air}$	-	Air Mass Flow Rate (kg/s)
v_{air}	-	Air Velocity (m/s)
w_v	-	Wind Velocity (m/s)
A_g	-	Cross Section Area of Glass Covers (m^2)
A_p	-	Cross Section Area of Absorber Plate Surface (m^2)
A_c	-	Cross Section Area of Collector (m^2)
A_{ext}	-	Cross Section Area of the Duct (m^2)
l	-	Absorber to Glass Cover Distance (m)
g	-	Gravitational Constant (m^2/s)
D_H	-	Hydraulic Diameter of the Air Flow Channel (m)
H_{ch}	-	Depth of Air Flow Channel (m)
W	-	Width of the Collector (m)
L	-	Length of the Collector (m)
P_c	-	Perimeter of the Collector (m)
R_e	-	Reynolds Number (Dimensionless)
P_r	-	Prandtl Number (Dimensionless)
R_a	-	Rayleigh Number (Dimensionless)
N_u	-	Nusselt Number (Dimensionless)
F_R	-	Removal Factor (Dimensionless)
F'	-	Collector Efficiency Factor (Dimensionless)
ρ	-	Density (kg/m^3)
σ	-	Stephan Constant (W/m^2 K)
τ	-	Transmittance (Dimensionless)
α_t	-	Thermal Diffusivity (m^2/s)
α	-	Absorptance (Dimensionless)
ε	-	Emissivity (Dimensionless)

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