THERMODYNAMIC ANALYSIS OF ABSORPTION COOLING SYSTEM WITH LiBr-Al₂O₃-WATER NANOFLUID USING SOLAR ENERGY

by

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Together with the developing nanotechnology, nanofluids and nanoparticles are used as working fluid in energy applications. It is foreseen that nanoparticles have high heat conduction coefficient and it will increase system performance by using as a working fluid in energy systems. Many studies in the literature show that nanofluids increase the heat transfer rate by improving heat transfer. In this study, a performance analysis of an absorption cooling system using solar energy was performed as numerically. LiBr-Al₂O₃-water nanofluid has been used in the cooling system as working fluid. The thermodynamic values and calculations used in the analyses were performed with Engineering Equation Solver program. Heat load necessary for the generator is provided with a flat plate solar collector. For different operation condition, the variation of COP values was determined depend on Al_2O_3 -water nanoparticle concentration ratio. When the Al_2O_3 -water nanoparticle concentrations are changed as 0%, 0.5% and 0.1%, it was determined that the COP values increased. Nanoparticles added to the refrigerant at certain concentration values affects the COP values positively of cooling systems. Maximum COP value is 0.86 for 85 °C generator temperature and 0.1% Al₂O₃-water nanoparticle concentration. The lowest COP value was obtained for the 75 °C generator temperature. When the Al₂O₃-water nanoparticle concentration was increased together with the generator temperature, COP values also increased. When the nanoparticle concentration of the working fluid increases, the viscosity of the nanofluid can be increases. Due to, increased viscosity increases the pressure drop in the flow channel and the pump power required for the flow. Thus, minimum viscosity with maximum thermal conductivity optimisation in applications is very important.

Key words: thermodynamic analysis, absorption, cooling, libr, alumina, nanofluid

Introduction

Today, nanotechnology is an extremely important issue for developed countries. It is necessary that to carry out theoretical and experimental studies because the increase use of nanotechnology applications. When dimensions of the device production materials become smaller, their working speed increases and new and superior properties of material are emerging. Nanotechnology provides to design, production and control of new materials with aid of structures and components in nanoscale [1]. Many properties of engineering materials are due to internal structures in micrometer level. The superior properties of the materials produced on the nanoscale are due to their structures ten or several hundred times smaller than the micro

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meter. As the nanodimensions of the materials are reduced, the quantum properties of those materials come to the forefront. This situation also offers superior properties of the material [2]. Nanotechnology has a very important potential for many sectors. Nanotechnology is started to be used in areas such as nanomedicine, manufacturing, energy, electronics and smart cities.

In absorption cooling systems, the compressor used in conventional cooling systems is replaced by a thermal compressor. Thermal compressor is consisting of generator, heat exchanger, absorber, pump and expansion valve. The necessary heat for the generator can be obtained from sources such as solar energy, geothermal energy and waste heat energy. In this study, the heat required for the generator is provided by solar energy. Schematic representation of LiBr-Al₂O₃-water absorption cooling system powered by solar energy is given in fig. 1.



Figure 1. Schema of LiBr- Al₂O₃-H₂O absorption cooling system powered by solar energy

Elberry et al. [3] investigated power plants using absorption refrigeration cycle. The energy of the exhaust waste heat was used for the power of the cooling system. The effects of different working parameters such as ambient temperature, relative humidity, compressor inlet air temperature, on performance were examined. It is determined that there is an 11% increase in the electricity produced when the inlet air temperature decreases. Sun et al. [4] have analyzed single-effect absorption refrigeration systems using R1234yf ionic liquid as working fluids. The effects of production, evaporation, condensation and absorption temperature and compression ratio on cooling performance and circulation rate were examined under different operating conditions. Wu et al. [5] investigated the effect of LiBr-H₂O nanofluid on magnetic field for vapor absorption as experimentally. They determined that increasing the rate of vapor absorption is related to the frequency of nanoparticle motion and related. Dai et al. [6] have examined NH₃-H₂O absorption heat pump using solar collector as heat source. A mathematical model of the heat pump has been created. They showed that the heat exchanger size of the solution cooled absorber had the highest effect on the cycle. It has also shown that adding solar collectors to the cycle can reduce operating costs by more than 25%. Arafia et al. [7] have investigated n-butane absorption refrigeration system using merchant hydrocarbons as absorbents. Waste heat was used as the heat source in

the cycle. Different evaporator, condenser and absorber temperatures were compared to select the most suitable working fluid in the absorption cooling system. The results revealed that the best performance among working fluids was achieved with butane/heavy naphtha. Liu et al. [8] have studied that performance analysis of a coupled LiBr-H₂O absorption chiller/kalina cycle for using of low grade waste heat. As a result of the study, it shows that for all analyzes, the optimum turbine inlet pressures were achieved as 3200-3300 kPa for certain conditions. De [9] have compared of solar-driven single and double-effect LiBr-H2O vapor absorption cycle for cold storage. They have developed a thermal model of cooling systems. In addition, an economical model has developed to calculate the pay-back period. Xu et al. [10] have theoretically examined the convective thermal properties of nanofluids in porous foams. They determined that the pressure drop in nanofluid caused an increase in nanoparticle concentration. Also, the raise in foam porosity reduction the Nusselt number. Xu et al. [11] have evaluated the physical properties of nanofluid and metal foam in different types of flow and heat transfer. They have summarized the properties of flow and heat transfer. Xu et al. [12] have examined the numerical analysis of convective heat transfer of a nanofluid in porous foams. They used the lattice Boltzmann (LB) method. As a result of the study, they found that the decrease in porosity, Reynolds number, and Darcy number, increased Nusselt number. Xu et al. [13] investigated the effects of thermal conductivity and concentration of nanoparticle on natural-convection. They found that natural-convection increase depend on Nusselt number and porosity. Xu et al. [14] examined the flow and heat transfer properties of the nanofluid-flowing from metal foams. The results have found that the increase in the volume fraction of nanoparticles increases the pressure drop and Nusselt number. Ghaneifar et al. [15] have carried out mixed convection heat transfer of Al₂O₃ nanofluid in a horizontal channel. Results of paper show that heat transfer increases due to the low thermal resistance for a high sources thermal conductivity. Moreover, the results show that the effect of nanofluid concentration on average Nusselt number is low, the effect on Reynolds number is high. Chen et al. [16] have investigated on bubble specifications of time periodic subcooled flow boiling in annular ducts due to wall heat flux oscillation. Results show that the bubble parameters do oscillate periodically in time and are at the same frequency as the applied wall heat flux. Tariq et al. [17] have examined thermal performance of normal-channel facile heat sink using water and TiO₂-H₂O nanofluids. Results presented that the base temperature of normal-channel facile heat sink was been like as mini-channel integral fin heat sink. The pressure drop of normal channel was found higher for when compared to mini channel heat sink. Shahsavar et al. [18] have investigated melting and solidifcation in a wavy double pipe latent heat thermal energy storage system as numerically. Results determined that effect of waviness on the pumping power is very low for dimensionless wavelengths higher than two. Bechir et al. [19] examined heat and mass transfer enhancement by using binary nanofluid in NH₃-H₂O bubble absorption processes. The study determined that the addition of nanoparticles improved the absorption performance in the bubble adsorption process. Jaballah et al. [20] examined the enhancement of the performance of bubble absorber using hybrid nanofluid as a cooled NH₃-H₂O absorption system. The results determined that the hybrid nanofluid is the best refrigaration platform. Hybrid nanofluids provide high heat transfer amount due to their high thermal conductivity and specific heat. Jaballah et al. [21] have investigated influence of hybrid nanofluid and refrigerant flow direction on heat and mass transfer improvement. The results of study show that the absorption process depends on the direction of refrigerant flow and the type of working platform.

There are studies in the literature showing that nanoparticles improve heat transfer and system performance. However, some studies have shown the opposite of these results. Therefore, studies on this subject should continue rapidly. This study showed that the Al_2O_3 nanoparticles added to the working fluid increased the heat transfer and system performance. It will continue to be used in nanofluid refrigeration systems, chemical processes and nuclear reactors as studies increase and positive results are achieved. In this study, alumina (Al_2O_3) particles were added to the working fluid in the LiBr-Al₂O₃-water absorption cooling system powered by solar energy. The effects of the added nanoparticle on cooling system performance have been examined.

Thermodynamic analysis

In this paper, while Al_2O_3 - H_2O nanofluid is refrigerant, lithium bromide is adsorbent in absorption cooling system. The working principle of this system can be summarized as follows according to fig. 1. Refrigerant vapor is produced from the weak solution (state Point 3) using generator heat (solar energy). The rich solution (state Point 4) transmits back to the absorber by means of the heat exchanger and expansion valve. The refrigerant vapor come from the evaporator (state Point 10) is absorbed into the rich solution (state Point 6) in the absorber (state Point 1). After that, the weak solution is pressurized by the pump and it enters the geneator by-passing the heat exchanger for heat recovery. The refrigerant vapor come from the generator condenses in the condenser (state Point 8), thereafter gets throttled by expansion valve. Lastly, refrigerant evaporates in the evaporator to produce cooling.

In this cycle, the mass-flow rate, specific and energy balances can be recognized:

$$\sum \dot{m}_{\rm in} = \sum \dot{m}_{\rm out} \tag{1}$$

$$\sum x_{\rm in} \dot{m}_{\rm in} = \sum x_{\rm out} \dot{m}_{\rm out} \tag{2}$$

$$\sum \dot{Q} + \sum W + \sum \dot{m}_{\rm in} h_{\rm in} - \sum \dot{m}_{\rm out} h_{\rm out} = 0 \tag{3}$$

$$\dot{m}_9 = \dot{m}_{10} \tag{4}$$

where \dot{m} [kgs⁻¹] is the mass-flow rate of working fluids and water, $\dot{m}_1 = \dot{m}_7$, $\dot{m}_2 = \dot{m}_1$, $\dot{m}_3 = \dot{m}_2$, $\dot{m}_5 = \dot{m}_4$, $\dot{m}_6 = \dot{m}_5$, $\dot{m}_8 = \dot{m}_7$, and $\dot{m}_9 = \dot{m}_8$.

Energy balance on the evaporator can be defined as eq. (5) [22]:

$$Q_{\rm E} = \dot{m}_{10} h_{10} - \dot{m}_9 h_9 \tag{5}$$

$$\dot{Q}_{\rm E} = \dot{m}_{17} \ C_p \left(T_{17} - T_{18} \right) = U A_E \Delta T_{m\rm E} \tag{6}$$

Evaporator temperature, $T_{\rm E}$, can be calculated using [23]:

$$T_{\rm E} = \frac{T_{10} - T_9}{\ln\left(\frac{T_{10}}{T_9}\right)} \tag{7}$$

$$\Delta T_{mE} = \left[\frac{\left(T_{17} - T_{10}\right) - \left(T_{18} - T_{9}\right)}{\ln\left(\frac{T_{17} - T_{10}}{T_{18} - T_{9}}\right)} \right]$$
(8)

Since \dot{m}_{10} is known, mass balances in the absorber evaporator can be calculated and written:

$$x_1 \dot{m}_1 = x_6 \dot{m}_6 \tag{9}$$

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 x_i : mass fraction

$$x_i = x(T_i, P_i)$$
 for LiBr and H₂O (10)

$$x_7 = 0, \ x_{11} = 0, \ x_2 = x_1, \ x_3 = x_2, \ x_5 = x_4, \ x_6 = x_5, \ x_8 = x_7, \ x_9 = x_8$$

$$P_{i} = P(T_{i}, x_{i}) \text{ for LiBr and for } H_{2}O$$

$$P_{2} = P_{3} = P_{4} = P_{5} = P_{7} = P_{8} = P_{\text{high}}, P_{1} = P_{6} = P_{9} = P_{10} = P_{\text{low}}$$
(11)

where $P_{high} = 9.66$ [kPa], $P_{low} = 0.934$ [kPa] (pressure values were calculated by EES), ambiant temperature $T_a = 25$ °C, evaporator temperature $T_{10} = 6$ °C, generator solution exit temperature $T_4 = 90$ °C, weak solution mass fraction $x_1 = 55\%$, and strong solution mass fraction $x_4 = 60\%$. Solution heat exchanger exit temperature $T_3 = 65 \text{ °C}$ (pressure values were calculated by

EES). Generator vapor exit temperature $T_7 = 85$ °C (temperature values were calculated by EES).

The thermodynamic properties at the Point 5 can be determined from the energy balance on the solution heat exchanger using eqs. (12) and (13), and assuming an adiabatic state [24-28]: $\dot{m}_2 h_2 + \dot{m}_4 h_4 = \dot{m}_2 h_2 + \dot{m}_4 h_4$

$$p_2h_2 + m_4h_4 = m_3h_3 + m_5h_5 \tag{12}$$

$$\dot{Q}_{\text{hex}} = \dot{m}_1 \left(h_3 - h_2 \right) = \dot{m}_4 \left(h_4 - h_5 \right)$$

$$T = T$$
(13)

$$\varepsilon_{\rm ff,hex} = \frac{T_4 - T_5}{T_4 - T_2}, \ \varepsilon_{\rm ff,hex} = 0.64$$
$$C_{\rm h} = \frac{\dot{m}_4 (h_4 - h_5)}{T_4 - T_5}, \ C_{\rm c} = \frac{\dot{m}_3 (h_3 - h_2)}{T_3 - T_2}$$

where $h_i = h(T_i, x_i)$ for LiBr and H₂O and $T_i = T(h_i, x_i)$ for LiBr and H₂O.

Concentration of solution at the absorber and generator, the pump work can be obtained [29]:

$$W_{\rm p} = \dot{m}_1 v_1 \left(P_2 - P_1 \right) \tag{14}$$

$$h_2 = h_1 + \frac{W_p}{\dot{m}_1} \tag{15}$$

$$v_i = v(T_i, x_i)$$
 for LiBr and H₂O (16)

Energy balance on the absorber can be defined [30]:

$$\dot{Q}_{\rm A} = \dot{m}_{10}h_{10} + \dot{m}_6h_6 - \dot{m}_1h_1 \tag{17}$$

$$\dot{Q}_{\rm A} = \dot{m}_{12} \ C_p \left(T_{14} - T_{13} \right) = U A_{\rm A} \Delta T_{m\rm A} \tag{18}$$

Absorber temperature, T_A , can be calculated:

$$T_{\rm A} = \frac{T_1 - T_{10}}{\ln\left(\frac{T_1}{T_{10}}\right)} \tag{19}$$

$$\Delta T_{mA} = \left[\frac{\left(T_6 - T_{14}\right) - \left(T_1 - T_3\right)}{\ln\left(\frac{T_6 - T_{14}}{T_1 - T_{13}}\right)} \right]$$
(20)

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$$\dot{m}_1 = \dot{m}_{10} + \dot{m}_6 \tag{21}$$

By applying the energy ba lance for the solution, the generator is given:

$$\dot{Q}_{\rm G} = \dot{m}_4 h_4 + \dot{m}_7 h_7 - \dot{m}_3 h_3 \tag{22}$$

$$\dot{m}_3 = \dot{m}_4 + \dot{m}_7, \quad \dot{m}_3 x_3 = \dot{m}_4 x_4 + \dot{m}_7$$
 (23)

$$Q_{\rm G} = \dot{m}_{11}C_p \left(T_{11} - T_{12}\right) = \dot{m}_7 h_7 + \dot{m}_4 h_4 - \dot{m}_3 h_3 = U A_{\rm G} \Delta T_{m\rm G}$$
(24)

$$f = \frac{\dot{m}_3}{\dot{m}_7} = \frac{1 - x_4}{x_3 - x_4} \tag{25}$$

Generator temperature, $T_{\rm G}$, can be calculated using:

$$\Delta T_{mG} = \left[\frac{\left(T_{11} - T_4\right) - \left(T_{12} - T_7\right)}{\ln\left(\frac{T_{11} - T_4}{T_{12} - T_7}\right)}\right]$$
(26)

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The condenser heat can be determined from an energy balance using [31, 32]:

$$\dot{Q}_{\rm C} = \dot{m}_4 \left(h_7 - h_8 \right)$$
 (27)

$$\dot{Q}_{\rm C} = \dot{m}_{15} C_p \left(T_{16} - T_{15} \right) = U A_{\rm C} \Delta T_{m\rm C}$$
⁽²⁸⁾

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Condenser temperature, $T_{\rm C}$, can be calculated using:

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$$\Delta T_{mC} = \left[\frac{\left(T_8 - T_{15}\right) - \left(T_8 - T_{16}\right)}{\ln\left(\frac{\left(T_8 - T_{15}\right)}{\left(T_8 - T_{16}\right)}\right)} \right]$$
(29)

The COP for the absorption cooling system is defined as the ratio of the sum of the evaporator heat load, generator heat load and pump power. The COP is defined [33, 34]:

$$COP_{\text{cooling}} = \frac{Q_{\text{E}}}{\dot{Q}_{\text{G}} + W_{\text{p}}} = \frac{(\dot{m}_{10}h_{10} - \dot{m}_{9}h_{9})}{(\dot{m}_{4}h_{4} + \dot{m}_{7}h_{7} - \dot{m}_{3}h_{3}) + W_{\text{p}}}$$
(30)

If W_p is neglected:

$$COP_{\text{cooling}} = \frac{\dot{Q}_{\text{E}}}{\dot{Q}_{\text{G}}} = \frac{\dot{m}_{10}h_{10} - \dot{m}_{9}h_{9}}{\dot{m}_{4}h_{4} + \dot{m}_{7}h_{7} - \dot{m}_{3}h_{3}}$$
(31)

$$COP_{\text{heating}} = \frac{\dot{Q}_{\text{A}} + \dot{Q}_{\text{C}}}{\dot{Q}_{\text{G}}}$$
(32)

$$\dot{Q}_{\rm G} = \dot{Q}_{\rm u} \tag{33}$$

Solar collectors are modeled with the formulation as using eq. (34) and eqs. (35)-(37):

$$\dot{Q}_{\rm u} = A_{\rm c} I_R \eta_{\rm c} \tag{34}$$

The uniform solar heat flux \dot{Q}_u on the absorber tube of the collector for the generator and absorber is defined [35-39]:

$$\dot{Q}_{\rm u} = F_R A \Big[\big(\tau \alpha \big) I - U_L \big(T_{\rm in} - T_{\rm a} \big) \Big]$$
(35)

where \dot{Q}_{u} is the useful energy collected in system collectors and A_{c} – the collector area. The collector efficiency η_{c} is:

$$\eta_{\rm c} = F_R \left[\left(\tau \alpha \right) - U_L \frac{T_{\rm in} - T_{\rm a}}{I_R} \right] = \dot{m} C_p \left(T_{\rm ref} - T_{\rm s} \right)$$
(36)

where T_{in} [°C] is the collector inlet temperature, T_a [°C] – the environment or ambient temperature, τ – the transmission coefficient, α – the absorption coefficient, U_L [Wm⁻²K⁻¹] – the overall heat transfer coefficient, and F – the solar-collector efficiency factor. Typical values of $\tau \alpha$ and U_L for the evacuated tube collector are commonly taken as 0.84-0.86 and 0.8 W/m²K, respectively, [36-38, 40-43].

In this work, nanofluids are considered as the working fluid (Al_2O_3) for the hot loop. Physical properties of the Al_2O_3 nanoparticles and water in the calculations are presented in tab. 1. Nanofluid thermal conductivity, specific heat capacity, density and dynamic viscosity are evaluated with eqs. (35)-(37).

Table 1. Physical properties of nanomaterial and water [44, 45]

	Material	ρ [kgm ⁻³]	$C_p \left[\mathrm{Jkg}^{-1} \mathrm{K}^{-1} ight]$	$K \left[\mathrm{Wm}^{-1} \mathrm{K}^{-1} ight]$
Nanoparticle, np	Al_2O_3	3970	765	40
Base fluid, bf	Water	$\rho_{\rm bf}(T,P)$ $\rho_{\rm bf}=997 \text{ kg/m}^3$	$C_{p,bf}(T, P)$ $C_{p,bf} = 0.605 \text{ j/kgK}$	$k_{ m bf}(T,P) \ k_{ m bf} = 0.605 \ { m W/mK}$

Several correlations for specific heat capacity of the nanofluid are available but the below formula [35, 46-50]:

$$C_{p,\text{nf}} = \frac{(1-\psi)\rho_{\text{bf}} C_{p,\text{bf}} + \rho_{\text{np}} C_{p,\text{np}}}{\rho_{\text{nf}}}, \ C_{p,\text{bf}} = C_p(T,x)$$
(37)

The density of nanofluid is evaluated:

$$\rho_{\rm nf} = (1 - \psi) \rho_{\rm bf} + \rho_{\rm np}, \quad \rho_{\rm nf} = \rho(T, x) \tag{38}$$

where ρ_{nf} , ρ_{bf} , and ρ_{np} , are the nanofluid, base fluid, and nanoparticles densities, respectively, and ψ is the volume fraction [43, 51-56]:

$$\dot{m}_{12}C_{p,nf}(T_{12} - T_{13}) = A_c I_R \eta_c$$

$$\dot{Q}_G = \dot{m}_{11}C_{p,nf}(T_{11} - T_{12}) = \dot{m}_7 h_7 + \dot{m}_4 h_4 - \dot{m}_3 h_3 = U A_G \Delta T_{mA}$$
(39)

Results

The COP values were determined of absorption cooling system for different generator temperatures and nanoparticle concentrations and are given in fig. 2. The Al_2O_3 nanoparticle concentrations were changed between 0 and 0.1. Both increasing the nanoparticle concentrations and increasing the generator temperature caused a significant increase in COP values. The COP value is 0.71 in the operating condition where the generator temperature is 75 °C, and it reaches 0.86 when the generator temperature rises to 85 °C. It is seen fig. 2 that nanoparticles

added to the refrigerant at certain concentration values change the COP values positively of cooling systems.

The COP values depending on the change in nanoparticle concentration were determined and are given in fig. 3. As the nanoparticle concentration in the working fluid increases, the thermal conductivity coefficient of the nanofluid increases. As an effect of this, as the amount of heat the evaporator extract from the environment will increase, the COP value also increases. The highest COP value was found to be about 0.86 for 85 °C generator temperature. This value was followed by COP value is 0.77 and generator temperature is 80 °C. The lowest COP value was obtained for the 75 °C generator temperature. When [5, 13, 15] are examined, it is seen that the nanoparticles added to the working fluid increase the heat transfer. Hence, the increase in COP seen in fig. 3 is supported by these results. Moreover, as seen in fig. 3, only increasing the nanoparticle concentration is not enough to increase the COP value. Increasing both the nanoparticle concentration and the generator temperature would be more suitable for increasing the COP value in absorption cooling system.



Changes of heat transfer rate depending on generator temperatures were calculated and are given in fig. 4. Increasing the generator temperature increases the amount of heat transfer in the evaporator. It is clearly seen that the nanoparticle added to the working fluid increases the heat transfer in the system elements. Nanoparticles increase the heat transfer co-



Figure 4. Change of heat transfer rate with generator temperature

efficient of the fluid, as a result, it increases heat transfer too. In addition, features that appear in nanometer size such as the interfacial layer between the particles, the random movement of the particles (Brownian motion) and Kapitza resistance are also very important in the increase of heat transfer. As the nanoparticle concentration in the working fluid increases, the thermal conductivity coefficient of the nanofluid increases. Hamida et al. [33] investigated the effect of copper nanoparticles on the absorption of vapor into a liquid film of LiBr aqueous solution flowing down over a cooled vertical channel. The results showed that binary nanofluids increase the mass

and heat transfer more than the base liquid, and the efficiency of the nanofluid is higher than the efficiency of the base liquid [22]. Similarly, the heat transfer in the absorber increases depending on the generator temperature. In this process, the effects of nanoparticles were seen. Also, with the increase of the generator temperature, there was a slight decrease in the heat transfer in the condenser.

Conclusions

In this study, a performance analysis of an absorption cooling system was performed. Heat load necessary for the generator was provided with a flat plate solar collector. The LiBr-Al₂O₃-H₂O nanofluid has been used in the absorption cooling system as working fluid. Change of COP values was determined for different operation conditions depend on Al₂O₃-H₂O nanoparticle concentration ratio. This study showed that nanoparticles added to the working fluid in absorption cooling systems increase the COP. In the absorption cooling system in this study, using the nanoparticle together with increasing the generator temperature increases the cooling performance. Therefore, in an absorption cooling system, several variables need to be optimized to achieve optimum cooling performance. As result of this study, it has been observed that the nanoparticles added to the working fluid increase the heat transfer and therefore, affect the system performance positively. Nanoparticles increase the heat transfer coefficient of the fluid, as a result, it increases heat transfer too. As the nanoparticle concentration in the working fluid increases, the thermal conductivity coefficient of the nanofluid increases. However, as the nanoparticle concentration of the working fluid increases, the viscosity of the nanofluid also increases. Also, increased viscosity increases the pressure drop in the flow channel and the pump power required for the flow. Therefore, it is very important to achieve a 'minimum viscosity with maximum thermal conductivity' balance in practice.

There are studies in the literature showing that nanoparticles improve heat transfer and system performance. However, some studies have shown the opposite of these results. Therefore, studies on this subject should continue rapidly. It will continue to be used in nanofluid refrigeration systems, chemical processes and nuclear reactors as studies increase and positive results are achieved.

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Nomenclature

- surface area, $[m^2]$ A
- area of collector absorber plate, [m²] A_{c}
- C- specific heat capacity, $[Jkg^{-1}K^{-1}]$
- C_p – specific heat, [Jkg⁻¹K⁻¹]
- ŕ - solar-collector efficiency factor
- I_R - solar irradiance, [kWm⁻²]
- \dot{m}_i – mass-flow rate, [kgs⁻¹]
- Р - pressure, [kPa]
- $\dot{Q}_{\rm A}$ absorber heat load, [kW]
- Qс - condenser heat load, [kW]
- $\dot{Q}_{\rm E}$ evaporator heat load, [kW]
- $\dot{Q}_{\rm hex}$ solution heat exchanger heat load, [kW]
- $\dot{Q}_{\rm G}$ generator heat load, [kW]
- \tilde{Q}_{μ} uniform solar heat flux, [kW]

- Т - temperature, [°C]
- $T_{\rm A}$ absorber temperature, [°C]
- $T_{\rm E}$ evaporator temperature, [°C]
- $T_{\rm C}$ condenser temperature, [°C]
- $T_{\rm G}$ generator temperature, [°C] ΔT dimensionless temperature difference
- U heat transfer coefficient, [Wm⁻²K⁻¹]
- U_L overall heat transfer coefficient, [Wm⁻²K⁻¹]
- ν - velocity, [ms⁻¹]
- $W_{\rm p}$ – pump work, [kW]
- mass fraction х

Greek symbols

 α – absorption coefficient

Subscripts in – inlet nf – nanofluid np – nanoparticle out – outlet

References

- Murshed, S. M. S., et al., Investigations of Thermal Conductivity and Viscosity of Nanofluids, International Journal of Thermal Sciences, 47 (2008), 5, pp. 560-568
- Choi, S. U. S., et al., Enhancing Thermal Conductivity of Fluids with Nanoparticles, Proceedings, ASME International Mechanical Engineering Congress & Exposition, San Francisco, Cal., USA, 1995
- [3] Elberry, M. F., et al., Performance Improvement of Power Plants Using Absorption Cooling System, Alexandria Engineering Journal, 57 (2018), 4, pp. 2679-2686
- Sun, Y., et al., Performance Analysis of R1234yf/ionic Liquid Working Fluids for Single-Effect and Com-[4] pression-Assisted Absorption Refrigeration Systems, International Journal of Refrigeration, 109 (2020), Oct., pp. 25-36
- [5] Wu, S., et al., Experimental Investigation of the Effect of Magnetic Field on Vapour Absorption with LiBr-H₂O Nanofluid, Energy, 193 (2020), 116640
- Dai, E., et al., Theoretical and Experimental Investigation on a GAX-Based NH₃-H₂O Absorption Heat Pump Driven by Parabolic trough Solar Collector, Solar Energy, 197 (2020), 7, pp. 498-510
- [7] Arafia, M., et al., A Simulation Study of n-Butane Absorption Refrigeration System Using Commercial Hydrocarbons as Absorbents, International Journal of Refrigeration, 112 (2020), Apr., pp. 110-124
- Liu, Z., et al., Thermodynamic and Parametric Analysis of a Coupled LiBr/H₂O Absorption Chiller/Ka-[8] lina Cycle for Cascade Utilization of Low-Grade Waste Heat, Energy Conversion and Management, 205 (2020), 112370
- De, R. K., et al., Performance Comparison of Solar-Driven Single and Double-Effect LiBr-Water Vapor [9] Absorption System Based Cold Storage, Thermal Science and Engineering Progress, 17 (2020), 100488
- [10] Xu, H., et al., Analytical Considerations of Flow-Thermal Coupling of Nanofluids in Foam Metals with Local Thermal Non-Equilibrium (LTNE) Phenomena and Inhomogeneous Nanoparticle Distribution, International Journal of Heat and Fluid-flow, 77 (2019), June, pp. 242-255
- [11] Xu, H. J., et al., Review on Heat Conduction, Heat Convection, Thermal Radiation and Phase Change Heat Transfer of Nanofluids in Porous Media: Fundamentals and Applications, Chemical Engineering Science, 195 (2019), Feb., pp. 462-483
- [12] Xu, H. J., et al., Lattice Boltzmann Modelling on Forced Convective Heat Transfer of Nanofluids in Highly Conductive Foam Metals with Local Thermal Non-Equilibrium (LTNE) Effect, Journal of Porous Media, 22 (2019), 12, pp. 1553-1571
- [13] Xu, H., et al., The lattice Boltzmann Modelling on the Nanofluid Natural Convective Transport in a Cavity Filled with a Porous Foam, International Communications in Heat and Mass Transfer, 89 (2017), pp. 73-82
- [14] Xu, H., et al., Flow and Heat Transfer Characteristics of Nanofluid-Flowing through Metal Foams, International Journal of Heat and Mass Transfer, 83 (2015), C, pp. 399-407
- Ghaneifar, M., et al., Mixed Convection Heat Transfer of AL2O3 Nanofluid in a Horizontal Channel Subject-[15] ed with Two Heat Sources, Journal of Thermal Analysis and Calorimetry, 143 (2021), June, pp. 2761-2774
- [16] Chen, A., et al., Experimental Study on Bubble Characteristics of Time Periodic Subcooled Flow Boiling in Annular Ducts Due to Wall Heat Flux Oscillation, International Journal of Heat and Mass Transfer, 157 (2020), 119974
- [17] Tariq, H. A., et al., Hydro-Thermal Performance of Normal-Channel Facile Heat Sink Using TiO₂-H₂O Mixture (Rutile-Anatase) Nanofluids for Microprocessor Cooling, Journal of Thermal Analysis and Calorimetry, 145 (2021), May, pp. 2487-2502
- [18] Shahsavar, A., et al., Numerical Study of Melting and Solidifcation in a Wavy Doublepipe Latent Heat Thermal Energy Storage System, Journal of Thermal Analysis and Calorimetry, 141 (2020), 141, pp. 1785-1799
- [19] Bechir, M., et al. Numerical Study of Heat and Mass Transfer Enhancement for Bubble Absorption Process of Ammonia-Water Mixture without and with Nanofluids, Thermal Science, 22 (2018), 6B, pp. 107-3120

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- [20] Jaballah, R. B., et al. Enhancement of the Performance of Bubble Absorber Using Hybrid Nanofluid as a Cooled Absorption System, International Journal of Numerical Methods for Heat & Fluid-Flow, 29 (2019), 10, pp. 3857-3871
- [21] Jaballah, R. B., et al. The Influence of Hybrid Nanofluid and Coolant Flow Direction on Bubble Mode Absorption Improvement, *Mathematical Methods in the Applied Sciences*, On-line first, https://doi. org/10.1002mma.6605, 2020
- [22] Fong, K. F., et al., Performance Advancement of Solar Air-Conditioning through Integrated System Design for Building, Energy, 73 (2014), Aug., pp. 987-996.
- [23] Kim, S., et al., Performance Simulation of Ionic Liquid and Hydrofluorocarbon Working Fluids for an Absorption Refrigeration System, Ind. Eng. Chem. Res., 52 (2013), 19, pp. 6329-6335
- [24] Liu, X. Y., et al., Performance Comparison of Two Absorption Compression Hybrid Refrigeration Systems Using R1234yf/ionic Liquid as Working Pair, Energy Conversion and Management, 181 (2019), Feb., pp. 319-330
- [25] Misenheimer, C. T., et al., The Development of a Dynamic Single Effect, Lithium Bromide Absorption Chiller Model with Enhanced Generator Fidelity, Energy Conversion and Management, 150 (2017), Oct., pp. 574-587
- [26] González-Gil, A., et al., Experimental Evaluation of a Direct Air-Cooled Lithium Bromide-Water Absorption Prototype for Solar Air Conditioning, Applied Thermal Engineering, 31 (2011), 16, pp. 3358-3368
- [27] El-Shaarawi, M. A. I., et al., Unsteady Analysis for Solar-Powered Hybrid Storage LiBr-water Absorption Air-Conditioning, Solar Energy, 144 (2017), Mar., pp. 556-568
- [28] Al-Amir, Q. R., et al., Performance Assessment of LiBr-H₂O Absorption Chiller for Air Conditioning Purposes, Journal of Kerbala University, 15 (2017), 3, pp. 160-173
- [29] McLinden, M. O., et al., A Thermodynamic Analysis of Refrigerants: Possibilities and Tradeoffs for Low-GWP Refrigerants, International Journal of Refrigeration, 38 (2014), Feb., pp. 80-92
- [30] Moreno, D., et al., Absorption Refrigeration Cycles Based on Ionic Liquids: Refrigerant/Absorbent Selection by Thermodynamic and Process Analysis, *Applied Energy*, 213 (2018), Mar., pp. 179-194
- [31] Paulechka, Y. U., et al., Evaluation of Thermodynamic Properties for Non-Crystallizable Ionic Liquids, Thermochim Acta, 604 (2015), Mar., pp. 122-128
- [32] Razmi, A., et al., Thermodynamic and Economic Investigation of a Novel Integration of the Absorption-Recompression Refrigeration System with Compressed Air Energy Storage (CAES), Energy Conversion and Management, 187 (2019), May, pp. 262-273
- [33] Hamida, B., et al., Heat and Mass Transfer Enhancement for Falling Film Absorption Process in Vertical Plate Absorber by Adding Copper Nanoparticles, Arabian Journal of Science and Engineering, 43 (2018), May, pp. 4991-5001
- [34] Lizarte, R., et al., The COP Optimisation of a Triple-Effect H₂O/LiBr Absorption Cycle under off-Design Conditions, Applied Thermal Engineering, 99 (2016), C, pp. 195-205
- [35] Said, Z., et al., Energy and Exergy Efficiency of a Flat Plate Solar Collector Using pH Treated Al₂O₃ Nanofluid, Journal of Cleaner Production, 112 (2016), 5, pp. 3915-3926
- [36] Raj, P., et al., A Review of Studies Using Nanofluids in Flat-Plate and Direct Absorption Solar Collectors, Renewable and Sustainable Energy Reviews, 84 (2018), Mar, pp. 54-74
- [37] Gupta, H. K., et al., Investigations for effect of Al₂O₃-H₂O Nanofluid-Flow Rate on the Efficiency of Direct Absorption Solar Collector, Case Studies in Thermal Engineering, 5 (2015), C, pp. 70-78
- [38] Sint, N., et al., Theoretical Analysis to Determine the Efficiency of a CuO-water Nanofluid Based-Flat Plate Solar Collector for Domestic Solar Water Heating System in Myanmar, Solar Energy, 155 (2017), Oct., pp. 608-619
- [39] Sarsam, W. S., et al., A Review of Studies on Using Nanofluids in Flat-Plate Solar Collectors, Solar Energy, 122 (2015), Dec., pp. 1245-1265
- [40] Kasaeian, A., et al., A Review on the Applications of Nanofluids in Solar Energy Systems, Renewable and Sustainable Energy Reviews, 43 (2015), Mar., pp. 584-598
- [41] Atmaca, I., et al., Simulation of Solar-Powered Absorption Cooling System, Renewable Energy, 28 (2003), 8, pp. 1277-1293
- [42] Beggs, C., Energy: Management, Supply and Conservation, Routledge, London, UK, 2010
- [43] Pilatowsky, I., et al., Performance Evaluation of a Monomethylamine-Water Solar Absorption Refrigeration System for Milk Cooling Purposes, Applied Thermal Engineering, 2 (2004), 7, pp. 1103-1115
- [44] Zakaria, I., et al. Thermal Analysis of Al₂O₃-Water Ethylene Glycol Mixture Nanofluid for Single PEM Fuel Cell Cooling Plate: An Experimental Study, *International Journal of Hydrogen Energy*, 41 (2016), 9, pp. 5096-5112

- [45] Hatami, M., et al., Thermal Performance Evaluation of Alumina-Water Nanofluid in an Inclined Direct Absorption Solar Collector (IDASC) Using Numerical Method, Journal of Molecular Liquids, 231 (2017), Feb., pp. 632-639
- [46] Zhou, S., et al., Measurement of the Specific Heat Capacity of Water-Based Al₂O₃ Nanofluid, Applied Physics Letters, 92 (2008), 9, 093123
- [47] Sekhar, Y. R., et al., Study of Viscosity and Specific Heat Capacity Characteristics of Water-Based Al₂O₃ Nanofluids at Low Particle Concentrations, *Journal of experimental Nanoscience*, 10 (2015), 2, pp. 86-102
- [48] Gupta, M., et al., A Review on Thermophysical Properties of Nanofluids and Heat Transfer Applications, Renewable and Sustainable Energy Reviews, 74 (2017), July, pp. 638-670
- [49] Kumar, D., et al., A Comprehensive Review of Preparation, Characterization, Properties and Stability of Hybrid Nanofluids, Renewable and Sustainable Energy Reviews, 81 (2018), 2, pp. 1669-1689
- [50] Zhang, J., et al., Thermal-Hydraulic Performance of SiC-water and Al₂O₃-water Nanofluids in the Minichannel, Journal of Heat Transfer, 138 (2016), 2, 021705
- [51] Zawrah, M. F., et al., Stability and Electrical Conductivity of Water-Base Al₂O₃ Nanofluids for Different Applications, HBRC Journal, 12 (2016), 3, pp. 227-234
- [52] Nassan, T. H., et al., A Comparison of Experimental Heat Transfer Characteristics for Al₂O₃-Water and CuO-water Nanofluids in Square Cross-Section Duct, *International Communications in Heat and Mass Transfer*, 37 (2010), 7, pp. 924-928.
- [53] Shahrul, I. M., et al., A Comparative Review on the Specific Heat of Nanofluids for Energy Perspective, Renewable and Sustainable Energy Reviews, 38 (2014), Oct., pp. 88-98
- [54] Haddad, Z., et al., A Review on Natural Convective Heat Transfer of Nanofluids, Renewable and Sustainable Energy Reviews, 16 (2012), 7, pp. 5363-5378
- [55] Kerme, E. D., et al., Energetic and Exergetic Analysis of Solar-Powered Lithium Bromide-Water Absorption Cooling System, Journal of Cleaner Production, 151 (2017), May, pp. 60-73
- [56] Ozgoren, M., et al., Hourly Performance Prediction of Ammonia-Water Solar Absorption Refrigeration, Applied Thermal Engineering, 40 (2012), July, pp. 80-90

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