DESIGN AND DEVELOPMENT OF HIGHLY EFFICIENT NANO FLUIDIC FLAT PLATE SOLAR COLLECTOR

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DOCTOR OF PHILOSOPHY

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award 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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ABSTRACT

The increase in demand for energy along with the depletion of conventional energy sources requires the improved utilization of renewable energy resources. Moreover, the unfavourable response of existing energy urges to take necessary action rapidly. Therefore, it is desired to generate an alternative source of energy or renewable energy for the industries. Among all renewable energy resources, solar energy is the most advantageous alternative to conventional energy sources owing to its inexhaustibility and green property. Generally, solar energy is harvested using different solar collectors. Solar collectors are devices that convert solar radiation into heat or electricity. However, the efficiency of the solar collector specifically flat plate solar collector is still not adequate. Thus, to form an optimum designed of a flat plate solar collector and by reintroducing the working fluid with the new transport medium; the efficiency of the collector can be improved. The competent step to enhance the efficiency of the solar collector is to redesign the flat plate solar collector considering the number and diameter of the header and riser tubes of flat plate solar collector. Secondly, replacing the working fluid inside the header and riser tubes with ethylene glycol-based Al_2O_3 and CNC nanofluids flowing through them. And finally, analysing the thermal performance of these new transport mediums in flat plate solar collector. This study is carried out in different phases viz. computational numerical simulations to design flat plate solar collector; measurement and evaluation of distinctive thermo-physical properties of Al_2O_3 and CNC nanofluids including stability, thermal conductivity, viscosity, specific heat, density and pH; implementation of nanofluids in the solar collector and finally, numerical simulation based on the experimental design and experimental properties of nanofluids. Experiment executed with a fixed flow rate and in the steady-state condition under solar irradiation. In results, the optimum 8-23-12 (number of riser tubes-diameter of header-diameter of riser) design of header and riser tubes of solar collector selected based on the statistical analysis of numerical simulations. From the thermo-physical point of view, thermal conductivity increased in a maximum of 13.4% and 11.5% for Al_2O_3 and CNC nanofluids respectively. Furthermore, the highest of 36% and 19% viscosity obtained with the augmentation of Al_2O_3 and CNC nanoparticle into the base fluid at 30^{o}C temperature respectively but decreased with the raising of temperature. Moreover, decrement of specific heat occurred due to an increment of volume concentrations of nanofluids. However, specific heat capacity enhanced by the progressive gradient of temperature. On the other hand, contraction of the density of nanofluids obtained with an improvement of temperature and of 3.8% decreased in maximum at 80^{o}C temperature. Al_2O_3 nanofluids showed the pH range of 2 to 4 and CNC nanofluids were within 5 to 7.5 scale of pH. The experimental study has implied that up to 2.48% and 8.46% efficiency of solar collector enhanced by using 0.5% Al_2O_3 and 0.5% CNC nanofluids respectively. And the most significant result is that of about 5.8% efficiency can be improved in flat plate solar collector by CNC/water-EG nanofluid. In addition, all types of nanofluids performed better convection heat transfer and quick heat diffusion characteristics with laminar fluid flow behaviour. Applying CNC/water-EG nanofluid enhances the efficiency of a flat-plate solar collector to consume the limitless solar energy to create an alternative source of energy for the industries.

ABSTRAK

Permintaan yang semakin menaik bagi sumber tenaga ditambah dengan pengurangan sumber tenaga konvensional memerlukan penggunaan sumber tenaga boleh diperbaharui yang lebih baik. Selain itu, tindak balas yang tidak baik daripada tenaga yang sedia ada memerlukan tindakan segera yang perlu diambil. Oleh itu, sumber tenaga boleh diperbaharui merupakan alternatif penting kepada industri. Di antara semua sumber tenaga boleh diperbaharui, tenaga suria adalah alternatif yang paling menguntungkan jika dibandingkan dengan sumber tenaga konvensional kerana sifatnya yang tidak habis serta mesra alam. Secara amnya, tenaga solar diperolehi menggunakan pengumpul suria yang berbeza. Pengumpul suria merupakan peranti yang menukarkan radiasi matahari menjadi haba atau tenaga. Walau bagaimanapun, kecekapan pengumpul suria terutamanya jenis plat rata masih tidak mencukupi. Bagi meningkatkan kecekapan pengumpul suria, reka bentuk optimum pengumpul suria plat rata dan cecair kerja dengan medium pengangkutan baru harus diperkenalkan. Langkah yang kompeten untuk meningkatkan kecekapan pengumpul suria adalah dengan mereka bentuk semula pemungut plat rata dengan mengambil kira bilangan dan diameter kepala dan riser tiub pengumpul suria plat rata. Kedua, menggantikan cecair kerja di dalam kepala dan tiub riser dengan nanofluid yang berasaskan etilena glikol Al_2O_3 dan CNC mengalir melalui mereka. Akhir sekali, prestasi haba medium pengangkutan baru di dalam pengumpul suria plat rata ini dianalisis. Kajian ini dijalankan dalam fasa yang berlainan. simulasi berangka komputasi untuk reka bentuk pengumpul suria plat rata; pengukuran ciri-ciri fizikal terma-fizikal nanofluid Al_2O_3 dan CNC termasuk kestabilan, kekonduksian terma, kelikatan, haba tertentu, ketumpatan dan pH; pelaksanaan nanofluid dalam pengumpul suria dan akhirnya, simulasi berangka berdasarkan sifat eksperimen nanofluid. Eksperimen dilaksanakan dengan kadar aliran yang tetap di bawah sinaran suria. Hasilnya, reka bentuk optimum 8-23-12 (bilangan tiub riser-diameter kepala-diameter riser) jenis kepala dan riser tiub pengumpul suria dipilih berdasarkan analisis statistik simulasi berangka. Dari sudut termo-fizikal, kekonduksian terma meningkat sebanyak 13.4% dan 11.5% bagi Al_2O_3 dan CNC nanofluid masing-masing. Tambahan pula, kelikatan tertinggi sebanyak 36% dan 19% diperolehi dalam penambahan Al_2O_3 dan nanopartikel CNC pada suhu 30^oC tetapi kemudian menurun dengan peningkatan suhu. Selain itu, pengurangan haba tertentu berlaku disebabkan peningkatan kepekatan jumlah nanofluid. Walaubagaimanapun, kapasiti haba tertentu dipertingkatkan oleh kecerunan suhu yang progresif. Sebaliknya, penurunan ketumpatan nanofluid diperoleh dengan peningkatan suhu dan 3.8% penurunan diperolehi pada suhu 80^oC. Al_2O_3 nanofluid menunjukkan julat pH 2-4 dan nanofluid CNC berada dalam lingkungan 5 hingga 7.5 skala pH. Kajian eksperimental menunjukkan bahawa kecekapan pengumpul suria sebanyak 2.48% dan 8.46% ditingkatkan dengan menggunakan 0.5% Al_2O_3 dan 0.5% nanofluid CNC. Keputusan yang paling ketara adalah kira-kira 5.8% kecekapan boleh ditingkatkan bagi pengumpul suria plat rata jenis CNC/air-EG nanofluid. Di samping itu, semua jenis nanofluid melakukan pemindahan haba perpecahan yang lebih baik dan ciri-ciri penyebaran haba yang cepat dengan aliran bendalir laminar. Penggunaan nanofluid CNC/air-EG dapat meningkatkan kecekapan pengumpul suria plat rata bagi mengumpul tenaga solar tanpa had sebagai sumber tenaga alternatif kepada industri.

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ρ	Density (kg/m^3 or g/m^3)
ϕ	Volumetric concentration of particles (%)
C_p	Specific heat (J/kg-K or J/g-K)
D	Characteristic linear dimension (m)
k	Thermal conductivity (W/m-K)
μ	Viscosity (kg/m. s or cP)
w	Mass fraction
Q_u	Energy gain (kW)
$\dot{m}$	Mass flow rate (kg/s)
I_t	Incident solar radiation (W/m^2)
A_c	Area of the solar collector (m^2)
η	Efficiency (%)
T	Temperature (K or ^{o}C)
v	Characteristic velocity (m/s)
Q	Volumetric flow rate (m^3/s)
A	Cross-sectional area of the tube (m^2)
τ	Shear stress/stress tensor
γ	Shear rate
U	Velocity vector
p	Pressure (kg/m. s^2)
g	Gravitational acceleration (m/s^2)
h	Sensible enthalpy (joule)
∇	Advection operator
R_e	Reynolds number
N_u	Nusselt number
P_r	Prandtl number

Subscripts

s	Solid
f	Fluid
nf	Nanofluid
p	Particle
bf	Base fluid

LIST OF ABBREVIATIONS

ASHRAE	The American Society of Heating, Refrigerating and Air Conditioning Engineers
Al_2O_3	Aluminium Oxide
Al	Aluminium
Ar	Argon
BBD	Box–Behnken design
CFD	Computational fluid dynamics
CNC	Crystal nano-cellulose
CO_2	Carbon Dioxide
CSR	Controlled shear rate
CTAB	Cetyl Trimethyl Ammonium Bromide
Cu	Copper
CuO	Copper Oxide
DC	Direct current
DI	Deionized
DOE	Design of experiment
DSC	Differential scanning calorimetry
DW	Distilled water
DWCNT	Double-Walled Carbon Nanotube
EDX	Energy dispersive x-ray spectroscopy
EG	Ethylene glycol
ELS	Electrophoretic light scattering
Fe_2O_3	Ferric Oxide
FESEM	Field emission scanning electron microscopy
FLIR	Forward-looking infrared
FPSC	Flat plate solar collector
FTIR	Fourier transform infrared spectroscopy
ICDD	International centre for diffraction data
IEP	Isoelectric point
Ipm	Inches per minute
L	Litre

Max	Maximum
MgO	Magnesium Oxide
Min	Minimum
MWCNT	Multi-Walled Carbon Nanotube
NPs	Nanoparticles
N_2	Nitrogen
PWE	Pulse wire evaporation
RH	Relative humidity
RSM	Response surface methodology
SC	Solar collector
SDBS	Sodium Dodecyl Benzene Sulphonate
SiO_2	Silicon Dioxide
SWCNT	Single-Walled Carbon Nanotube
TEM	Transmission electron microscopy
TiO_2	Titanium Dioxide
W	Water
WD	Working distance
ZnO	Zinc Oxide
ZrO_2	Zirconium Dioxide

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