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Original Article

Analysis of Solar Absorption Chiller driven by CuO Nanofluid-based PV- Thermal Solar collectors (PVT)

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Abstract *- A numerical model based upon the energy conversion equations and heat transfer mechanisms of magnetized nanofluids taking place during PV-Thermal solar collector and absorption system, PV cell and the heat transfer fluid flowing in thermal tubes welded in the back of the PV panel and heat exchangers of the absorption system. is presented". This permitted the prediction of the electrical power output of the PV panel, thermal energy generated, and the characteristics of the water-based nanofluids in terms of solar radiation, different nanofluids, and other system geometry parameters." The presented model compared fairly with experimental data with reasonable discrepancy. Radiation higher solar radiations have a significant impact on heat transfer fluid flow rates; however, low solar radiations increase the nanofluid-based CuO heat transfer flow rates over the water-based ones. Also, it has been shown that the higher the concentration of the magnetized nanofluid CuO, the higher the generator's thermal energy input compared to the heat transfer fluid-based water and the coefficient of performance of the absorption system. Finally, the model results in question are compared fairly with available experimental data.*

Keywords *- Analysis, solar PV-Thermal, Absorption Chiller, CuO Nanofluid, Solar collectors (PVT).*

1. Introduction

The International Energy Agency (IEA) reports that the global energy required for space cooling applications will increase three-fold by 2050 [1-3]. Solar thermal energy-driven systems for space cooling and refrigeration applications help reduce fossil fuel consumption, reduce their associated greenhouse gas (GHG) emissions and combat climate change. Using the Lithium-Bromide and water-driven absorption refrigeration cycle not only helps minimise fossil fuel usage but also reduces CO2 gas emission and utilizes the low-grade waste heat from various industries. However, Solar cooling systems are environmentally friendly compared to conventional cooling systems and are important technology to reduce emissions and combat climate change. Therefore, the concept presented hereby is more advantageous as it uses the solar energy photovoltaic-thermal solar collectors (PV-Thermal) as a driver to the absorption process, thus dramatically reducing the carbon footprint and helping to combat climate change.

Many researchers have focused on solar cooling systems, and different types of solar thermal cooling systems have been reviewed [2-10]. In particular, Alili et al. [6] presented a complete review of solar thermal air conditioning technologies. They reported several research outcomes on working fluid temperature, solar collector type, collector area, storage volume, and COP values. The authors [6] evaluated the different research work related to conditions such as the temperature of evaporators, condensers, and generators on experimental and simulation levels.

Absorption papers focusing on solar cooling absorption technology are scarce; however, Zhai, Qu et al. [11] provided an excellent literature review of solar cooling absorption systems but only included CPVT with single absorption chillers. Raja and Shanmugam [12] also reviewed solar absorption systems and discussed auxiliary components typically used in the systems, such as backup heating and some solar collector types. Different types of absorption solar cooling systems that include single-effect, double-effect, and half-effect absorption cycles have also been reported in the review papers [13-15].

The integration of the PV solar panels and a thin tube heat exchanger collector (CF Figure 1), known as a photovoltaic/thermal collector (PV/T), has been proposed by many researchers. This integration has led to a higher solar energy utilization efficiency [18-23].

Nanofluids have excellent thermal conductivity [8–27] and have been applied as working fluids in traditional thermal applications to enhance thermal performance. "Consequently, the efficiency of commercial solar PV solar panels is up to 15%, and most incoming solar radiation energy is either absorbed or reflected, and significant excess heat is dissipated and wasted. To improve the efficiency of solar PVs, the novel concept of a photovoltaic–thermal solar panel hybrid system using nanofluids has been developed” [19–28].

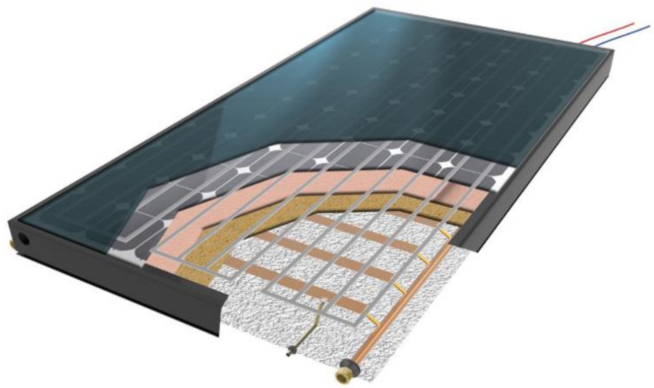

Fig. 1 PV -Thermal solar collector [18].

2. Numerical Modeling

2.1. PV Model

The solar photovoltaic panel is constructed of various modules, and each module consists of arrays and cells. The dynamic Current output can be obtained as follows [10-27];

$$I_P = I_L - I_o\left[exp\left(\frac{q(V+I_PR_S)}{AkT_C} - \frac{V+I_PR_S}{R_{sh}}\right)\right] \quad (1)$$

I_p: Output current of the Pv module
I_L: Light-generated current per module
I_o: Reverse saturation current per module
V: Terminal voltage per module
R_s: Diode series resistance per module
R_{sh}: Diode shunt resistance per module
q: Electric charge
k: The Boltzmann constant
A: Diode ideality factor for the module

The AC power of the inverter output P(t) is calculated using the inverter efficiency η_{inv} , output voltage between phases, neutral V_{fn}, and for single-phase Current I_o and $cos\varphi$ as follows.

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

Interested readers in the detailed calculations of the different terms of the above equation are advised to consult references [17-23].

2.2. PV-Thermal Model

It is assumed in this model that all PV cells behave the same; therefore, this model can be applied to the whole PV solar panel. This model is an extension of the work presented by Sami and Campoverde [17] in which the thermal heat absorbed by the PV solar cell can be calculated by the following equation.

$$Q_{in} = \alpha_{abs}GS_p \quad (3)$$

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 as per Sami and Martin [18].

$$mC_{p\_module}\frac{dT_C}{dt} = Q_{in} - Q_{conv} - Q_{elect} \quad (4)$$

Where.

T_C: PV Cell Temperature
mC_{p_module}: Thermal capacity of the PV module
t: time
Q_{in}: Energy received due to solar irradiation,
Q_{conv}: Energy loss due to Convection
Q_{elect}: Electrical power generated.

Interested readers in the detailed calculations of the different terms of the above equation are advised to consult references [17-23].

2.2. Absorption Chiller Analysis

The absorption chiller is driven by a heat source supplied by the PV Thermal solar collector and is defined as [3, 16]:

$$Q_G = c_p\, m_G\, (T_G, in - T_G, out) \quad (5)$$

Where.

Q_G (kW) is the thermal power of the generator, m_G(kg/s) is the mass flow of the
generator, and T_G, in and T_G, out (K) are the inlet and outlet temperatures of the generator.
The cooling capacity of the chilled water from the absorption chiller is shown as:

$$Q_E = cp\, m_E(TE,out - TE,in) \quad (6)$$

Where.

Q_E (kW) is the refrigerating capacity of the evaporator, T_E, in, and T_E out (K) is the inlet and outlet temperatures of the evaporator, and m_E (kg/s) is the mass flow of the evaporator.

The following formula shows the calculation of the COP and exergy efficiency:

$$COP_{ac} = Q_E/(Q_G + W_{ac}) \quad (7)$$

$$\xi ac = - Q_E(1 - T_0/T_E)Q_G/ ((1 - T_0/T_G) + W_{ac}) \quad 8)$$

Where T_E (K) is the average temperature, and T_G (K) is the average temperature

Table 1. Thermophysical Properties of magnetized nanofluids

	$Ai_2 0_3$	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

2.3. 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 [19-27].

$$\alpha_{total} = \alpha_{particles} + \alpha_{base\ fluid} \quad (9)$$

Where α represents the thermophysical property of a particular nanofluid.

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

$$\alpha_{total} = \alpha_{base\ fluid} + \alpha_{particles} .(\Phi) \quad (10)$$

Where Φ represents the nanoparticles' volumetric concentration.

The nanofluids' thermal conductivity to thermal diffusivity and density are related as follows.

$$\lambda = \alpha\ \delta\ C_p \quad (11)$$

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 [19-27]. These references discuss the impact of the nanofluids concentrations on the thermophysical properties of the said nanofluids.

2.4. Magnetized Nanofluids

Equations (9) through (11) can be used to determine other thermophysical properties such as α is the thermal diffusivity, ʎ, and ρ represent the thermal conductivity and density at different magnetic forces Gauss published in the literature properties ([20] through [23]) as a function of the properties outlined in the Table.1. However, in this study, only nanofluid CuOO magnetized properties are considered.

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 energy conversion equations and heat transfer mechanisms of nanofluids taking place during PV-Thermal solar collector and absorption system", as shown in Figures 1 and Figure 2, were outlined in Equations (1) through (11). The model presented hereby was based on "mass and energy balances of the individual components of the PV/T hybrid driven absorption system; PV cell and the heat transfer fluid flowing in thermal tubes welded in the back of the PV panel and heat exchangers of the absorption system. This permitted the prediction of the electrical power output of the PV panel, thermal energy generated, and the characteristics of the water-based nanofluids in terms of solar radiation, different nanofluids, and other system geometry parameters." The aforementioned "energy conversion equations have been numerically solved where the input parameters of the solar PV-Thermal driven absorption conditions, such as solar radiation, ambient temperature, and humidity, and other independent parameters, such as nanofluids, are defined. The dependent parameters were calculated and integrated into the system of finite-difference formulations developed after the energy conservation equations under nanofluids. Iterations were performed until a converged solution was reached with an acceptable iteration error". "The thermodynamic and thermophysical properties of Heat Transfer Fluid, HTF, were employed to calculate the water-based nanofluids flow rate. This was followed by using the finite-difference formulations to predict the time variation characteristics of the PV cell temperature, the PV back temperature, and thermal heat transferred to the Heat Transfer Fluid, Heat transfer fluid outlet temperature at the heat exchanger, as well as other hybrid system power outputs, cooling effect, efficiencies and the different characteristics of the components of solar absorption system as shown in Figure.2. Finally, hybrid system efficiency was calculated at each input condition of solar radiation, nanofluids, and their concentrations."

4. Results and Discussion

The present " integrated hybrid PV-Thermal system absorption chiller consists of a photovoltaic solar panel and welded thin parallel tubes on its backside for the circulation of the heat transport fluid with nanofluids and the absorption chiller components as shown in Figures 1 and 2. The parallel thin tubes were soldered to the back of the PV solar panel and connected to a thermal tank from which water-based nanofluids flow through the solar collector copper pipes and carry the excess heat away from the PV-thermal panel, as shown in Figure 1.

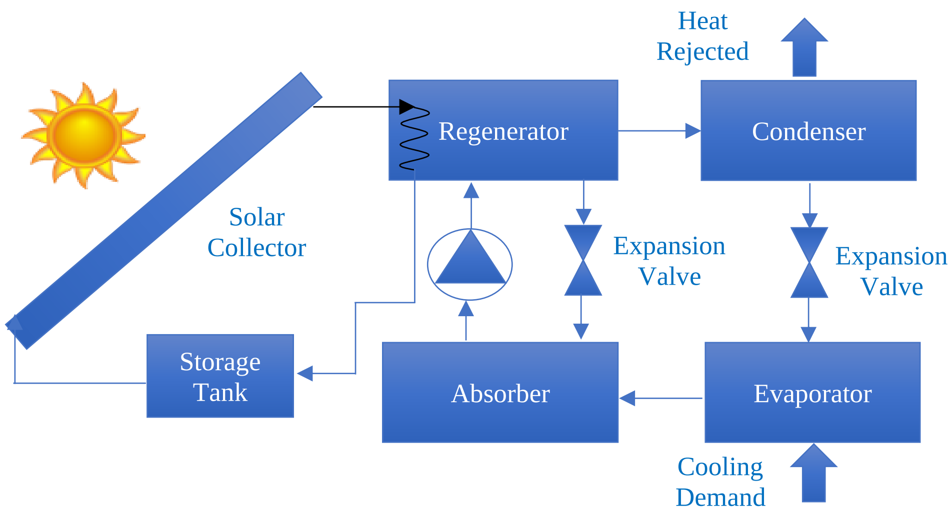

Fig. 2 Solar absorption chiller [17]

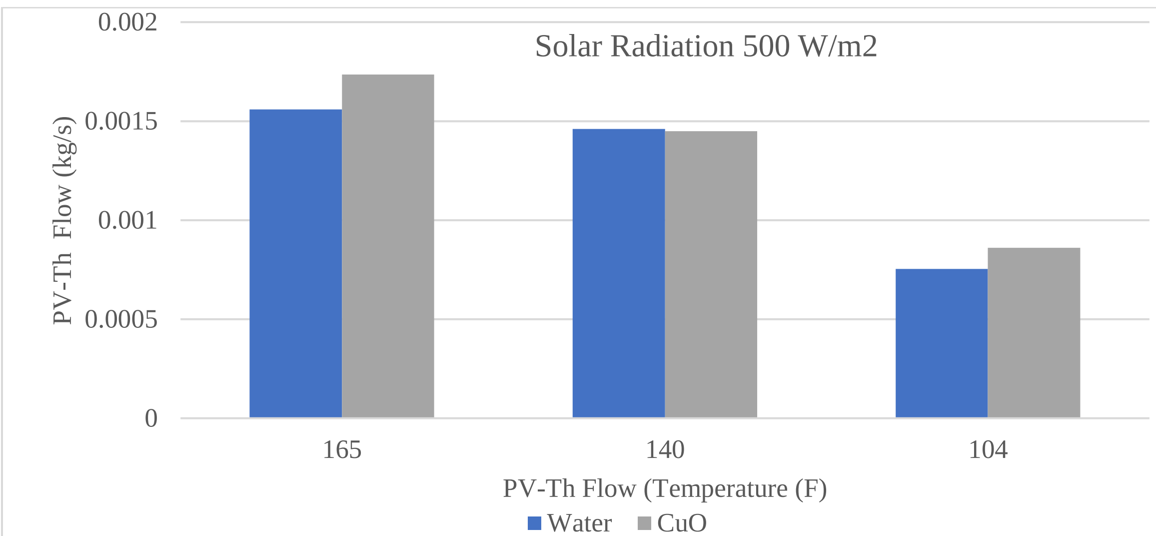

Fig. 3 PV-Thermal flow rates

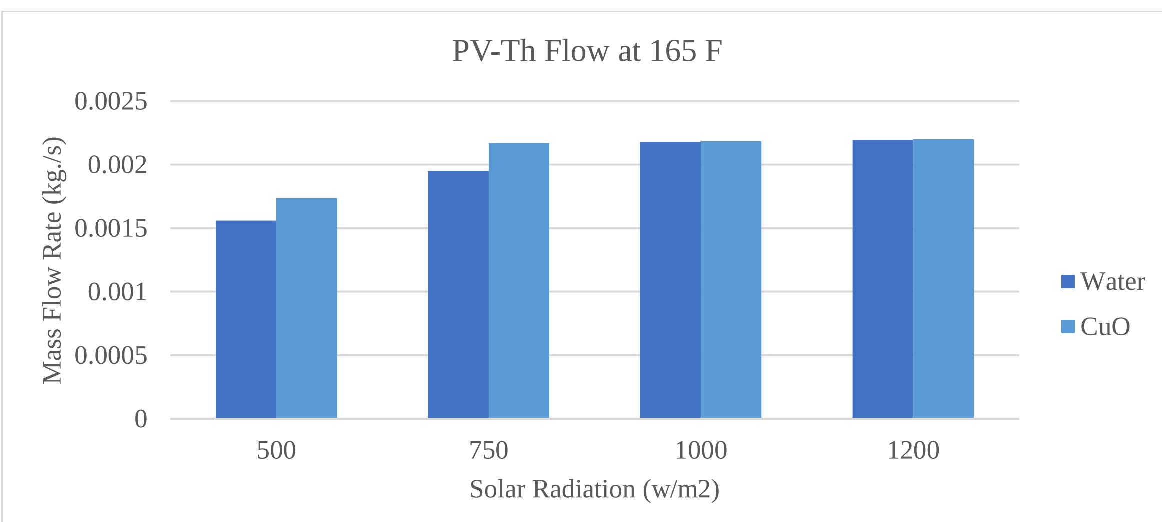

Fig. 4 PV-Thermal Mass Flow Rates at Different Solar Radiations

The excess heat released by the PV-Thermal solar panels is transferred to the generator of the absorption chiller (C.F. Figure .2) to drive this absorption effect and generate the desired cooling effect". A simple absorption refrigeration system uses a solution of lithium bromide or lithium chloride salt and water. Low-pressure water is evaporated from the coils and chilled. The water is absorbed by a lithium bromide/water solution.

In principal absorption, cycles generate cooling and/or heating with thermal input and minimal electric input, as shown in Figure 2. Thus, an absorption thermodynamic cycle can be considered like a mechanical vapor-compression cycle, replacing the compressor with a generator, absorber, and liquid pump. This cooling cycle is driven by the evaporation and condensation of the water rather than electricity.

The predicted behavior of the PV-Thermal solar panel has been shown in Figures 3 and 4. Where the PV-Thermal nanofluid flow rates are plotted against the different temperatures and at different solar radiations, it can be shown that the nanofluid-based CuO Heat Transfer Flow rates have higher values compared to the water-based heat transport fluid. However, Figure 4 demonstrates that higher solar radiations do not impact heat transfer fluid flow rates. Low solar radiations increased the nanofluid-based CuO heat transfer flow rates over the water-based ones. It can be interpreted that the thermophysical properties of CuO-based nanofluids at higher solar radiation have no impact on the heat transfer properties and, consequently, the flow rates as they have thermophysical properties similar to those of the water-based heat transfer fluid. This is an important observation, as the designers should be cautioned not to use the nanofluids-based CuO in applications with higher solar radiation.

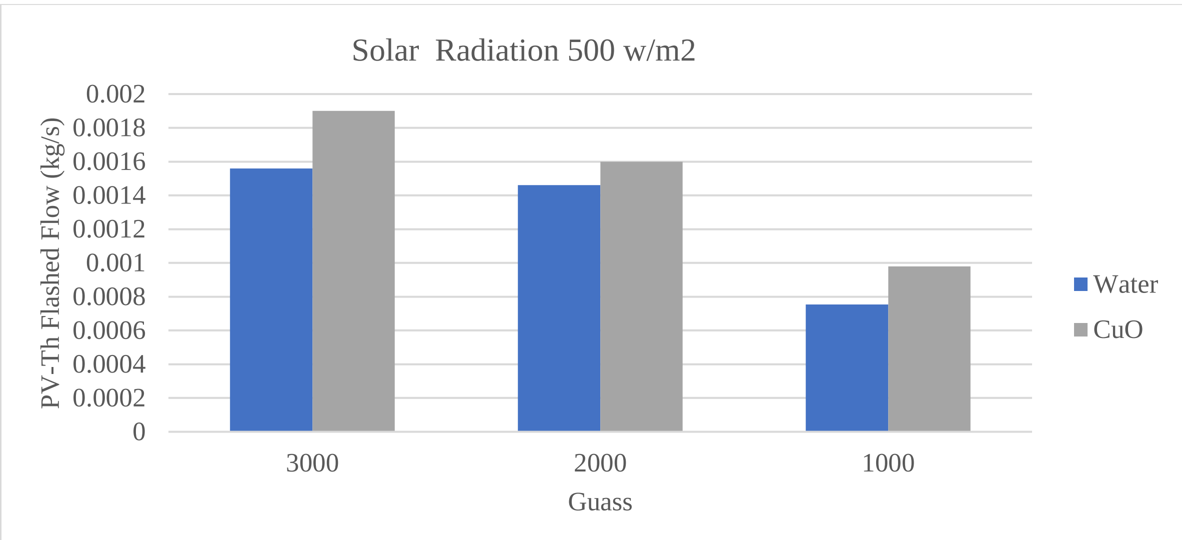

Fig. 5 PV-Thermal Flow rates at different magnetic force

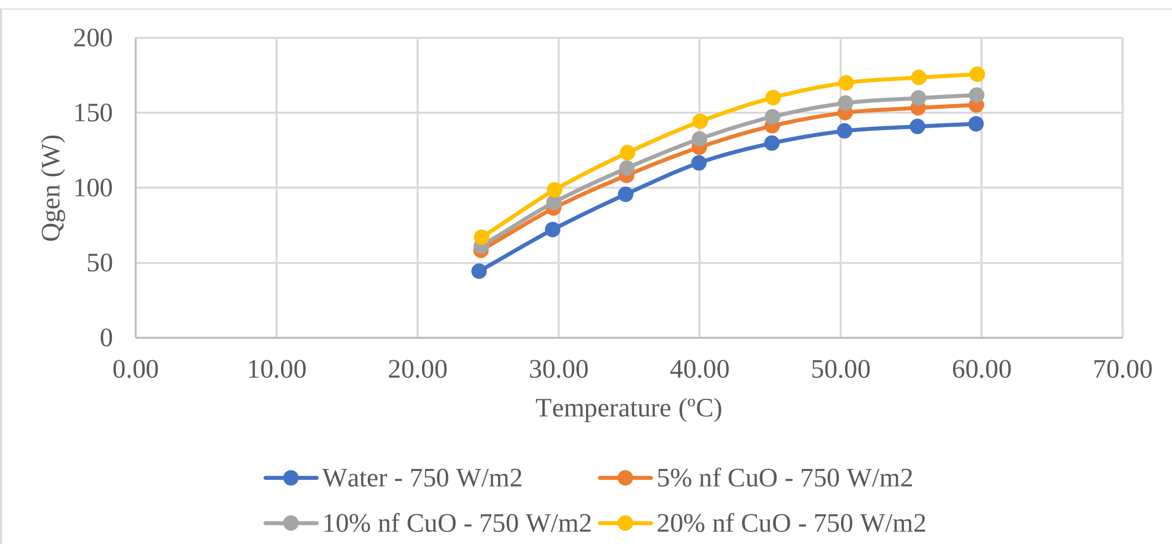

Fig. 6 Generator Heat Exchanger Thermal Energy

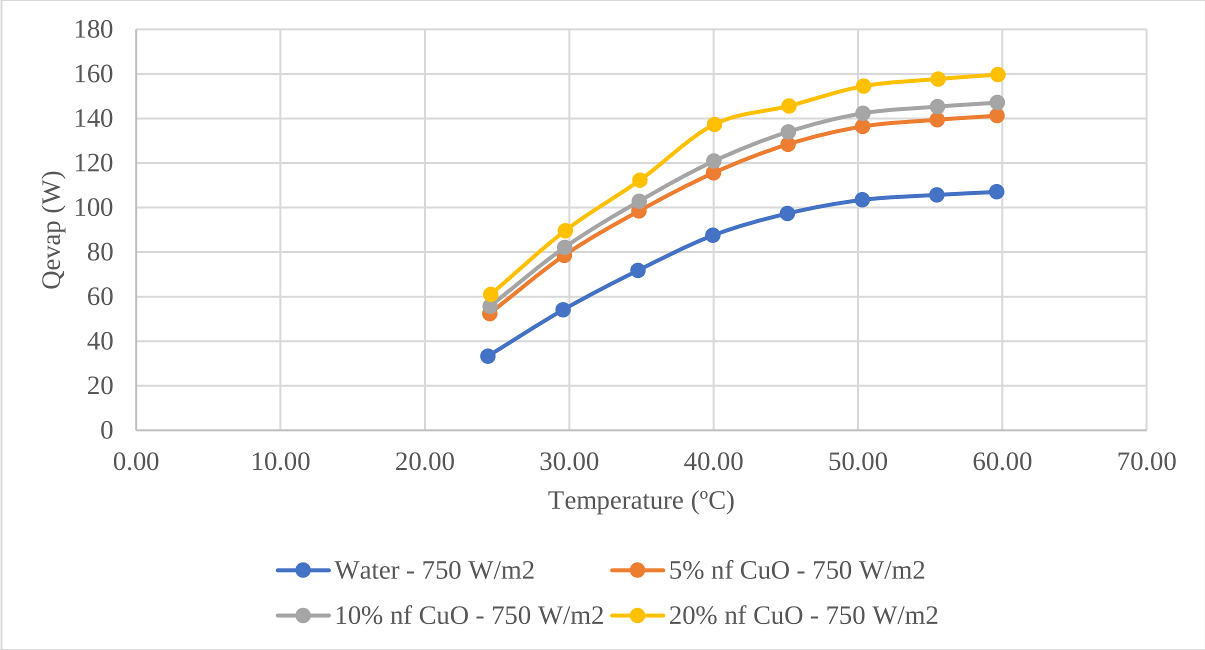

Fig. 7 Evaporator Heat Exchanger Thermal Energy

The impact of the magnetic force on the performance of PV-thermal solar collectors has been studied and discussed by Sami et al. [20-25], where it was shown that the magnetic field enhances its performance and increases the PV-Thermal flow rate with CuO over the water-base heat transfer fluid. Figure 5 illustrates this effect. This enhancement of the PV-Thermal Solar collector results in the enhancement of thermal energy to drive the absorption cycle and increased cooling effect, as demonstrated in the following discussion.

A numerical simulation of the predicted behavior of the different heat exchangers of the absorption cycle with lithium bromide or lithium chloride salt-water driven by nanofluids-based CuO at the generator heat exchanger side is shown in Figure 6.

The data suggests that the higher the concentration of the nanofluid CuO, the higher the generator's thermal energy input compared to the heat transfer fluid-based water. It also appears that the same trend can be observed for the thermal energy absorbed at the evaporator heat exchanger side, where the cooling effect is produced by the absorption cycle.

The pressure drop losses have to be taken into account, as the higher the concentration of the nanofluid, the higher the pressure drops and the pumping power required by the cycle. Also, the same trend was observed for the generator, and the evaporator can be extended to the condenser of the absorption cycle, where a higher nanofluid concentration of CuO results in higher thermal energy at the condenser side. Figure. 9 shows the impact of the nanofluid concentration CuO on the cooling effect of the absorption cycle, where it can be easily concluded that the higher the concentration of the nanofluid CuO, the higher the cooling effect produced at the evaporator side of the absorption cycle. On the other hand, the inherent flow rate of the absorption cycle, as plotted in Figure 9, is increased at higher nanofluid concentrations of CuO, which leads to higher performance of the absorption cycle.

The coefficient of performance of the absorption cycle is calculated by equation (7) and is plotted in Figure. 11, where it can be observed that a higher concentration of CuO results in a higher coefficient of performance compared to water used as a heat transfer fluid to drive the generator of the absorption cycle. It is also worthwhile noting that the aforementioned observations regarding the impact of higher concentrations of CuO have been observed at different solar radiations ranging from 500 w/m2 through 1200 W/m2, as illustrated in Figure 4.

The exergy efficiency is determined by equation (8) in terms of the generator temperature and ambient temperature and plotted in Figure 12. The data in Figure 12 clearly demonstrate that higher concentrations of CuO increased the exergy efficiency as higher concentrations induce pressure losses and loss of thermal energy; thus, higher concentrations of CuO are beneficial; however, caution must be exercised to avoid higher thermal energy losses that will affect the coefficient of performance of the absorption cycle and the cooling effect.

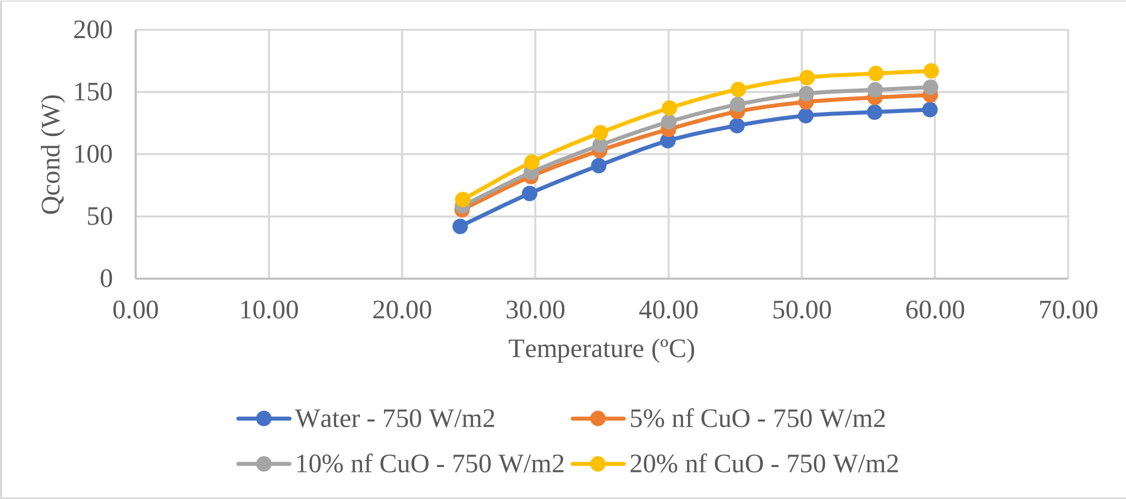

Fig. 8 Condenser heat exchanger thermal energy

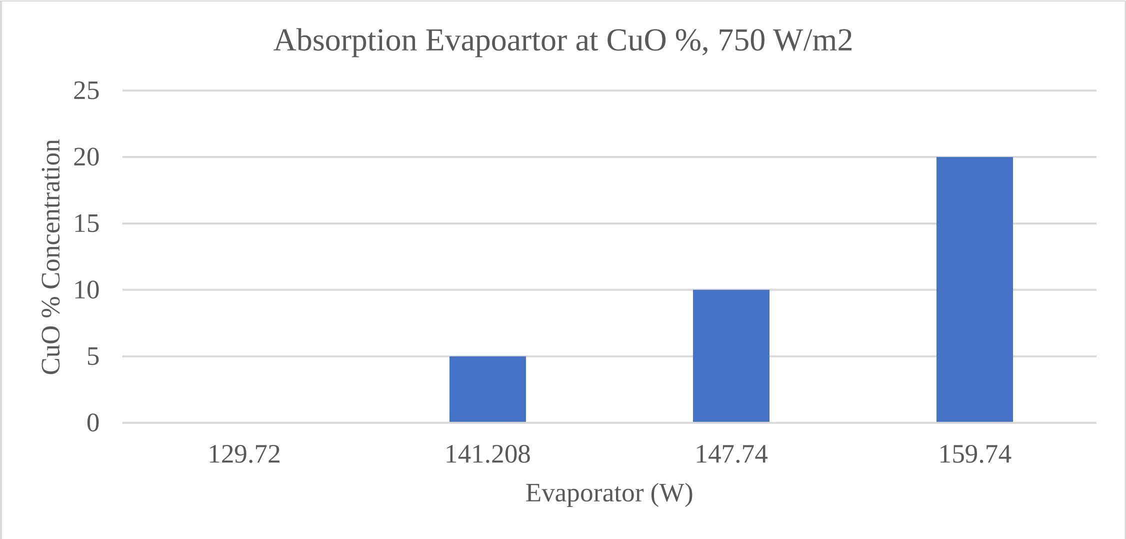

Fig. 9 Evaporator Thermal Energy at different CuO %

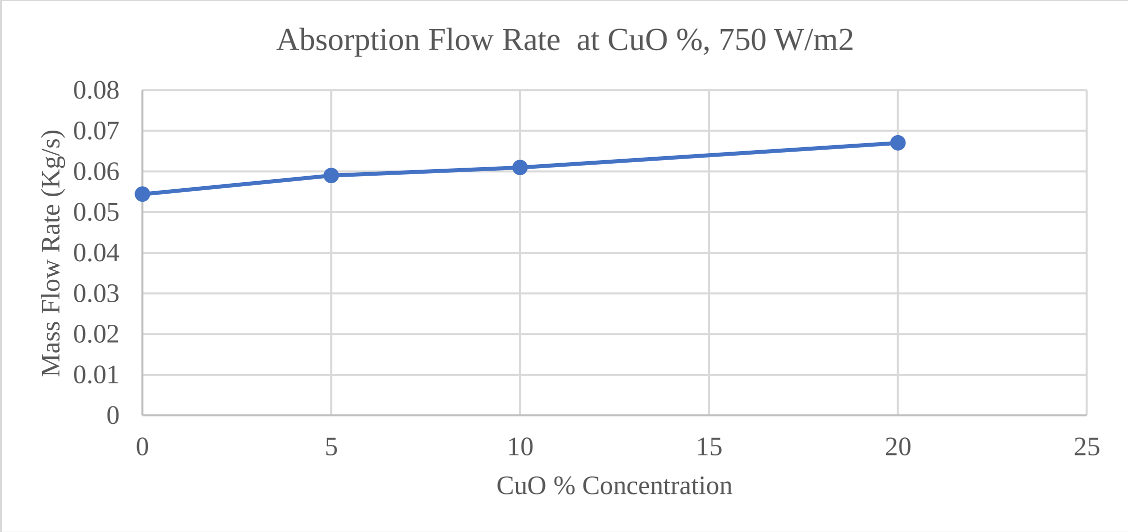

Fig. 10 Mass Flow rates at different CuO %

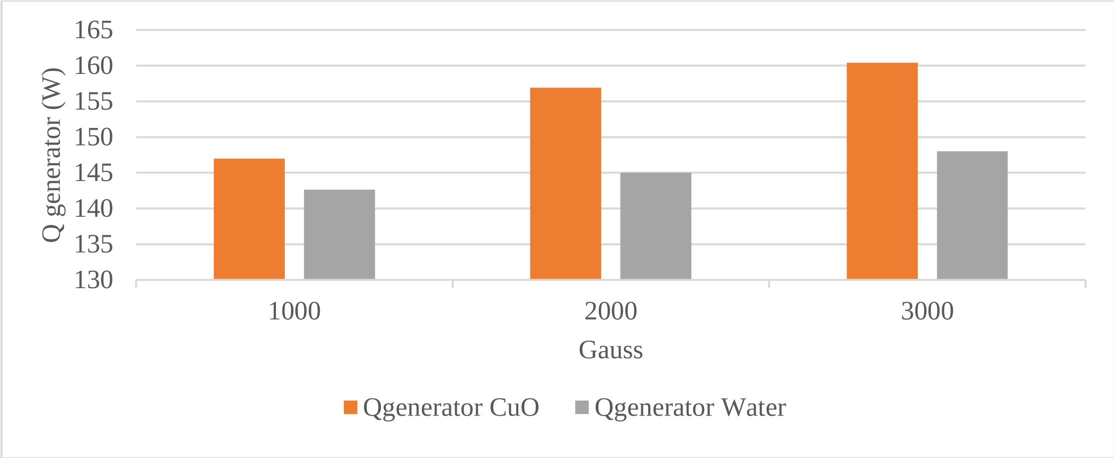

Fig. 11 Thermal Energy at Generator at Different Magnetic Fields

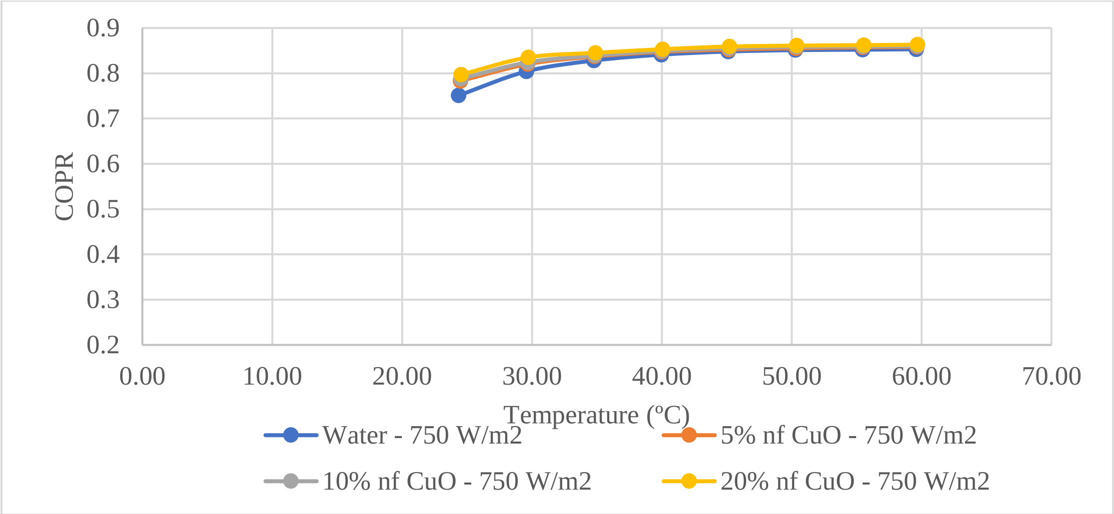

Fig. 12 Coefficient of Performance at different CuO %

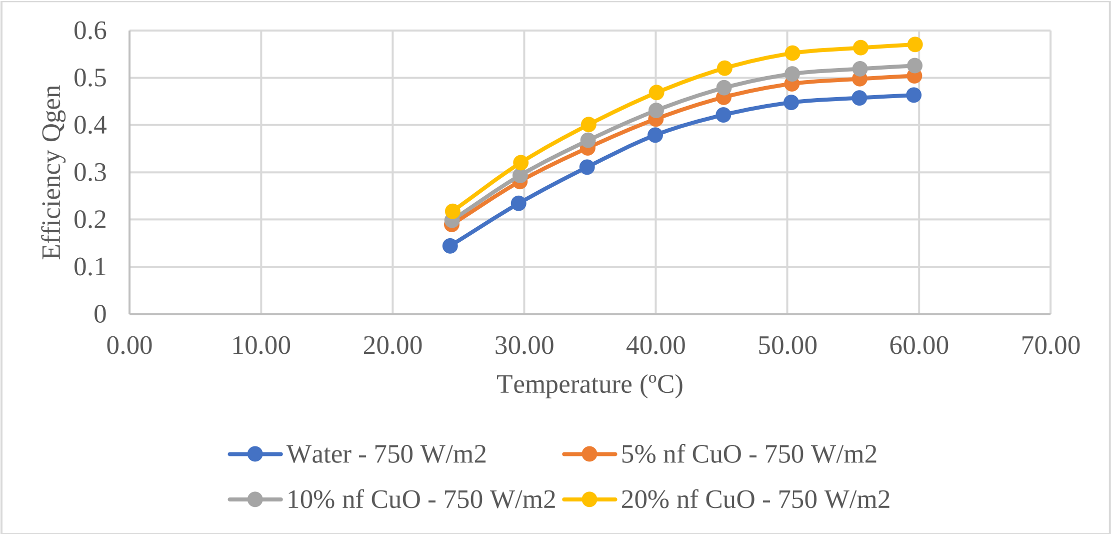

Fig. 13 Generator efficiency at different CuO %

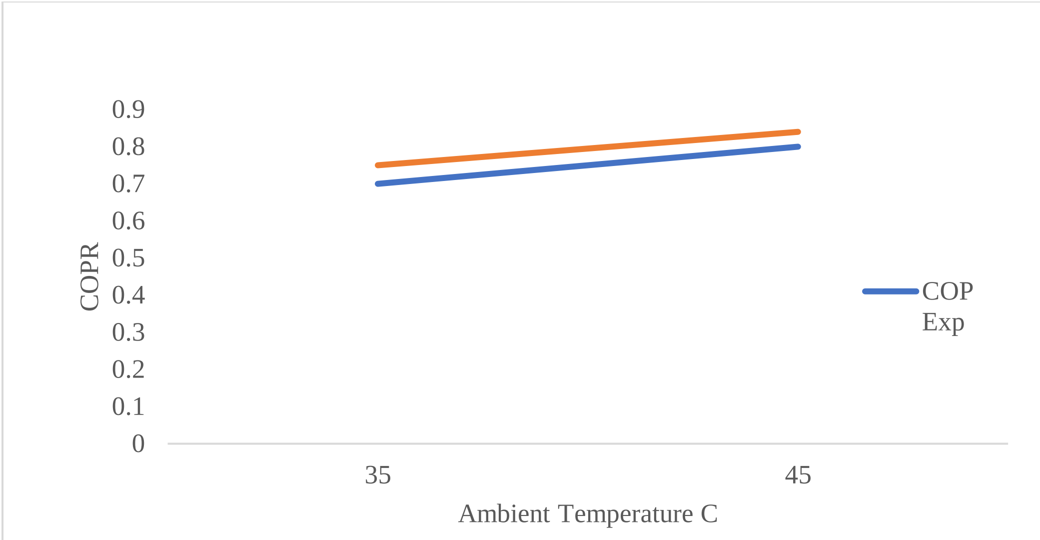

Fig. 14 Predicted COP versus experimental data, Rejeb et al. [4]

5. Model Validation

The data collected after a solar air conditioning system (SACS) using Lithium-Bromide/water (Li–Br/ H2O) solution and nanofluid-based Al2O3/H2O and Cu/H2O) with parabolic trough collectors (PTC) under hot and humid climate conditions reported by Rejeb et al. [4] has been used to validate the model predicted resulted of the Coefficient of Performance as presented in Figure.14. As reported in reference [4] the best performance results were obtained using nanofluid Cu/H2O; thus, Figure .14 was established using the data of reference [4] at the concentration of nanoparticle CuO (0.2 and 0.5 wt %) and the coefficient of performance (COP) of an absorption chiller for hot and cold days under Sharjah weather conditions i.e. ambient temperatures between 35-45 ºC and solar radiation of about 750 w/m^2 and compared with our predicted numerical results and same conditions. It can be shown from Figure 14 that a satisfactory agreement was achieved between the present model and the data of Rejeb et al. [4] with a discrepancy of a maximum of 5%. We feel that this discrepancy was caused by the choice of the parameters in Table 1 to calculate the thermophysical properties of the nanofluid CuO that impact the heat transfer coefficient and the heat transfer flow driving the absorption chiller at the generator.

6. Conclusion

The presented model compared fairly with experimental data with reasonable discrepancy. It was demonstrated that higher solar radiations have a significant impact on heat transfer fluid flow rates; however, low solar radiations increased the nanofluid-based CuO heat transfer flow rates over the water-based ones. Also, it has been shown that the higher the concentration of the nanofluid CuO, the higher the generator's thermal energy input compared to the heat transfer fluid-based water and the coefficient of performance of the absorption system.

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References

[1] International Energy Agency (IEA), Solar Heating and Cooling Programme, International Energy Agency: Paris, France, Annual Report, 2019. [Online]. Available: https://www.iea-shc.org/annual-reports

[2] The Future of Cooling, Opportunities for Energy-Efficient Air Conditioning, International Energy Agency, OECD/IEA: Paris, France, 2018. [Online]. Available: https://www.iea.org/reports/the-future-of-cooling

[3] Werner Weiss, and Monika Spö;rk-Dür, “Solar Heat Worldwide 2019 Edition: Global Market Development and Trends in 2018, In Detailed Market Figures 2017; IEA Solar Heating & Cooling Programme: Graz, Austria, 2019. [Online]. Available: https://www.iea-shc.org/Data/Sites/1/publications/Solar-Heat-Worldwide-2019.pdf

[4] Oussama Rejeb, Chaouki Ghenai, and Maamar Bettayeb, “Modeling and Simulation Analysis of Solar Absorption Chiller Driven by Nanofluid-based Parabolic Trough Collectors (PTC) under Hot Climatic Conditions,” *Case Studies in Thermal* Engineering, vol. 19, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[5] Han Yue et al., “Study on the Performance of Photovoltaic/Thermal Collector–Heat Pump–Absorption Chiller Tri-Generation Supply System,” *Energies*, vol. 16, no. 7, pp. 1-26, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[6] Ali Al-Alili, Yunho Hwang, and Reinhard Radermacher, "Review of Solar Thermal Air Conditioning Technologies," *International Journal of Refrigeration*, vol. 39, pp. 4-22, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[7] Christopher Baldwin, and Cynthia A. Cruickshank, "A Review of Solar Cooling Technologies for Residential Applications in Canada," *Energy Procedia*, vol. 30, pp. 495-504, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[8] Carlos Infante Ferreira, and Dong-Seon Kim, "Techno-Economic Review of Solar Cooling Technologies Based on Location-Specific Data," *International Journal of Refrigeration*, vol. 39, pp. 23-37, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[9] A. Allouhi et al., "Solar Driven Cooling Systems: An Updated Review," *Renewable and Sustainable Energy Reviews*, vol. 44, pp. 159-181, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[10] Ioan Sarbu, and Calin Sebarchievici, "Review of Solar Refrigeration and Cooling Systems," *Energy and Buildings*, vol. 67, pp. 286-297, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[11] X.Q. Zhai et al., "A Review for Research and New Design Options of Solar Absorption Cooling Systems," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 9, pp. 4416-4423, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[12] V. Boopathi Raja, and V. Shanmugam, "A Review and New Approach to Minimize the Cost of Solar Assisted Absorption Cooling System," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 9, pp. 6725-6731, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[13] A. Aliane et al., "An Illustrated Review on Solar Absorption Cooling Experimental Studies," *Renewable and Sustainable Energy Reviews*, vol. 65, pp. 443-458, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[14] H.Z. Hassan, and A.A. Mohamad, "A Review on Solar Cold Production through Absorption Technology," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 7, pp. 5331-5348, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[15] M.U. Siddiqui, and S.A.M. Said, "A Review of Solar-Powered Absorption Systems," *Renewable and Sustainable Energy Reviews*, vol. 42, pp. 93-115, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[16] Zain Ul Abdin, and Ahmed Rachid, "A Survey on Applications of Hybrid PV/T Panels," *Energies*, vol. 14, no. 4, pp. 1-23, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[17] Emiliano Bellini, Photovoltaic-Thermal Panel from China, PV Magazine, 2022. [Online]. Available: https://www.pv-magazine.com/2022/01/21/photovoltaic-thermal-panel-from-china/

[18] Muhammad Tauha Ali, "Solar Cooling Overview," *Thermopedia*, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[19] Sachin Kaushik, and S. Singh, "Thermodynamic Analysis of Vapor Absorption Refrigeration System and Calculation of COP," *International Journal for Research in Applied Science and Engineering Technology*, vol. 2, no. 2, 2014. [Google Scholar] [Publisher Link]

[20] Samuel Sami Howard, "Investigation of Low-Temperature Desalination Process by Flashing, PV-Thermal, Thermal Storage, and Magnetized Nanofluid," *SSRG International Journal of Thermal Engineering*, vol. 9, no. 1, pp. 1-11, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[21] Samuel Sami Howard, "Modeling and Validation of PV Solar-Thermoelectric Generators Using Magnetized Nanofluids," *Journal of Modern Green Energy*, vol. 1, no. 5, pp. 1-12, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[22] Samuel Sami Howard, "The Behavior of Magnetized PV-Th Integrated Organic Rankine Cycle ORC with Cooling Capabilities," *SSRG International Journal of Thermal Engineering*, vol. 8, no. 1, pp. 1-12, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[23] Samuel Sami Howard, "Prediction of Behavior of Thermal Storage, PV-Thermal Solar Collector with Nanofluids and Phase Change Material," *SSRG International Journal of Thermal Engineering*, vol. 6, no. 1, pp. 11-27, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[24] Samuel Sami Howard, "Analysis of Nanofluids Behavior in a PV-Thermal-Driven Organic Rankine Cycle with Cooling Capability," *Applied System Innovation*, vol. 3, no. 1, pp. 1-21, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[25] Samuel Sami Howard, "Study of the Impact of PV-Thermal and Nanofluids on the Desalination Process by Flashing," *Applied System Innovation*, vol. 3, no. 1, pp. 1-22, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[26] Liu Yang et al., "Simulating and Experimental Research on a Low-Concentrating PV/T Triple-Generation System," *Energy Conversion and Management*, vol. 199, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[27] Samuel Sami Howard, and C. Campoverde, "Dynamic Simulation and Modeling of a Novel Combined Hybrid Photovoltaic-Thermal Panel Hybrid System," *International Journal of Sustainable Energy and Environmental Research*, vol. 7, no. 1, pp. 1-23, 2018. [Google Scholar] [Publisher Link]

[28] Samuel Sami Howard, and E. Marin, "Modelling and Simulation of PV Solar-Thermoelectric Generators using Nano Fluids," *International Journal of Sustainable Energy and Environmental Research*, vol. 8, no. 1, pp. 70-99, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[29] Satha Aphornratana, and Thanarath Sriveerakul, "Experimental Studies of a Single-Effect Absorption Refrigerator Using Aqueous Lithium-Bromide: Effect of Operating Condition to System Performance," *Experimental Thermal and Fluid Science*, vol. 32, no. 2, pp. 658–669, 2007. [CrossRef] [Google Scholar] [Publisher Link]