SSRG International Journal of Thermal Engineering
ISSN: 2395-0250/ https://doi.org/10.14445/23950250/IJTE-V10I2P101

Volume 10 Issue 2, 1-11, May-Aug 2024

Original Article

Analysis of Hybrid Systems using Magnetized Nanofluids in a PV-Thermal-Driven Organic Rankine Cycle with Heat Pump

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Received: 26 May 2024 Revised: 04 July 2024 Accepted: 22 July 2024 Published: 08 August 2024

Abstract - *Analysis of a Hybrid System using Magnetized Nanofluids composed of a PV Thermal-driven Organic Rankine Cycle (ORC) and Heat pump has been presented. This study was carried out to investigate the enhancement effect of using Magnetized nanofluids Al_2O_3, CuO, Fe_3O_4, and SiO_2 on the performance of the hybrid system composed of PV Thermal, ORC, and heat pump. A quaternary refrigerant mixture used in the ORC cycle to enhance the ORC efficiency is an environmentally sound refrigerant mixture composed of R152a, R245fa, R125, and R1234fy. It was shown that the efficiency of the hybrid system in question has been significantly dependent upon not only the solar radiation but also the nanofluids concentration and the type of nanofluid as well as the fluid temperature driving the ORC.*

This study demonstrates that the higher the magnetic field force in Gauss, the higher the thermal energy supplied to the waste heat boiler, which consequently results in higher power generated at the ORC. Also, the results showed that CuO outperforms the other nanofluids and water across the different magnetic fields in this investigation. It was observed that magnetized nanofluid CuO has the highest ORC efficiency and the highest hybrid system efficiency compared to other nanofluids under study, including water as the heat transfer fluid. The results observed in this paper on the hybrid system's efficiency and PV-Thermal solar panel efficiency are comparable to what has been published in the literature.

Keywords - *PV-thermal solar collector, Nanofluids, Organic Rankine Cycle, Heat pump, Modeling, Simulation.*

1. Introduction

Fossil fuel energy usage is considered the main cause of global temperature rise and global warming [1]. "Space and water heating represent a significant share of the overall energy consumption in the domestic and industrial sectors. Decarbonizing heat, though challenging, is acknowledged as having a key role in achieving emissions reduction targets and alleviating energy shortages and environmental deterioration". Novel, highly efficient heating technologies have been developed from applications in regions with colder climates and higher heating demands. Thermally driven heat-pumping technologies are promising solutions to meeting energy-efficiency targets by increasing the effective Heat-to-Fuel Ratio (HFR) of heating systems. However, despite these promising technologies being energy-efficient, they still require electricity produced by fossil fuels and contribute to global warming and carbon. Emissions.

Solar energy is regarded as a favorable and clean renewable energy resource. "Solar energy is clean and the most abundant energy source available around the globe. Sami [1-7] recently, reported on Photovoltaic-thermal (PV/T) technology and its different applications use. The concept of a PV/T system was first introduced by Florschuetz [8] in the early seventies of the 20th century and since then significant developments have been made to improve the designs of PV/T systems". A typical "solar PV-T module is composed of a PV solar panel integrated with a thin-tube solar thermal collector, that recovers the wasted thermal energy from the PV panel dissipated to the ambient and transfers it to the heat transfer fluid circulating in the welded thin-tube heat exchanger." The PV/T system also generates electricity and thermal energy simultaneously. A PV-Thermal solar collector can be used as the heat source to drive an Organic Rankine cycle (ORC) for power generation.

Kosmadakis et al. [10] reported on the combination of PV solar collectors' silicon cells integrated ORC operating with R-245fa at an evaporation temperature of 90 °*C* and 130 °*C*. Their research concluded that there is a potential benefit in both efficiency and electricity cost of a CPV-ORC system, compared with a CPV system operating alone. This concept was pursued further to increase the performance efficiency and combination of PV and ORC parameters to achieve the best-integrated system.

Reference [11] presented the theoretical analysis of the thermal solar energy-driven ORC by stationary solar collectors. Different working fluids are considered for the ORC with four different models of solar collectors (flat plate collectors, compound parabolic collectors, and evacuated tube collectors) at different operating conditions of the solar ORC, including a direct vapor generation configuration and also with water as heat transfer fluid circulating in the solar collector.

A review paper by Loni et al. [12] discusses the principles of solar-ORC systems. Various solar thermal-ORC technologies are investigated, flat plate collectors, evacuated tube collectors, compound parabolic collectors, parabolic trough collectors, linear Fresnel reflectors, dish concentrators, and solar towers on simulated experimental investigations. Hybrid systems and different thermal storage techniques are also included. The research work concluded that the development of trigeneration and polygeneration systems with ORC subsystems is promising.

This study published by Sami [13] investigates the enhancement effect and “characteristics of nanofluids; Al2O3, CuO, Fe3O4, and SiO2 used in PV Thermal, ORC, and cooling coil capabilities. It was found that the efficiency of the hybrid system in question is significantly dependent upon not only the solar radiation but also the nanofluids concentration and the type of nanofluid as well as the fluid temperature driving the ORC”.

Higher hybrid system efficiency has been overserved with nanofluid CuO and also enhanced the higher cooling effect produced compared to the other nanofluids under investigation. The results observed that the hybrid system efficiency was comparable to what has been published in the literature.

Another paper reported by Sami [14] analyzes the behavior of “magnetized nanofluids in PV Thermal integrated Organic Rankine Cycle, ORC, with cooling capabilities, that intended to investigate the enhancement effect of the magnetized nanofluids, AI2O3, CuO, Fe3O4, and SiO2, on the performance of the hybrid system composed of PV Thermal, ORC, and its cooling capabilities”.

A special low-temperature environmentally sound quaternary refrigerant mixture was used in the ORC cycle that is designed and formulated to enhance the ORC efficiency. It has been shown that the enhancement of the efficiency of the hybrid system in question is significantly dependent upon not only the solar radiation but also the magnetized nanofluids and their concentrations and the type of nanofluid as well as the fluid temperature driving the ORC.

Different types of different nanofluids are considered for use in the solar PV-Thermal to improve its efficiency. Research work reported in the literature [2-7, 13 -14] discusses the Organic Rankine Cycle, ORC, driven solar PV-Thermal, and different nanofluids as heat transfer fluid to drive the waste heat boiler of ORC is worth consulting for interested readers in the subject matter.

Nowadays, the organic Rankine cycle (ORC) has become an important technology for recovering waste heat and heat from renewable heat sources for improving thermal performance. This technology is mainly used for low-temperature and low-grade energy resources [13-25]. ORC can be integrated with different working thermal power plants such as a combined gas-steam power plant, a solar-integrated combined cycle, a solid oxide fuel cell, geothermal, biomass, or a combination of these hybrid power plants to be used as a heat source to ORC.

Yu et al. [20] studied a systematic scheme to determine the optimal operating conditions of the integration system of the organic Rankine cycle (ORC) and heat pump for the low-temperature waste heat recovery system. His case study, adopted from the literature, demonstrates the potential benefits of the integration of heat pumps and ORCs. The results showed that the net power output_and the amount of waste heat recovered increased by 9.37% and 12.04%, respectively. They concluded that when the critical temperature of the working fluid is lower than the inlet temperature of the waste heat source and the ratio of latent to sensible heat is small, the Cop is improved; thus, the integration process is profitable.

References [7,21] declared that thermal conductivity increased with temperature when suspended with nanostructure Al_2O_3, CuO, and water were used. The results of their study showed that the cooling fluid, which contains smaller particulate nanoparticles (CuO), shows a thermal conductivity greater than the larger particles.

Furthermore, A.H.A. Al-Waeli et al. [22] concluded that among these seven mechanisms, thermophoresis and Brownian diffusion can be considered the most important. The study also showed clearly that nanoparticles move homogeneously with fluid in the presence of turbulent eddies, so their negative impact on the density of disturbance is doubtful.

This research work focuses on the performance inherent parameters of a novel concept of such a hybrid system and the hybrid system efficiency as well as the heating/cooling effect produced by the heat pump. The study represents a new contribution that is hardly addressed in the literature and implements a numerical finite difference model based on conservation equations to predict the inherent parameters of the system and their impact on the system's performance.

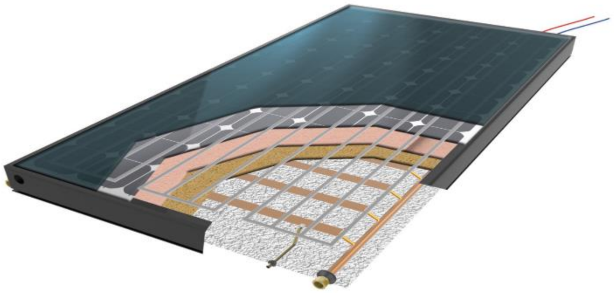

Fig. 1 PV -Thermal solar collector [14,31].

2. Mathematical Model

The hybrid system under consideration is shown in Figure.1 The system is composed of a PV-Thermal solar collector (Figure 1) driving a low-temperature Organic Rankine Cycle (ORC); the return of the condenser to the waste heat boiler of the ORC, feeds the condenser of the heat pump, as shown in Figure 1-a. The solar radiation was absorbed by the PV solar panels and converted into electricity and thermal energy. The latter is dissipated and heats the magnetized nanofluids heat transfer fluid that is used to drive the waste heat boiler of the ORC and generate vapor refrigerant. In the turbine, thermal energy is converted into kinetic energy and produces power at the turbine shaft and the generator.

The low-pressure refrigerant mixture vapor condensed liquid is pumped back to the waste heat boiler through the heat pump condenser, as illustrated in Figure 1. The hybrid system is self-powered, and the power generated by the ORC and the PV solar panels is used to drive the compressor of the heat pump, fans, and pumps and then the balance is fed to the grid. “The hybrid system is divided into several discrete control volumes and each one represents one of the system components. The mass and energy equations are written for each discrete control volume to describe the thermodynamic behavior of the hybrid system, including PV Thermal, ORC, and Heat pump”.

The quaternary refrigerant mixture circulates in the ORC loop is an environmentally sound quaternary mixture and composed of R512a, R125, R1234fy, and R245fa with a boiling temperature of −28.13 °F, a critical temperature of 220.67 °F at a critical pressure of 59.85 Psi. The thermodynamic and thermophysical properties of the refrigerant mixture were obtained at REFPROP [9].

The different “equations of mass and energy are written and integrated with the thermophysical equations of the magnetized nanofluids for each definite control volume element of the hybrid system. It is assumed in the model that the magnetized nanofluid heat transfer is homogeneous, isotropic, incompressible, and Newtonian, that inlet velocity and inlet temperature are constant, and that the thermophysical properties of the nanofluids” are constant.

2.1. Numerical Modeling

2.1.1. PV Thermal Model

The following thermal analysis is performed for the PV cell; however, it is assumed that all PV cells behave the same; therefore, it is applied to the PV solar panel. The heat absorbed by the PV solar cell can be calculated by the following [10-16],

$$Q_{in} = \alpha_{abs} G S_p \qquad (1)$$

Where;

α_{abs}: Overall absorption coefficient

G: Total Solar radiation incident on the PV module

S_p: Total area of the PV module

The solar photovoltaic panel is constructed of various modules, and each module consists of arrays and cells. The AC power is calculated using the following equation.

$$P(t) = \sqrt{3}\, \eta_{inv} V_{fn} I_o \cos\varphi \qquad (2)$$

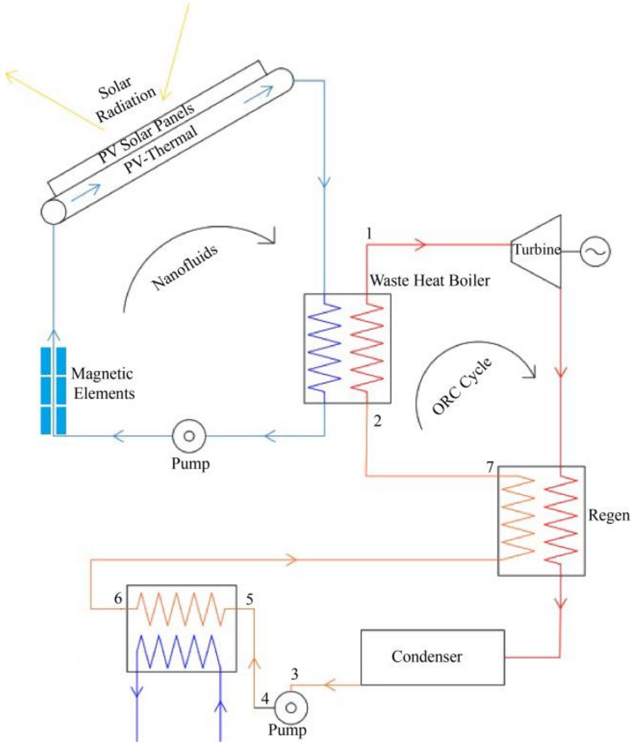

Fig. 1(a) PV-Thermal driven organic rankine cycle with heat pump

Where the inverter efficiency ηinv, output voltage between phases, neutral Vfn, and for single-phase current I_o and cosφ as follows [10-16];

2.1.2. Organic Rankine Cycle Model

The energy balance at the ORC cycle gives the following [6,7-19]:

$$W_{ORC} = m_{ref}(h_1 - h_2) \quad (3)$$

$$Q_{WHB} = m_{ref}(h_1 - h_4) \quad (4)$$

$$Q_{COND} = m_{ref}(h_2 - h_3) \quad (5)$$

$$W_{P_{ORC}} = m_{ref}(h_4 - h_3) \quad (6)$$

$$Q_{Cc} = m_{ref}(h_6 - h_5) \quad (7)$$

$$Q_{regcn} = m_{ref}(h_7 - h_6) \quad (8)$$

Where,

h_1: enthalpy at the outlet of the waste heat boiler (KJ/Kg)
h_2: enthalpy at the exit of the vapor turbine (KJ/Kg)
h_3: enthalpy at the condenser outlet (KJ/kg)
h_4: enthalpy at ORC pump outlet (KJ/kg)
h_5: enthalpy at the inlet of cooling/freezing coil (KJ/kg)
h_6: enthalpy at the outlet of cooling/freezing coil (KJ/kg)
h_7: enthalpy at the outlet of the regenerator (KJ/Kg)
m_{ref}: refrigerant mass flow rate (kg/s)

2.1.3. Heat Pump Model

$$Q_{evaporator} = m_{ref}(h_5 - h_6) \quad (9)$$

$$Q_{condenser} = m_{ref}\left(h_{1hp} - h_{2hp}\right) \quad (10)$$

$$W_{Compressor} = m_{ref}\left(h_{2hp} - h_{3hp}\right) \quad (11)$$

Where;

h_{1hp} and h_{2hp} represent enthalpies of refrigerant entering and leaving the heat pump condenser,

h_{2hp} and h_{3hp} are the refrigerant enthalpies entering and leaving the heat pump compressor,

Finally, due to the throttling process at the heat pump expansion valve enthalpies at the inlet and outlet are the same.

The ORC thermal efficiency is determined as follows.

$$\eta_{ORC} = (W_{ORC} - WP_{ORC}) / Q_{in} \quad (12)$$

The ORC-PV-Th and Heat Pump hybrid system efficiency can be calculated as follows:

$$\eta_{ORC-h} = \frac{W_{ORC} + p(t) - Wcompressor - W_{P_{ORC}}}{Q_{in}} \quad (13)$$

Where;

W_{ORC}: power produced by ORC (KW)
$p(t)$: PV solar output (kW) defined by equation (2)
Qcc: cooling coil thermal capacity (kW) and defined by equation (8)
$W_{P_{ORC}}$: pump power consumption (7)
$W_{compressor}$: Heat pump compressor power (11)
Q_{in}: solar radiation (kW) and defined by equation (1)

2.2. Nanofluid Heat Transfer Fluid

The thermophysical, thermodynamic, and heat transfer properties of nanofluids are determined in terms of specific heat, thermal conductivity, viscosity, and density using the law of mixtures and the volumetric concentration of the nanoparticles as per the following equation [15, 17, 18, 31].

$$\alpha_{\text{total}} = \alpha_{\text{particles}} + \alpha_{\text{base fluid}} \quad (14)$$

Where α represents the thermophysical property of a particular nanofluid.

The nanofluid thermal and thermophysical properties, α_{total}, can be calculated as follows.

$$\alpha_{\text{total}} = \alpha_{\text{base fluid}} + \alpha_{\text{particles.}} (\Phi) \quad (15)$$

Where Φ represents the nanoparticles' volumetric concentration.

The thermal conductivity to thermal diffusivity and density of the nanofluids are related as follows [16-18}.

$$\lambda = \alpha\ \delta\ C_p \quad (16)$$

Where Cp is the specific heat, α is the thermal diffusivity, ʎ and ρ represent the thermal conductivity and density, respectively.

Interested readers in further details about the calculations of the nanofluid's thermophysical and thermodynamic properties are advised to consult references [2-7, 19-20, 22-24].

These references discuss the impact of the nanofluids concentrations on the thermophysical properties of the said nanofluids. Moreover, the scope of this study is to discuss the MSF process using the PV-Thermal with magnetized nanofluids as heat transfer fluids.

2.3. Magnetized Nanofluids

Equations (14) through (16) can be used to determine other thermophysical properties such as α is the thermal diffusivity, ʎ, and ρ represent the thermal conductivity and density as different magnetic forces Gauss published in the literature properties ([4] through [6]) as a function of the properties outlined in the Table.1

Table 1. Thermophysical properties of magnetized nanofluids

	Ai_20_3	CuO	Fe304	SiO_2
$C_{p\ nf}$	b = 0.1042a + 6226.5	b = 0.2011a + 5730.8	b= 0.8318a + 4269.8	b = 0.6187a + 4293.2
K_{nf}	b = 2E-05a + 1.4888	b = 5E-05a + 1.3703	b= 0.0002a + 1.0209	b = 0.0001a + 1.0265
h	b = 0.0031a + 73.092	b = 0.0031a + 73.073	b = 0.003a + 73.225	b = 0.003a + 73.231

Where "b" represents the nanofluid-specific property and "a" is the magnetic field force in Gauss. C_{pnf}*, Knf, and h are the specific heat, thermal conductivity, and heat transfer coefficients of nanofluids.*

3. Numerical Procedure

The mass and energy conversion equations in the aforementioned hybrid system with integrated ORC and heat pump cooling have been described by Equations (1)-(16) and were programmed and solved. The calculation starts with the input of the independent parameters of the PV-Thermal solar panel, heat transfer fluid circulating in the thin thermal tubes welded to the PV solar collector and driving the ORC using the magnetized nanoparticles; Al_2O_3, CuO, Fe_3O_4, and SiO_2, Gauss magnetic force, and quaternary refrigerant mixture in the heat pump; R152a, R245fa, R125, and R1234fy. The system equations were integrated into the finite-difference formulations to determine the behavior of the process shown in Figure 1. Iterations were performed using MATLAB iteration techniques until a converged solution was reached with less than 0.05. With the known values of solar radiation, the mass flow rate of the nanofluid was determined. Then, the thermophysical properties and the heat transfer characteristics of the base fluid, water, and magnetized nanofluids at different concentrations were determined and followed by calculations of the parameters describing the behavior of PV-Thermal solar panels, ORC and the heat pump components at different conditions. Finally, the hybrid system efficiencies were calculated.

4. Discussion and Analysis

The system of equations (1) through (16) has been numerically solved in finite-difference formulation for predicting the hybrid system performance using magnetized nanofluids at different concentrations, solar radiations, Gauss magnetic field forces, and water as base heat transfer fluid. Equations (1) through (4) have been solved to predict the PV dynamic total power generated, thermal energy dissipated by the PV solar panels, and efficiencies in terms of the key parameters of a photovoltaic-thermal solar panel.

As reported and discussed by Sami and others ([13] through [16]), it is evident from the results presented on the dynamic PV-Thermal studies that the higher the solar radiations, the higher the thermal and hybrid efficiencies and the hybrid efficiency exhibits lower values than the PV-Thermal efficiency due to the PV solar panel efficiency is significantly lower than the thermal efficiency of the heat exchanger. Also, it was reported in these references that the higher the solar radiation, the accelerated increase in the PV cell temperature, and subsequently, the higher the solar radiation, the higher the PV power and PV amperage, as shown in Equation (1). After that, the designer of the PV panel and its modules and the cell temperature must take into consideration solar radiation as well as the ambient conditions.

Also, it was shown in Figure. 2 that PV-Thermal flow rate outlet temperatures of the magnetized nanofluids, such as Ai_2O_3 CuO, Fe3O4, and SiO_2, have been enhanced with the increase of the Gauss magnetic force. Also, other results obtained during this research work have shown that this temperature increased at higher concentrations of the magnetized nanofluids and higher solar radiation.

When a magnetic field is applied to the magnetized nanofluid, and there is a temperature gradient (temperature difference) within the fluid, the aligned magnetic particles can induce fluid flow through a phenomenon called magnetohydrodynamic convection. This induced flow can significantly enhance heat transfer by promoting mixing and convective heat exchange within the fluid.

Examining the results presented in Figures 3 and 4 suggest that the higher the magnetic field force, the higher the magnetized nanofluid heat transfer fluid flow generated by the solar PV-Thermal panels that drive the waste heat boiler of the ORC, where the refrigerant is evaporated to drive the ORC turbine generator.

In particular, Figure 4 demonstrates that the higher the magnetic field force in Gauss, the higher the thermal energy supplied to the waste heat boiler, and consequently results in higher power generation at the ORC. This can be interpreted that magnetic nanoparticle materials exhibit a phenomenon known as magnetic heating or hyperthermia. When these materials are exposed to a changing magnetic field, the magnetic moments of the atoms within the material align themselves with the field.

This process involves the absorption of energy from the magnetic field, and it can increase temperature. The alternating magnetic field induces electric currents within the material, leading to resistive heating due to the material's electrical resistance. This phenomenon, as displayed in Figure 4, showed that the magnetized nanofluid CuO outperforms the other nanofluids and water across the different magnetic field values in this investigation. This finding has also been observed, namely by Sami [2] and others reported in the literature under different nanofluid concentrations and solar radiation conditions.

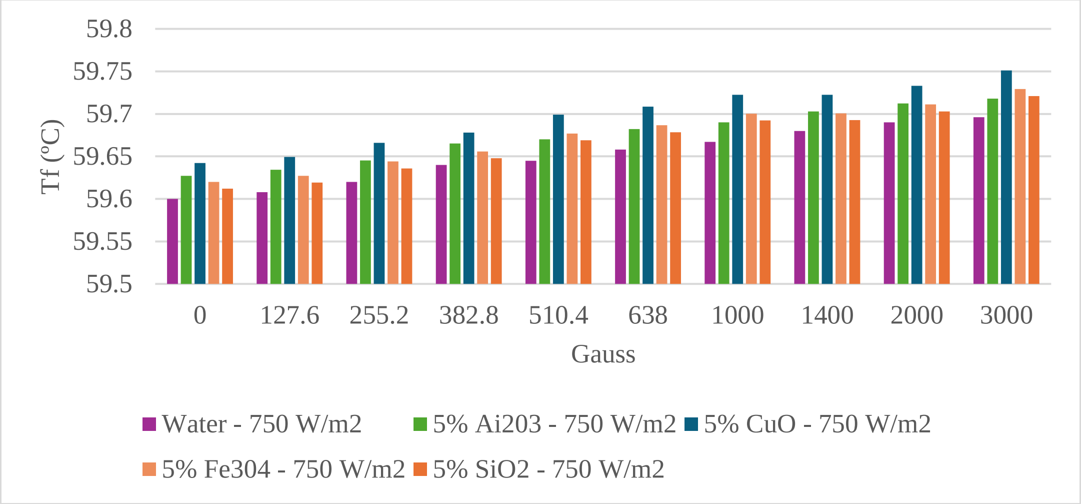

Fig. 2 PV-Thermal flow rate outlet temperatures

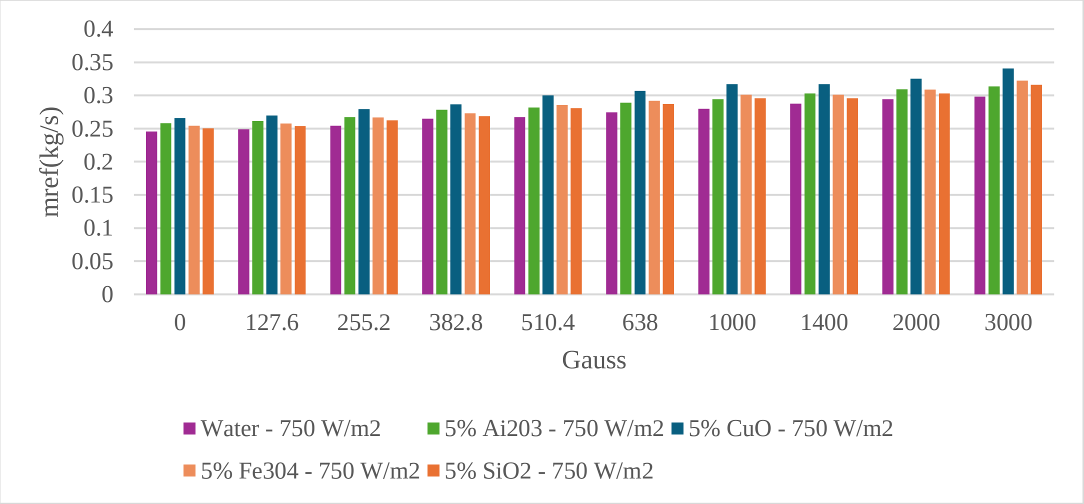

Fig. 3 PV-ORC Quaternary Refrigerant Mixture Mass Flow Rate rates

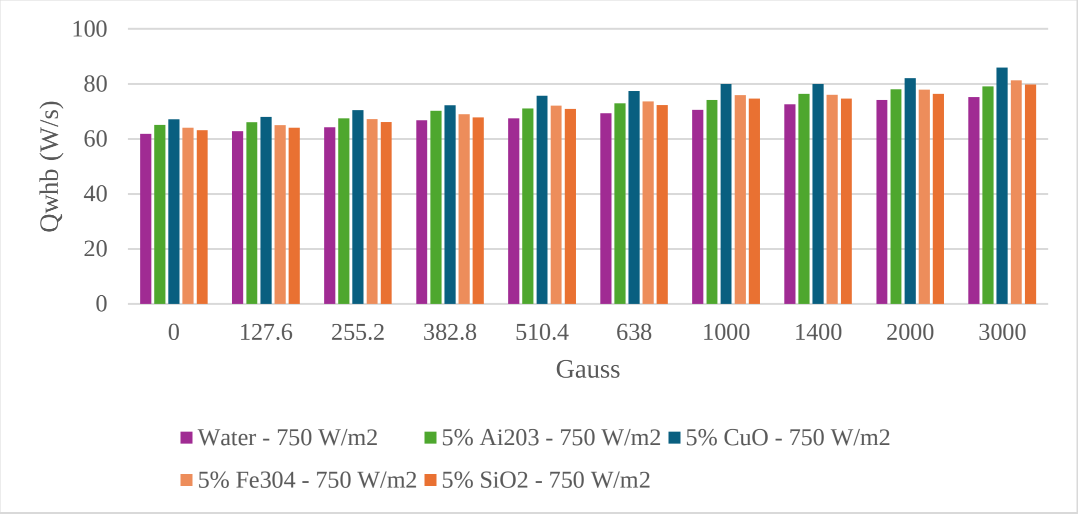

Fig. 4 ORC Waste heat boiler thermal energy

The predicted results of the power produced using the ORC simulations model are presented in equations (3) through (8) with the quaternary refrigerant mixture environmentally sound refrigerant mixture composed of R152a, R245fa, R125, and R1234fy, and displayed in Figures 4 through 6, at different solar radiations, clearly showed the use of magnetized nanofluids has impacted the thermal energy supplied to the waste heat boiler of the ORC, the magnetic field force and the nanofluids concentrations. Also, it can be observed from the data displayed in these figures that the magnetized nanofluid CuO as heat transfer fluid has superior thermal absorption of thermal energy performance compared to the other nanofluids under consideration, including the water as base heat transfer fluid.

In addition, as illustrated in Figure. 6, enhancing more refrigerant evaporation at the waste heat boiler of the ORC, consequently producing more output work by the ORC cycle. Also, it can be seen from the data displayed in this figure that the magnetized nanofluid CuO as heat transfer fluid produced more output work at the ORC turbine's generator. The aforementioned findings demonstrate that the magnetized nanofluid CuO as heat transfer fluid has higher absorption rates of thermal energy. The magnetic field is involved in the transfer or absorption of energy, which can manifest as an increase in temperature and consequently produce more output work at the ORC turbine's generator. Also, data presented in Figure 6 showed that the higher the magnetic field forces the higher the power generated at the turbine generator. This is attributed to magnetized nanofluids, which are nanometer-sized magnetic particles suspended in a fluid and can enhance heat transfer through a phenomenon known as magnetohydrodynamic (MHD) convection. When a magnetic field is applied to the nanofluid, the magnetic particles within the fluid align themselves along the direction of the magnetic field. This alignment creates chains or structures within the fluid, altering its thermal conductivity and flow behavior. This enhanced thermal conductivity leads to better heat transfer rates compared to conventional fluids.

Magnetohydrodynamic Convection: When a magnetic field is applied to the magnetized nanofluid, and there is a temperature gradient (temperature difference) within the fluid, the aligned magnetic particles can induce fluid flow through a phenomenon called magnetohydrodynamic convection. This induced flow can significantly enhance heat transfer by promoting mixing and convective heat exchange within the fluid. By adjusting the magnetic field strength and direction, researchers can manipulate the alignment of magnetic particles. Interested readers in this subject matter are advised to consult references [2-4] and, very recently, Philip [26].

The efficiency of the ORC is determined by equation (12) and displayed in Figure 7 at solar radiation of 750 W/m^2 with 5% nanofluid concentration. As predicted, higher efficiencies were encountered with the nanofluid CuO compared to the other nanofluids under investigation. This is quite expected as with the nanofluid CuO, more thermal energy is transferred to the refrigerant mixture in the waste heat boiler, resulting in higher refrigerant flow and, consequently, higher power generated at the turbine generator and higher ORC efficiency. This was also observed under other different solar radiations and other nanofluids concentrations. Furthermore, as demonstrated in Figure 7, the higher the magnetic force, the higher the ORC efficiency. Thus, to maximize the ORC efficiency it's highly recommended to use the nanofluid CuO and the maximum magnetization force.

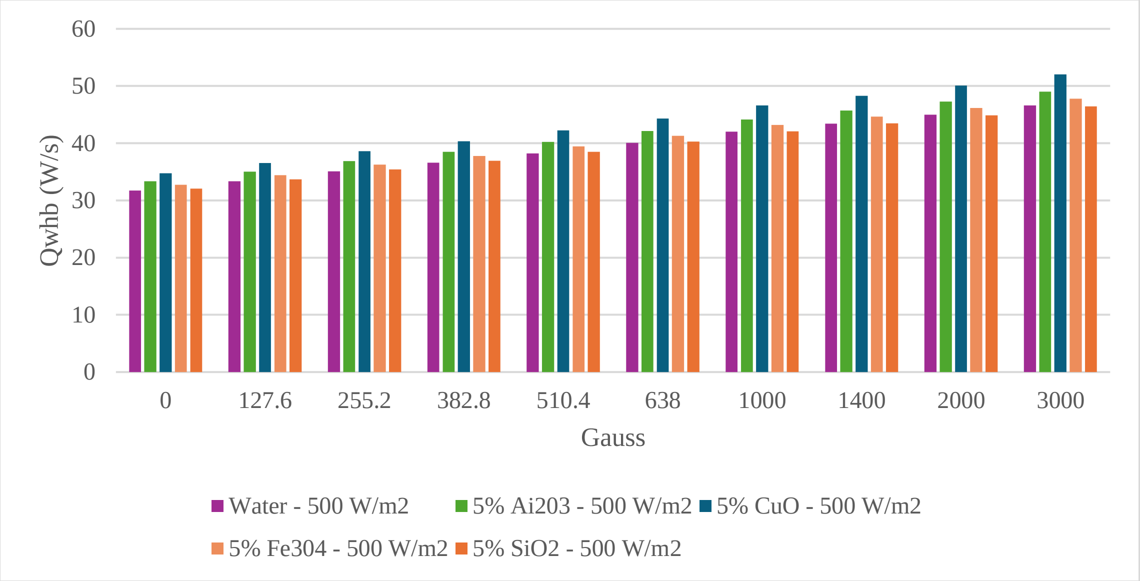

Fig. 5 PV-Thermal ORC driven thermal energy

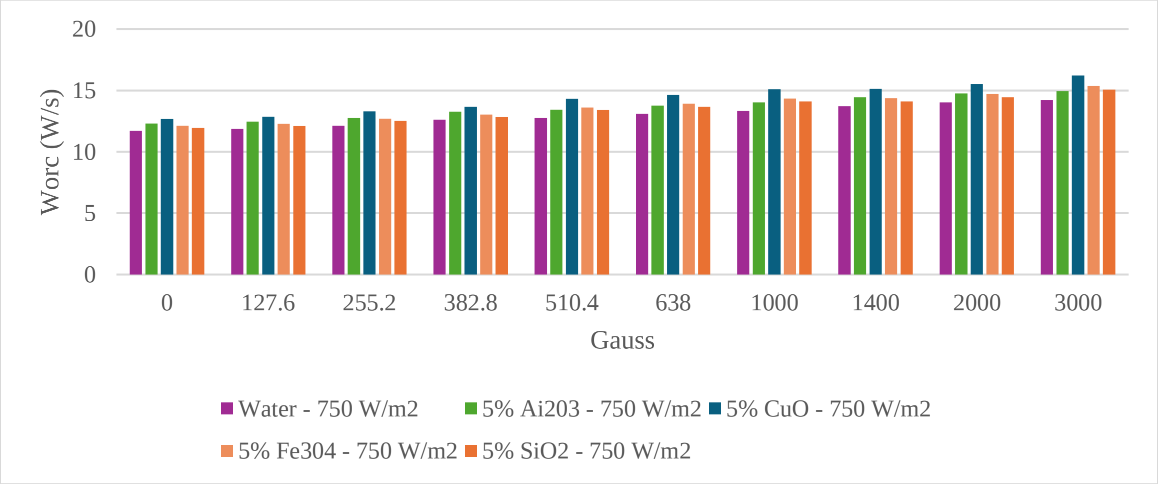

Fig. 6 ORC output power

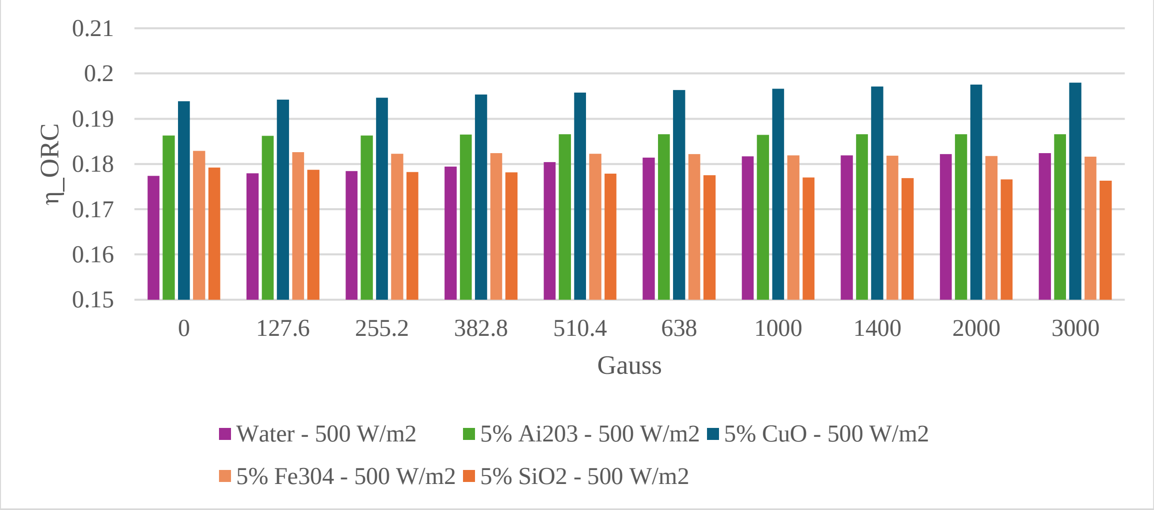

Fig. 7 Efficiency of ORC

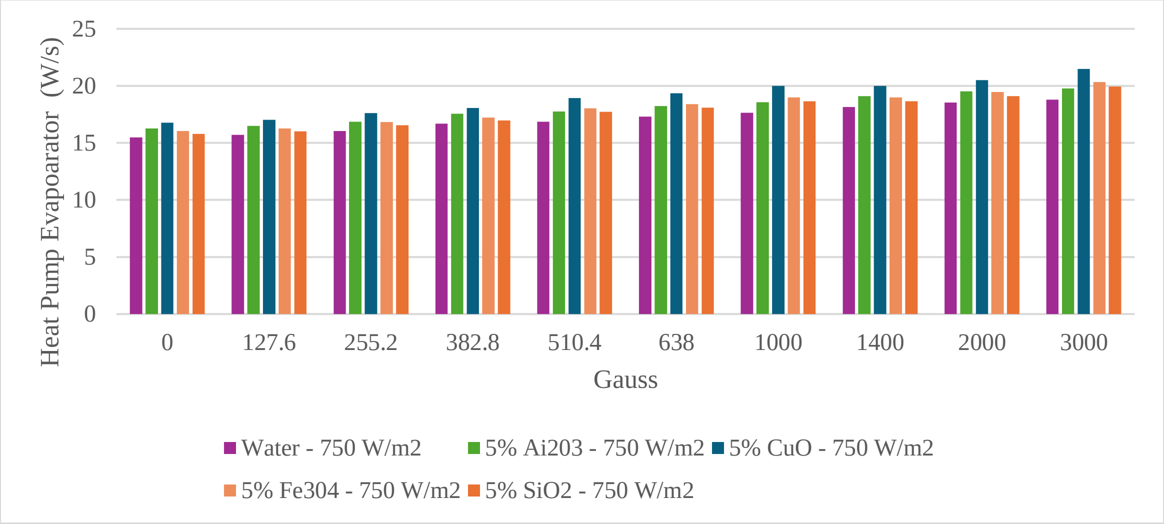

Fig. 8 Heat pump evaporator thermal capacity

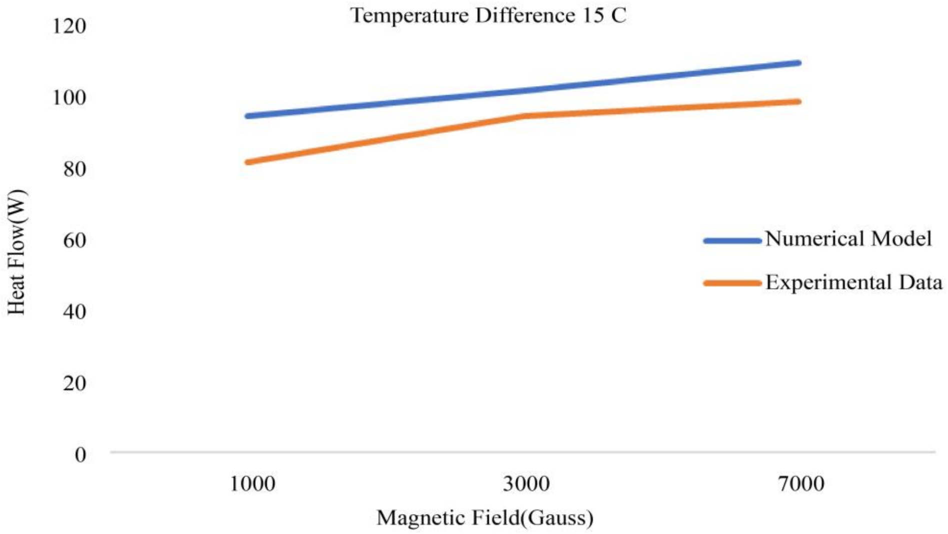

Fig. 9 Comparison between the Experimental data and the present model

5. Model Validation

Reporting in the literature on the PV-Th, magnetic fields, and nanofluids is extremely rare. The thermal energy to drive the waste heat boiler of the ORC was calculated using Equation (4) under a magnetic field up to 3000 Gauss and with nanofluids as heat transport fluid and compared to experimental data reported in the literature. The data reported by references [27] through [30] on Fe_3O_4 nanofluid were considered under the different magnetic fields up to 7000 Gauss and at a temperature difference of 15 °C and presented in Figure. 9. It was reported by Joubert [29] that the stability of the results under a magnetic field was found to be less certain for nanofluids at a lower volume concentration, coupled with the possibility of higher settlement rates due to the additional magnetic force on the nanoparticles. The Fe_3O_4 nanofluid as heat transport fluid used in his study had a 0.1% volume concentration. The results of our model prediction compared fairly with the data of reference [29] at similar conditions as shown in Figure 9. The comparison in this figure showed some discrepancy that varied from 8% to 14% between the model and the experimental data of reference [29], particularly at higher magnetic fields. We feel that these discrepancies stemmed from the fact that the heat transfer coefficient under the magnetic field and the thermophysical properties of Fe_3O_4 reported by Goshayeshi, H.R.; Chaer, [30], and used in this simulation, as well as the PV–thermal heat transfer efficiency, were not fully disclosed for each nanofluid concentration by references [27] through [30].

6. Conclusion

In this study, the numerical integration describing an ORC and a heat pump driven by solar PV-Thermal is investigated, presented, and validated. This study was carried out to investigate the enhancement effect of using Magnetized nanofluids Al_2O_3, CuO, Fe_3O_4, and SiO_2 on the performance of the hybrid system composed of PV Thermal, ORC, and heat pump. A quaternary refrigerant mixture used in the ORC cycle to enhance the ORC efficiency is an environmentally sound refrigerant mixture composed of R152a, R245fa, R125, and R1234fy. It was shown that the efficiency of the hybrid system in question has been significantly dependent upon not only the solar radiation but also the nanofluids concentration and the type of nanofluid as well as the heat transfer fluid temperature driving the ORC.

Results also showed that the proposed integrated system's efficiency increased, and the output power produced has been enhanced with the use of nanofluids. It was demonstrated that higher solar radiations have a significant impact on heat transfer fluid flow rates and system performance. Our findings demonstrated that the magnetized nanofluid CuO as heat transfer fluid has higher absorption rates of thermal energy when the magnetic field is implemented in the heat transfer process or the absorption of energy. This manifested an increase in the heat transport fluid's temperature and consequently produced more output work at the ORC turbine's generator. However, at low solar radiations, the magnetized nanofluid-based CuO heat transfer flow rates were increased over the water-based ones. Also, it has been shown that the higher the concentration of the nanofluid CuO the higher the thermal energy input compared to the heat transfer fluid-based water, and the same observation was noted for the coefficient of performance of the system. The predicted results of our model compared fairly with the data reported in the literature at similar conditions.

7. Acknowledgment

The research work presented in this paper was made possible through the support of TransPacific Energy Inc. The authors are indebted to all contributors for help in the computation and programming of this model.

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