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Original Article

The Behavior of Magnetized PV-Th Integrated Organic Rankine Cycle ORC with Cooling Capabilities

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Abstract *- This paper analyzes the behavior of magnetized nanofluids in PV Thermal integrated Organic Rankine Cycle, ORC, with cooling capabilities. This study is 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 cooling capabilities. A special quaternary refrigerant mixture was used in the ORC cycle to enhance the ORC efficiency, which is environmentally sound. 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.*

Keywords *- PV-Thermal solar collector, Nanofluids, Magnetic field, Organic Rankine Cycle, Cooling, Modelling, Simulation.*

I. INTRODUCTION

Organic Rankine cycles (ORC) have received significant consideration in recent years because this cycle can operate at low pressures and temperatures in comparison to the conventional Rankine cycle and especially from low-grade heat sources because it uses refrigerants as working fluids [1-4]. “Recently, solar parabolic collectors as low-grade thermal energy sources have received great attention to driving ORCs for power generation mainly near industrial installations and rural areas without the necessity for connection to the grid to avoid high cost. Disadvantages of parabolic solar ORCs are comparatively high costs and low thermal efficiency mainly because of low heat transfer fluids temperature in the solar collector” [5-10].

Recently, nanofluids are colloidal suspensions of nanoparticles in fluids, “have been suggested as potential heat transport fluids to drive organic Rankine cycle power systems due to their enhanced thermal, thermophysical properties and enhanced heat transfer. However, higher concentrations of nanofluids can cause an increased pressure drop in heat exchangers and friction losses. Thus, the impact of the nanoparticles on the heat transport fluid thermophysical properties must be carefully analyzed “ before implementation [11-13].

Excess thermal energy is generated due to the inherent conversion efficiency process limitation of the PV cell. “It has been shown that the higher the solar radiation results in the higher temperature of the PV cell and higher the excess thermal released from the PV solar panels. This, in turn, reduces the conversion efficiency of the cell and the solar PV panel. With the use of cold-water flow through the thermal tubing underneath the PV cell, this excess thermal energy can be recovered for a useful purpose. This process reduces the PV cell temperature and enhances the energy conversion efficiency of the PV solar panels” [9-12].

A theoretical investigation of a new configuration of the combined power and cooling cycle known as the Goswami cycle of ammonia as a refrigerant has been reported in the literature [15-18]. “A comprehensive analysis was conducted to determine the effect of key operating parameters such as ammonia mass fraction at the absorber outlet and boiler-rectifier on the power output, cooling capacity, effective first efficiency, and effective exergy efficiency. Also, Guzmán et al. [9] showed that the new dual-pressure configuration generated more power than the single pressure cycle. However, the results also showed that the new dual-pressure configuration reduced the cooling output as there was less mass flow rate in the refrigeration unit”.

A review of three cycles, namely the Organic Rankine cycle, Kalina cycle, and Goswami cycle, and various works on them has been reported in the literature [15]. “This research work was performed by different authors on optimization of the cycles and introduction of new efficient cycles. The selection of heat transport fluids, three cycles, namely Kalina Cycle, Goswami Cycle, and Organic Rankine cycle (ORC), has been optimized by different authors using different types of fluids, and their reviews are concluded in this reference [10]. This paper presented the electricity generation from low-grade heat sources such as solar thermal, geothermal, and industrial waste heat using different cycles, mainly ORC, Goswami Cycle, and Kalina Cycle". In addition, the authors presented an analysis of the different thermodynamic cycles for a combined power plant using low-grade heat sources are reviewed. The Different thermodynamic cycles reported in this reference using low-grade heat sources for the combined power plant were also reviewed.

The paper review presented by Kosmadakis et al. [19] was concerned with presenting the recent studies dealing with cooling the photovoltaic thermal (PVT), concentrated photovoltaic thermal (CPVT), and other solar systems using nanofluids. In addition, "the paper considered the definition of nanofluids, nanoparticle types, nanofluid preparation methods, and thermophysical properties of the most common nanoparticles and base fluids. Moreover, the major factors which affect the nanofluid's thermal conductivity according to the literature have been reviewed". Kosmadakis et al. [19] presented a detailed experimental investigation of a small-scale low-temperature Organic Rankine cycle (ORC) using refrigerant R-404A. "The tests were conducted at laboratory conditions to evaluate the main components at both design and off-design conditions, for variable heat input to 48 kWth and hot water temperature in the range of 65-100 ◦C. A reverse scroll compressor was used, and a dedicated helical coil heat exchanger was also installed, suitable for high-pressure and temperature operation. The ORC's pump was a diaphragm one and was coupled with an induction motor. The rotational speeds of both expander and pump were controlled with frequency inverters to have full control of the engine operation. The ORC was then connected with concentrating PV/ thermal collectors, which produced electricity and heat and drove the ORC. These field tests were focused on the performance of the whole ORC unit and its power contribution. The tests have revealed that such a low-temperature ORC unit can have adequate efficiency and that it can be coupled with a solar field to increase the power production of the integrated system".

Recently a paper published by Sami [13] discussed the performance of nanofluids in a PV Thermal-driven Organic Rankine Cycle (ORC) with cooling capabilities. This study was intended to investigate the enhancement effect and characteristics of nanofluids, Al2O3, CuO, Fe3O4, and SiO2, on the performance of the hybrid system composed of PV Thermal, ORC, and cooling coil. "The 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 enhancement of 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. A higher hybrid system efficiency has been overserved with nanofluid CuO. Moreover, it has also been shown that, on average, the hybrid system efficiency was higher by 17% with nanofluid CuO compared to water as the heat transfer fluid. In addition, it was also observed that the higher cooling effect produced is significantly increased with the use of the nanofluid CuO compared to the other nanofluids under investigation and water as heat transfer fluid. The results observed in this paper on ORC efficiency and PV solar panel efficiency are comparable to what has been published in the literature".

The literature review demonstrated that research reported in the literature was focused on ORC only driven by water-based heat transport fluids and rarely by nanofluids fluids; however, none was reported on magnetized nanofluids driven ORCs. Therefore, this study is condider5ed as a new contribution to the ORCs driven by nanofluids.

The research work presented hereby is intended to study and present a new concept of a hybrid system using an Organic Rankine Cycle ORC with built-in cooling capabilities driven by PV-Thermal solar panels and magnetized nanofluids. This research work focused in particular on the performance inherent parameters of the new concept system, such as the hybrid system efficiency, power generated, ORC efficiency, and the cooling effect produced. The study implements a numerical finite-difference model based upon the conservation energy and mass equations to predict the inherent parameters of the hybrid system and their impact on the system performance.

II. MATHEMATICAL MODEL

The mathematical model presented hereby was established based on the mass and energy equations written to describe the behavior of the nanofluids circulating in the PV thermal solar collectors, driving an Organic Rankine Cycle, ORC, with a quaternary refrigerant mixture as shown in Figure 1. The solar radiation is absorbed by the PV solar panels and converted into electricity and thermal energy. The latter is dissipated and heats the nanofluids heat transfer fluid that is used to drive the waste heat boiler of the ORC and generate vapour refrigerant. In the turbine, the thermal energy is converted into kinetic energy and produces power at the turbine shaft and the generator. The low-pressure vapour exiting the turbine is condensed in the condenser into liquid and pumped back to the waste heat boiler through the cooling/freezing coil and the regenerator, as illustrated in Figure.1. The refrigerant mixture that circulates in the ORC loop is an environmentally sound quaternary mixture composed of R512a, R125, R1234fy, R245fa with a boiling temperature of -28.13 F, the critical temperature of 220. 67 F at a critical pressure of 59.85 Psi. Thermodynamic and thermophysical properties of the refrigerant mixture were obtained at REFPROP [23].

In the following sections, the different equations of mass and energy are written and presented for each definite control volume element of the nanofluids loop and ORC cycle presented. It is assumed in the model that the nanofluid is homogeneous, isotropic, incompressible, and Newtonian; that inlet velocity and inlet temperature are constant; and that the thermophysical properties of the nanofluids are constant.

A. 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 [6-10, 16-18],

$$Q_{in} = \alpha_{abs} G S_p \tag{1}$$

Where;
α_{abs}: Overall absorption coefficient
G: Total Solar radiation incident on the PV module
S_p: Total area of the PV module

Meanwhile, the PV cell Temperature is computed from the following heat balance;

$$mC_{p\_module} \frac{dT_C}{dt} = Q_{in} - Q_{conv} - Q_{elect} \tag{2}$$

Where;
T_C: Pv Cell Temperature
mC_{p_module}: Thermal capacity of the PV module
t: time
Qin: Energy received due to solar irradiation
Qconv: Energy loss due to Convection
Qelect: Electrical power generated

And the Solar energy absorbed by the PV cell, Qin, is given by equation (1).

a) PV Model

The solar photovoltaic panel is constructed of various modules, and each module consists of arrays and cells. The AC power is calculated using the inverter efficiency η_inv, output voltage between phases, neutral V_fn, and for single-phase current I_o and cosφ as follows [8, 9, 10];

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

b) Organic Rankine Cycle Model

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

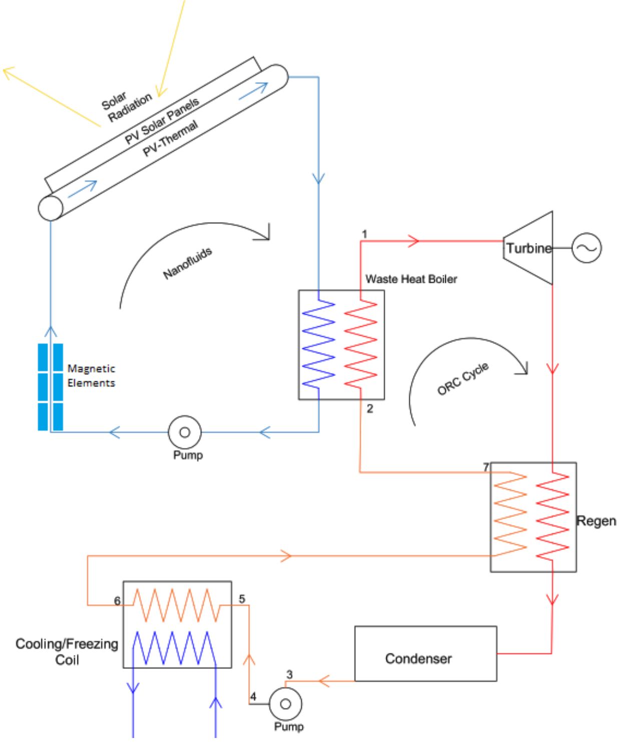

Fig. 1 Organic rankine cycle with magnetized nanofluids for cooling capability

$$W_{ORC} = m_{ref}(h_1 - h_2) \tag{4}$$

$$Q_{WHB} = m_{ref}(h_1 - h_4) \tag{5}$$

$$Q_{COND} = m_{ref}(h_2 - h_3) \tag{6}$$

$$W_{PORC} = m_{ref}(h_4 - h_3) \tag{7}$$

$$Q_{Cc} = m_{ref}(h_6 - h_5) \tag{8}$$

$$Q_{regcn} = m_{ref}(h_7 - h_6) \tag{9}$$

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 regenerator (KJ/Kg)
m_{ref}: refrigerant mass flow rate (kg/s) the ORC thermal efficiency is determined as follows;

$$\eta_{ORC} = (W_{ORC} - WP_{ORC}) / Q_{in} \tag{10}$$

The ORC-PV hybrid system efficiency can be calculated as:

$$\eta_{ORC-h} = \frac{W_{ORC}+p(t)+Q_{cc}-W_{P_{ORC}}}{Q_{in}} \qquad (11)$$

Where;

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

B. Magnetized Nanofluids

The thermophysical and thermodynamic properties of nanofluids, such as specific heat, thermal conductivity, viscosity, and density, using the law of mixtures in terms of the volumetric concentration of nanoparticles [21-22];

$$\alpha_{\text{total}} = \alpha_{p} \quad \alpha_{\text{total}} = \alpha_{\text{particles}} + \alpha_{\text{base fluid}} \qquad (12)$$

Where α represents a particular thermophysical property of the nanofluid under investigation.

The nanofluid thermal and thermophysical properties, α_{total}, can be calculated as follows [9-13]

$$\alpha \quad \alpha_{\text{total}} = \alpha_{\text{base fluid}} + \alpha_{\text{particles}}(\Phi) \qquad (13)$$

Where Φ represents the nanoparticle's volumetric concentration.

Other thermophysical nanofluids were calculated using the following relationship:

$$\lambda = \alpha\, \delta\, C_p \qquad (14)$$

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

This research considers that magnetic metallic solids under different magnetic forces Gauss because they exhibit significantly higher thermal properties compared to conventional heat transfer fluids. In the following, we present the formulas developed based upon the magnetic data published in the literature (12) properties ([9], [10], [20]); they were used to take into account the impact of the magnetic field as outlined in the table.1;

Table.1 Thermophysical Properties of magnetized nanofluids

	Ai203	**CuO**	**Fe304**	**SiO2**
Cp 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. Cpnf, Knf, and h are the specific heat, thermal conductivity, and heat transfer coefficients of nanofluids.

Equation (13) 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 a function of the properties outlined in Table.1

III. NUMERICAL PROCEDURE

Figure.2 presents the energy conversion process encountered in the PV-Th panels, integrated ORC, and cooling described by equations (1) through (14) that have been programmed and solved according to the logical diagram in this figure. The calculation starts with the input of the parameters of the PV-Thermal solar panel, thermal tubes, and characteristics of the nanoparticles; AI2O3, CuO, Fe304, and SiO2 and water as the heat transfer fluid. The system equations have been integrated with 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 the solar radiation, the mass flow rate of the nanofluid circulating in the thin tubes welded to the PV solar collector is determined. Then the thermophysical properties and the heat transfer characteristics of the base fluid, water, and nanofluids at different concentrations are determined. Then the parameters describing the behavior of PV-Thermal solar panels, ORC, and the cooling coil were determined under different conditions. Finally, the hybrid system efficiencies were calculated.

IV. DISCUSSION AND ANALYSIS

The system of equations (1) through (14) has been numerically solved in finite-difference formulation for the energy conversion process in the hybrid system of PV-Thermal solar collector, ORC with cooling capacity employing nanofluids; AI2O3, CuO, Fe304, and SiO2 at different concentrations and water as base heat transfer fluid. In the following sections, the predicted results were presented under different inlet conditions such as solar insolation, heat transfer fluid flow rates from the PV-Thermal loop, heat transfer fluid temperatures, and various nanofluids at different volumetric concentrations, 5%,10%, and 20%, however, only 5% was considered in this study. In the numerical simulation, 100 PV solar panels were assumed with 300 watts per PV solar panel. Solar radiations were taken as 500 w/m2, 750 w/m2, 1000 w/m2, and 1200 w/m2. The heat transfer fluid temperature varied from 176 ◦F to 212 ◦F. As reported in references [6] through [10], calculations using equations (1) through (4) yielded the efficiency of the PV solar panels used in this study varies between 19-23% depending upon the solar radiation that varies between 500 w/m2 to 1200 w/m2. These values were considered in this study. The heat transfer fluid flow rate circulating in the loop driving the waste heat boiler of the ORC varied between 8.89 GPM (4208 lb/hr) to 22.6 GPM (10550 lb/hr) at temperatures varying between 176 ◦F to 212 ◦F. The 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 [6]. The pressure in the refrigerant mixture cycle of the ORC was kept constant between the waste heat boiler and condenser at 133 psi and 55 psi, respectively.

The impact of the solar radiations, magnetic field, and nanofluids on the ORC performance and the cooling/freezing effect was determined by equations (8) through (9), and the efficiency of the hybrid system composed of the PV solar panel, PV-Thermal, and the ORC and the cooling/freezing coil were calculated using equation (4) through (14) and Table .1 to account for the calculations of thermophysical properties of magnetized nanofluids as a function of the magnetic field in Gauss.

Nanofluid Ai2O3 has been reported the most and studies in the literature for comparison purposes, and it was used in this study as a reference base nanofluid. We have constructed Figures .3 through .9 to analyze and analyze the different parameters of the thermal energy converted and transferred to the nanofluid Ai2O3 heat transport fluid that drives the waste heat boiler of the ORC under investigation; our predicted results of the ORC behavior presented were at different temperatures ranging from 23 ◦F to ◦60 F and concentrations %5, circulating beneath the PV-Th solar panel under solar radiation of 750 w/m2 and at different magnetic fields forces varied between 127 up to 3000 Gauss. However, other nanofluid concentrations were presented only for illustrations of the impact of increasing the concentrations on the system parameters' performance.

The refrigerant mass flow rate circulating in the ORC cycle can be determined from equation (5). Figure .3 depicts the variations of the refrigerant flow at different temperatures o the heat transport nanofluid Ai2O3 driving the ORC. It is quite evident from the results presented in this figure that the higher the nanofluid flow temperature, the higher the refrigerant mass flow rate. Also, it can be observed that the higher the magnetic field, the higher the mass flow rate. This can be interpreted that higher heat transport fluid temperature has resulted from higher thermal energy absorbed by the heat transport fluid and consequently generated higher mass flow refrigerant. Also, it can be seen that the higher the magnetic field, the higher the thermal energy generated and dissipated into the heat transport fluid and the higher refrigerant mass flow rate, as reported very recently this year by Sami [9] and Sami and Martin [11]. the of the hybrid system efficiency. This can be interpreted as pointed out by references [9} through [14] that convective heat transfer performance of suspended magnetized nanoparticles outstandingly increases the heat transfer thermal capacity of the base fluid, and the nanofluids have higher heat transfer coefficients than that of the base-fluids such as water for the same Reynolds number.

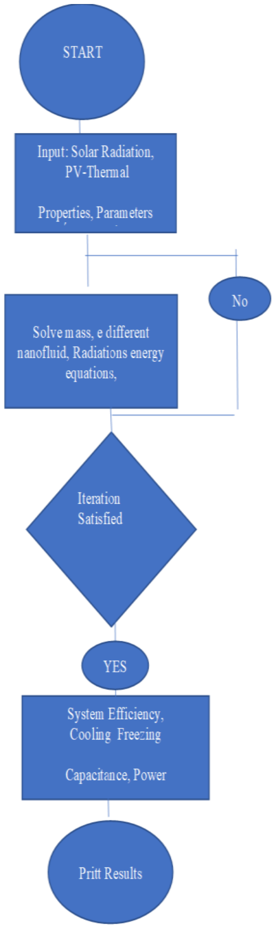

Fig. 2 Logical diagrams for the numerical solution

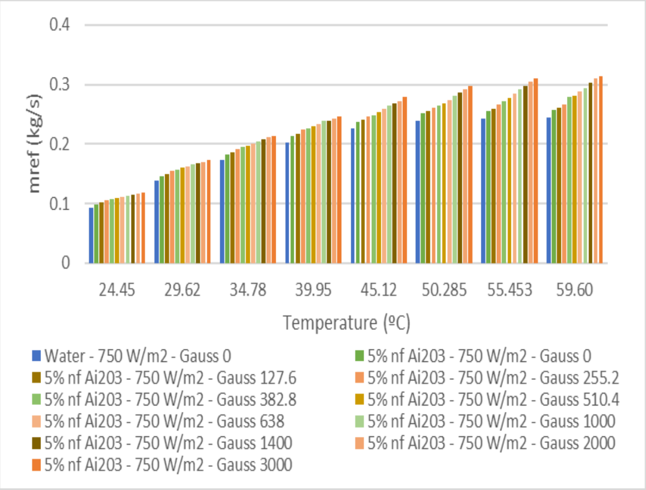

Fig. 3 ORC refrigerant flow rate at different Gauss fields

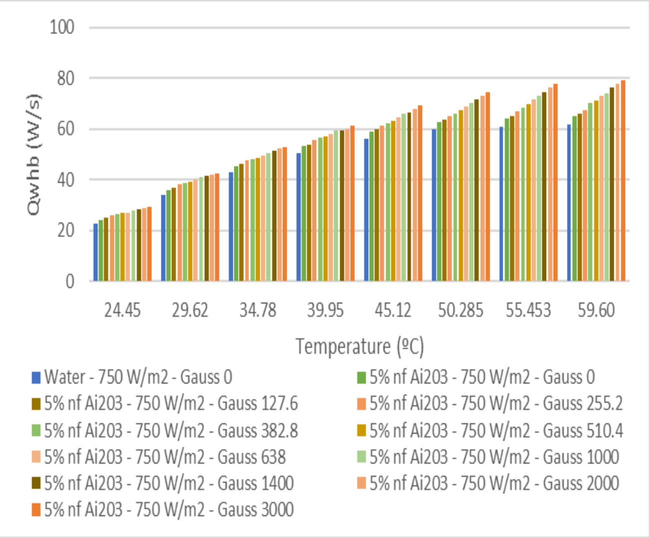

Fig. 4 Waste heat boiler thermal energy (w/s) at different magnetized nanofluid temperatures

The magnetized nanoparticles' impact on the refrigerant mass flow rate and consequently the boiler heat transfer area, the pressure drops, and the pump power consumption and ORC power generated has been illustrated in Figure.3. This provides insights into the potential benefit of the nanofluids on the ORC power systems. The impact of the magnetized nanoparticles on the working fluid has been accounted for in the following areas; thermophysical properties of the working fluid, the heat transfer and heat transfer coefficient and evaporation, the heat transfer impact factor in the boiler, condensation in the condenser; the pressure drops in the evaporation in the boiler, and the pump efficiency affected by the increase in viscosity of the nanofluid [30]. The effect of magnetized nanoparticles on expansion devices (vapor turbines) has not been considered in this study.

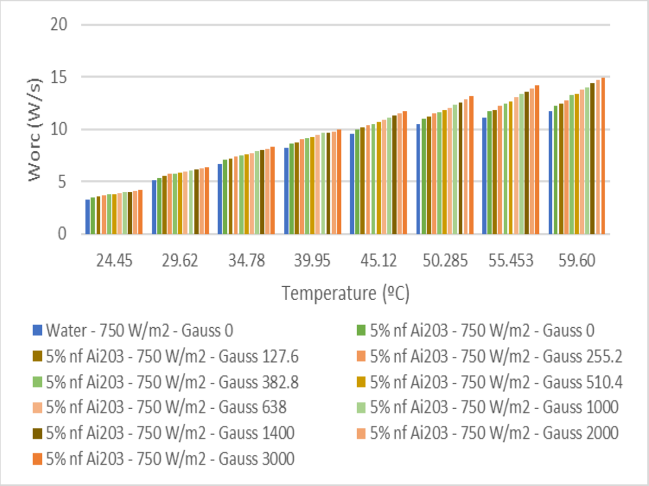

Fig. 5 ORC work produced (w/s) at different magnetic field

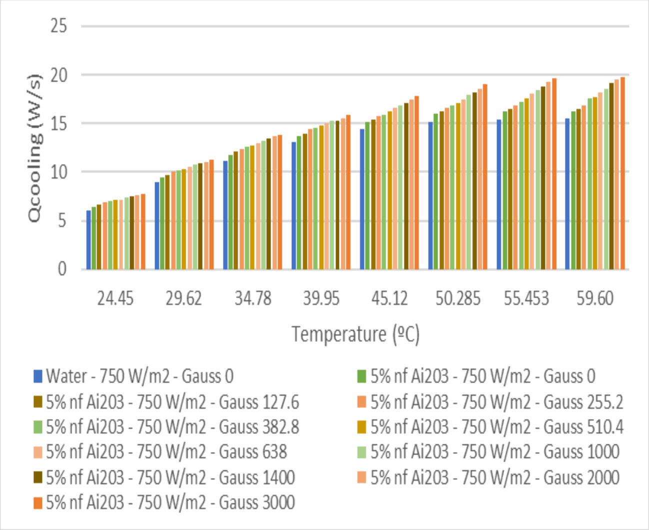

Fig. 6 ORC cooling thermal energy (w/s) at different magnetic field

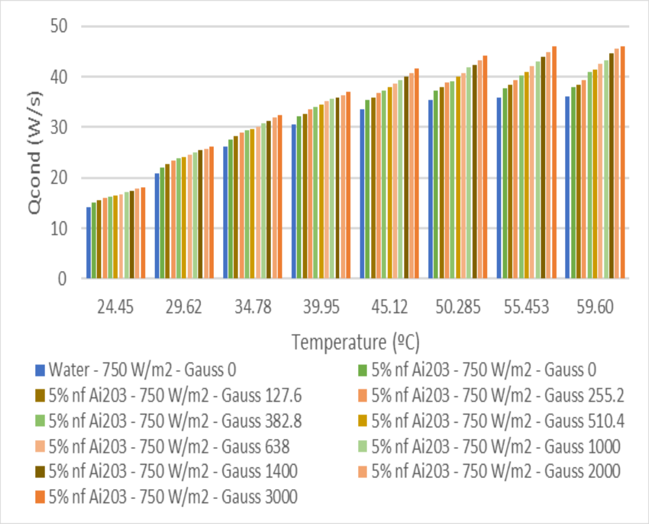

Fig.7 ORC condenser thermal energy (w/s) at different magnetic fields

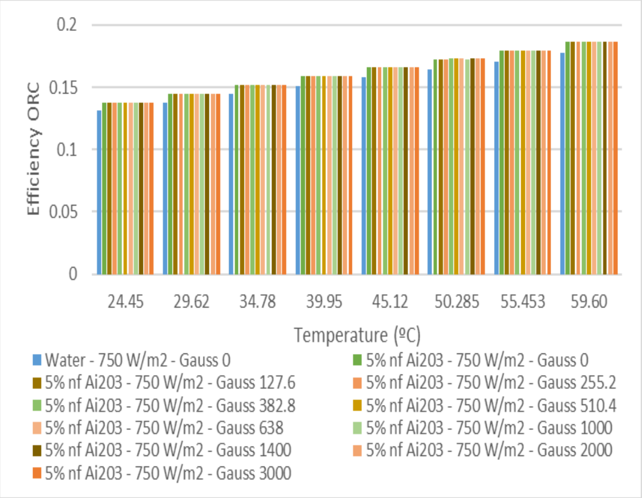

Fig. 8 ORC thermal efficiency at different magnetic fields

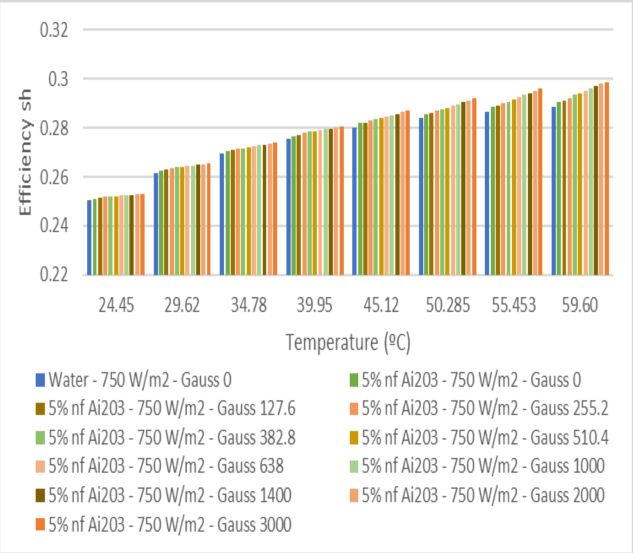

Fig. 9 ORC Hybrid efficiency at different magnetic field

It has been shown that conventional fluids such as water and oil exhibit poor thermal properties as compared to solid metals [11-17]. The enhancement of the heat transfer characteristics has gravitated the interest of the researchers by improving the thermophysical properties of the conventional fluids with the use of nanofluids. The addition of magnetized nanoparticles in base fluid resulted in the formation of nanofluids and eventually enhanced heat transfer of the fluid thermophysical properties such as viscosity, thermal conductivity, density, and specific heat are the important thermophysical properties that determine the behavior of nanofluids in a heat transfer system. It should be noted that the nanoparticles have a much larger relative surface area compared with conventional particles, which not only significantly improve the heat transfer capabilities but also improve the stability of suspensions. Figure. 4 showed clear evidence that the addition of nanofluid Ai2O3 to the base-fluid water enhanced the thermal energy transferred to the refrigerant at the waste heat boiler of the ORC. That enhancement increased with the increase of the magnetic field and temperatures. Its believed that the magnetic force on nanoparticles could change the microstructure of nanofluid, and the movement of nanoparticles resulted in increasing the thermal energy transferred to the refrigerant in the waste heat boiler[14]. That thermal energy increased the evaporation of the refrigerant and its mass flow rate, as shown in Figure.3. As can be noticed from Figure. 5 and Figure .7 that, the enhancement of the thermal energy transferred at the waste heat boiler caused augmenting of the refrigerant mass flow rate, and as per equations (4) through (9), the higher the refrigerant mass flow rate, the higher thermal energy absorbed and rejected by the ORC, and the work produced at the turbine of the ORC.

As a result of the argumentation of the refrigerant mass flow due to the combined effect of the use of the nanofluid and higher nanofluid temperature by the presence of the magnetic field, the cooling effect displayed in Figure .6 showed a clear indication that the higher the nanofluid temperature and the higher the magnetic field, the higher the cooling effect produced by the ORC cycle.

The thermal efficiency of the ORC and the hybrid system employing magnetized nanofluids have been determined using equations (10) and (11) and are displayed in Figures 8 and 9, respectively. These two figures provided insights into the potential benefit of the use of magnetized nanofluids in ORC systems as it can be demonstrated that magnetized nanofluids enhanced the ORC efficiency and the hybrid system efficiency over the water-based fluid, in Figures 8 and 9, respectively. It is quite evident from these figures that both efficiencies were enhanced at higher magnetic fields. As also can be observed, both efficiencies were increased with the magnetized nanofluid's heat transport temperatures. This can be interpreted as the temperature of the magnetized nanofluids increased, the more refrigerant mass flow rate was evaporated, and consequently, the ORC output work produced is increased, and the efficiencies of the ORC augmented. The same observation can be noted from Figure .9 on the argumentation of the hybrid system efficiency as calculated by equation (11), where the ORC work and cooling effect have been increased as it can be noted from Figure.6 that The higher refrigerant mass flow rate, the higher the cooling

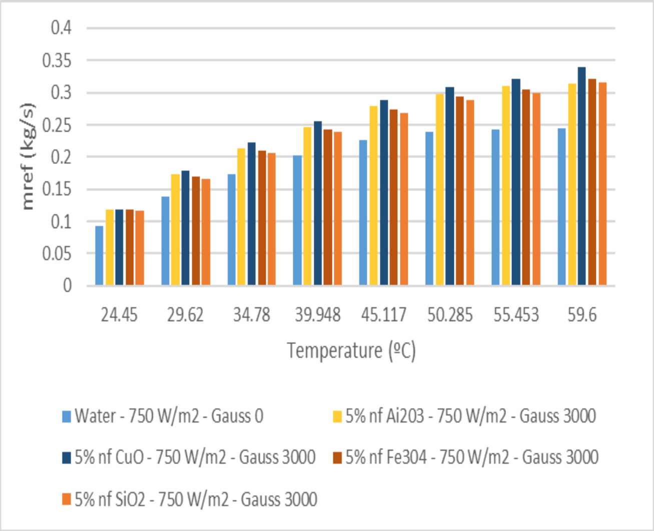

Fig. 10 ORC refrigerant flow rate at different nanofluids

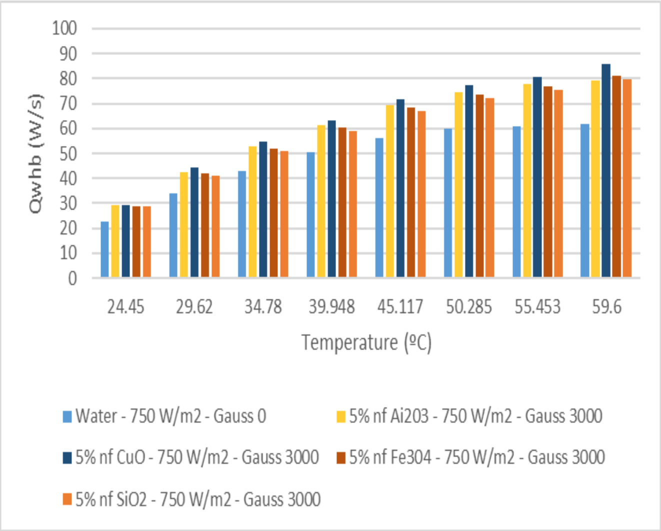

Fig. 11 ORC waste heat boiler at different nanofluids

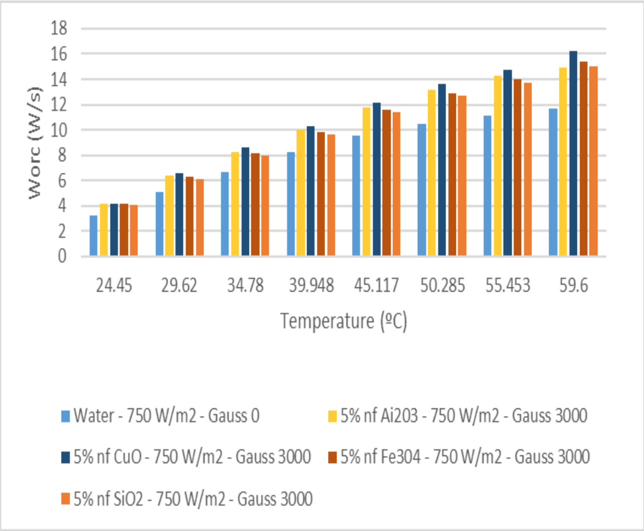

Fig. 12 ORC Output work at different nanofluids

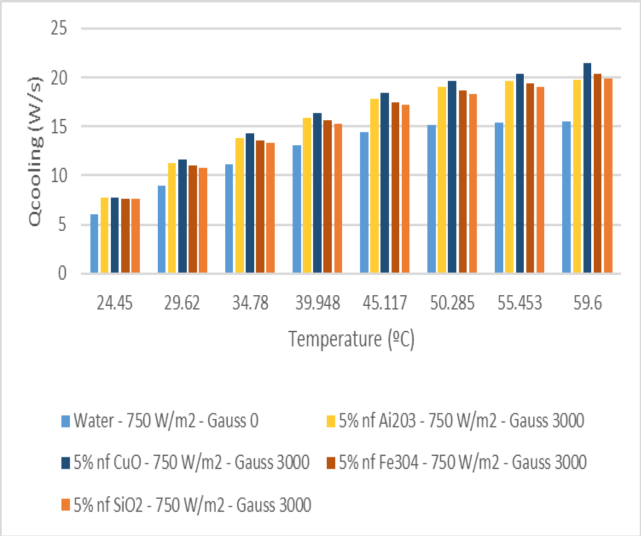

Fig. 13 ORC Cooling effect on different nanofluids

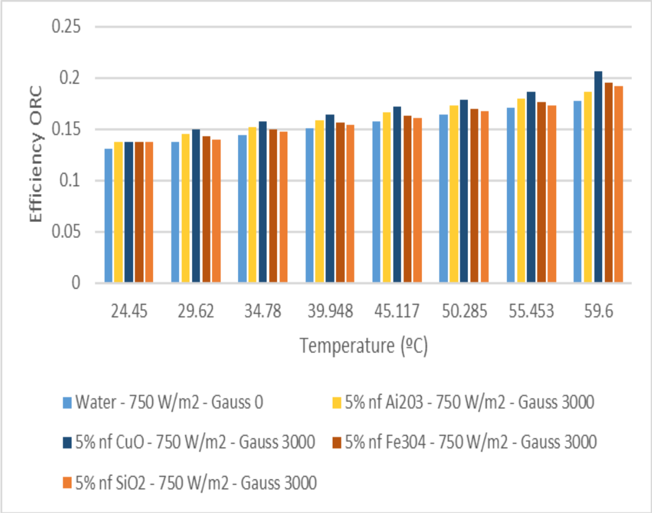

Fig. 14 ORC Efficiency at different nanofluids

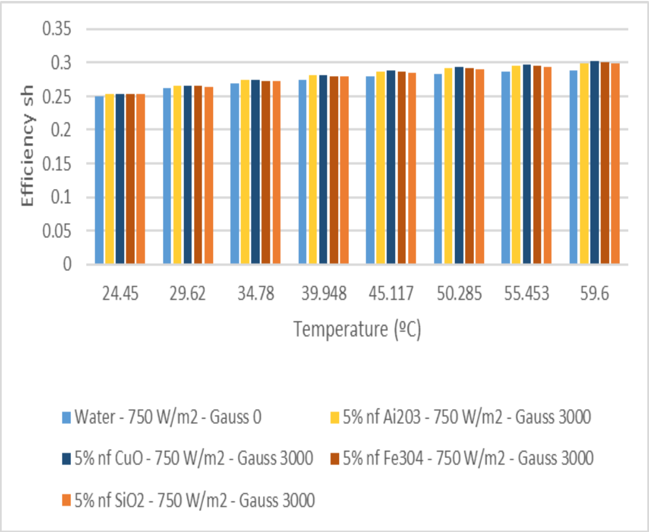

Fig. 15 ORC-Hybrid system efficiency at different nanofluids

The different nanofluids, Al2O3, CuO, ZnO, SiO2, SiO2, and TiO2, were the most studied nanoparticles in the literature due to their low costs and availability. In addition, data related to the density was most abundantly available, and reasonable data related to thermal conductivity was relatively available. In this study, we focused on the magnetized nanofluids; Al2O3, CuO, SiO2, and Fer304. Figures 10 through 15 were constructed to study the impact of different nanofluids on the Characteristic behavior of the ORC under consideration. It has been reported by references [11] through [20] the aforementioned nanofluids showed an increase in temperature and concentration increases thermal conductivity. With increasing concentration, the thermal conductivity of the nanofluids increases because of the Brownian motion, and it results in an augmented heat transfer mechanism. It has been reported by reference [17] that with the use of nanoparticles, the waste heat boiler area was reduced by almost 4% for a greater than 1% volumetric concentration of nanoparticles.

The heat transfer enhancement of magnetized nanofluids is because the magnetic force on nanoparticles can change the microstructure of nanofluids and the movement of nanoparticles [10-14]. Density is also an important property as it affects Reynolds number, pressure loss, and Nusselt number, where nanofluids are implemented. Therefore, the comparison between the impact of various magnetized nanofluids on the ORC behavior is illustrated in figures 10 through 15. The most important parameter that affects the behavior of the ORC is the refrigerant flow circulating in the ORC. It can be seen from Figure 10 that CuO nanofluid has the most noticeable impact among other nanofluids under investigation, including water-based heat transport fluid on the refrigerant flow. It can also be seen that the higher the heat transport fluid temperature, the higher the refrigerant flow rate and the better the ORC performance.

It can also be noted from samples of the results presented in Figure.11 through Figure.15 that increasing the nanofluids temperatures resulted in an improvement in the characteristics behavior of the ORC components and, in particular, the cooling effect of the ORC. That also improved the efficiency of the ORC and the hybrid system of the PV-Thermal integrated ORC. This can be interpreted as a direct result of the increase in heat transfer caused by the use of magnetized nanofluid that increases the thermal energy delivered to the waste heat boiler of the ORC and thus increases the power output of the ORC.

Moreover, as presented in the aforementioned figures, as well as others obtained, also demonstrated that slightly higher hybrid system efficiency has been observed with nanofluid CuO compared to other nanofluids under investigation. This has been reported in other references, namely Sami [9 through 13], Mohammad et al. [37], and Lazarus et al. [38]. It should be noted that the transport properties have a unique function on the temperature of the base heat transfer fluid. Therefore, as reported in other references, namely Sami {9-13] and [38] that the nanofluid CuO thermo-physical properties are the main driver for the higher hybrid system efficiency when CuO is used.

The cooling or freezing effect is an added feature of the standard cycle of an ORC. Figures 13 demonstrated that the cooling effect depends upon the solar radiation, the temperature of the heat transfer fluid, and the nanofluids concentrations, as well as the type of magnetized nanofluid. It is quite evident from the results presented hereby and others obtained under different nanofluid concentrations that the higher the heat transfer fluid temperature, the higher the cooling effect. As discussed elsewhere in this paper, it can be observed that the nanofluid CuO has a higher cooling effect than the other nanofluids under investigation. This observation is because the CuO thermo-physical properties are the main driver for the higher cooling effect and, consequently, the hybrid system efficiency.

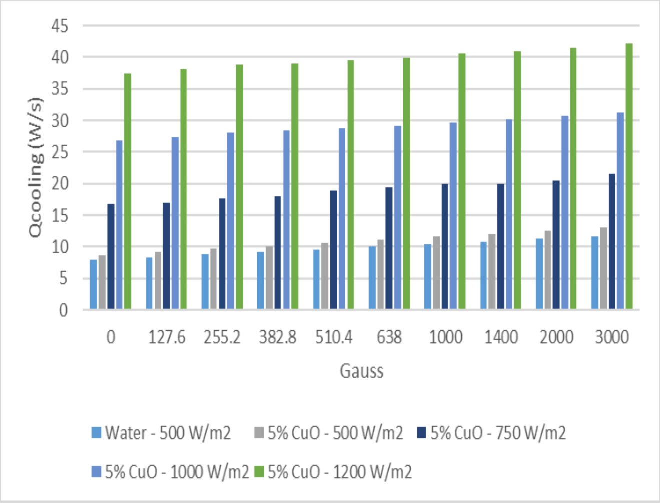

Fig. 16 Cooling effects at different solar radiations.,

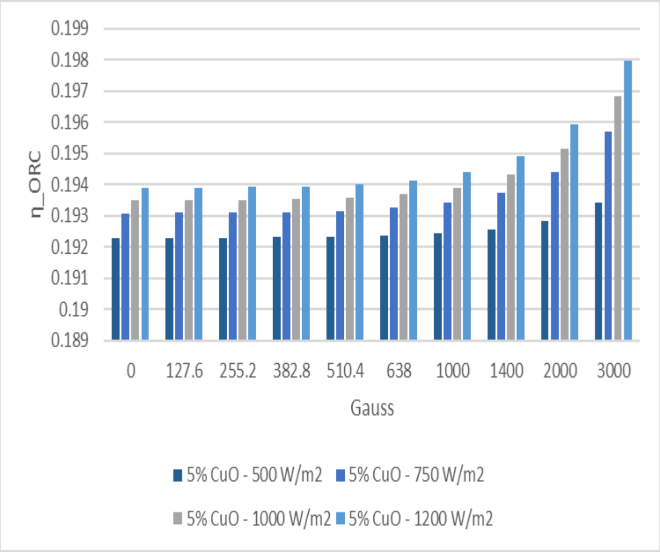

Fig. 17 ORC efficiency at different solar radiations

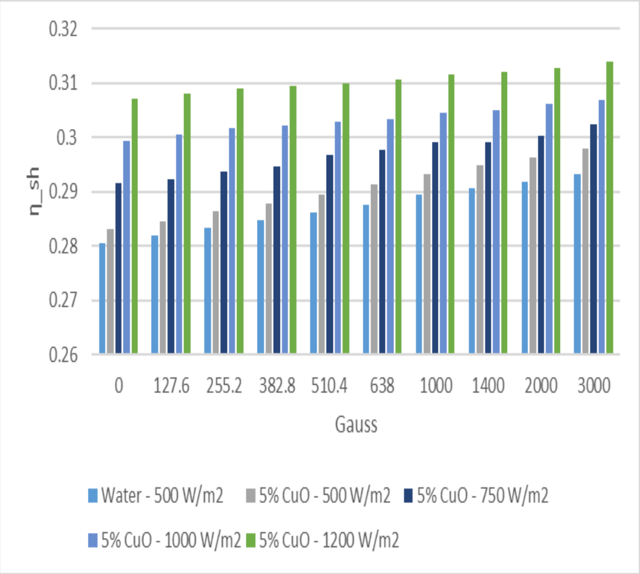

Fig. 18 Hybrid system efficiency for different solar radiations

Moreover, as discussed earlier, the cooling effect produced by this hybrid system is an important feature of the present concept and is impacted by different parameters, including solar radiations. Therefore, Figure. 16 through Figure. 18 have been constructed to illustrate the impact of solar radiation on the cooling effect as well the oRc efficiency and the hybrid system efficiency. It is quite clear from the results presented in Figure. 16 and others obtained at different conditions that the higher the solar radiation and the heat transfer fluid temperatures, the higher the cooling effect produced. However, also, the data presented in these figures show that the higher the heat transfer fluid temperature, the higher the cooling effect. Furthermore, Figures 17 and 18 clearly showed that the higher the solar radiation and the heat transfer fluid temperatures and the higher the efficiency of the ORC and hybrid system. This can be interpreted that higher solar radiations enhanced the transport properties of the nanofluids such as density, specific heat, heat capacity, viscosity, and thermal conductivity and significantly impacted the convective heat transfer of nanofluids [10-19] and the thermal efficiencies of the ORC and hybrid system.

V. MODEL VALIDATION

The thermal energy was calculated using Equation (1) and Equation (2) under a magnetic field up to 3000 Gauss and with Fe3O4 nanofluid as heat transport fluid and compared to experimental data reported in the literature by reference [42] were considered and compared with the different magnetic fields up to 7000 Gauss. Reference [42] reported 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 Fe3O4 nanofluid, the choice for his study, was found to be the nanofluid with a 0.1% volume concentration. The results predicted by our model were compared under similar conditions and are plotted in Figure 19. The comparison showed some discrepancy, and it varied between 8% to 14% with the model when predicting the thermal energy transferred to the heat transport fluid under higher magnetic fields. We believed that these discrepancies stemmed from the heat transfer coefficient under the magnetic field not being similar and the thermophysical properties of Fe3O4 [42] and the PV–thermal heat transfer efficiency, which were not fully disclosed for each nanofluid concentration by reference [42].

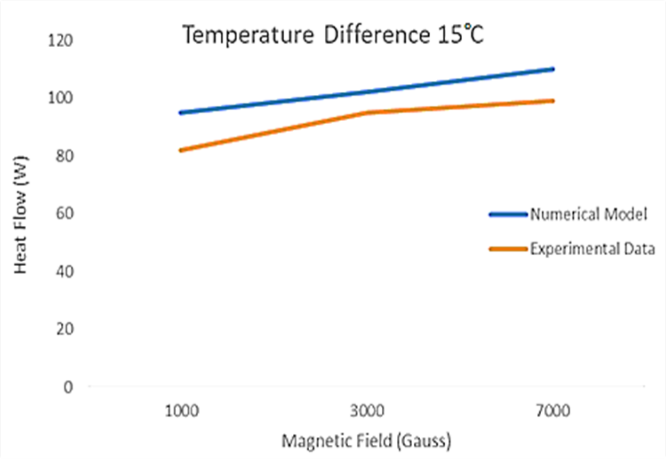

Fig. 19 Comparison between present model and data for nanofluid Fe3O4 data with different magnetic fields [42].

VI. CONCLUSION

We presented and discussed the behavior of the Organic Rankine Cycle, ORC, with cooling capabilities driven by magnetized nanofluids in a PV Thermal loop. This study was intended to investigate the enhancement effect and characteristics of magnetized nanofluids, AI2O3, CuO, Fe3O4, and SiO2, on the hybrid system's performance composed of PV Thermal, ORC with an integrated cooling coil. It has been shown that the enhancement of the efficiency was significantly dependent upon not only the solar radiation but also the magnetized nanofluids concentration and the type of nanofluid and its temperature driving the ORC. It was also found that the higher the nanofluid concentrations, solar radiation, and heat transfer fluid temperature, the higher the cooling effect.

Moreover, This research work demonstrated that the ORCefficency and the hybrid system efficiency have been higher with nanofluid CuO. In addition, it was also observed that a higher cooling effect has occurred with the use of the nanofluid CuO compared to the other magnetized nanofluids under investigation and water as heat transfer fluid. Furthermore, the model validation showed a fair agreement with experimental data reported in the literature.

A. Nomenclature

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 regenerator (KJ/Kg)
m_{ref}: refrigerant mass flow rate (kg/s)α_{abs}: Overall absorption coefficient

G: Total Solar radiation incident on the PV module
S_p: Total area of the PV module
W_{ORC}: power produced by ORC (KW)
$p(t)$: PV solar output (kW) is defined by equation (4)
Qcc: cooling coil thermal capacity (kW) and defined by equation (9)
$W_{P_{ORC}}$: pump power consumption (9)
Q_{in}: solar radiation (kW) and defined by equation (1)

VII. ACKNOWLEDGEMENT

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