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EXPERIMENTAL ANALYSIS OF HYBRID AIR-CONDITIONING SYSTEM USING AL2O3 NANOFLUID VIA HEAT & MASS TRANSFER CHARACTERISTICS

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Abstract: Air conditioning systems are essential for maintaining comfortable indoor environments, but their energy consumption and environmental impact have become significant concerns. To address these issues, hybrid air conditioning systems have been developed, which combine different cooling technologies to improve energy efficiency and reduce environmental impact. One potential enhancement for such systems is the use of nanofluids, which have shown promise in improving the heat transfer characteristics of cooling fluids. This research work aimed to investigate the performance of a hybrid air conditioning system with and without nanofluids. The objectives were to compare the performance of the hybrid air conditioning system with and without nanofluid, and to evaluate the refrigeration effect and Coefficient of Performance (COP) of the hybrid air conditioning system using different concentrations by weight varies from 0 to 1% in steps of 0.2% of nanofluids. Experiments were carried out with flow rates of air varied by 0.15-0.25 m^3/s. The experimental results showed that the hybrid air conditioning system with nanofluid had a higher COP and refrigeration effect compared to the system without nanofluid. Moreover, the optimal concentration of nanofluid was found to be 0.8% Al_2O_3 by weight, which resulted in a COP improvement of 34% and a refrigeration effect improvement of 32% compared to the system without nanofluids. At lower air velocity and higher nanofluid flow rate values, greater values of the VCRS coefficient of performance were achieved. Thus, the results demonstrate that the addition of Al_2O_3 nanofluid can significantly enhance the performance of hybrid air conditioning systems. This research work provides insights into the potential benefits of nanofluid for air conditioning systems and could contribute to the development of more energy-efficient and environmentally friendly cooling technologies.

Keywords: Computational Fluid Dynamics, Air-conditioning System, Nanofluid, Refrigeration, Heat Transfer.

1. Introduction

Air conditioning systems have become essential in modern society to maintain comfortable indoor environments. However, the increasing energy consumption and environmental impact of these systems have become significant concerns. Therefore, researchers and engineers have been exploring various methods to improve the efficiency of air conditioning systems and reduce their environmental impact. One promising approach is the use of hybrid air conditioning systems, which combine different cooling technologies to improve energy efficiency and reduce environmental impacts.

In recent years, nanofluids have emerged as a potential enhancement for cooling fluids used in air conditioning systems. Nanofluids are suspensions of nanoparticles in a base fluid and have shown promise in improving the heat transfer characteristics of the base fluid. The use of nanofluids in air conditioning systems could potentially improve the efficiency and performance of these systems.

This paper work aims to investigate the performance of a hybrid air conditioning system with and without nanofluid. The objectives are to compare the performance of the hybrid air conditioning system with and without nanofluid, and to evaluate the refrigeration effect and Coefficient of Performance (COP) of the hybrid air conditioning system for different concentrations of nanofluid. The experimental results could provide insights into the potential benefits of using nanofluid in hybrid air conditioning systems and contribute to the development of more energy-efficient and environmentally friendly cooling technologies.

The remainder of this paper is organized as follows. Section 2 provides a literature review of hybrid air conditioning systems and nanofluids. Section 3 describes the experimental setup and methodology used to conduct the experiments. Section 4 describes measurements uncertainties and accuracy in experiment. Section 5 presents and discusses the experimental results. Section 6 concludes the paper and provides recommendations for future research & deployment under real-time scenarios.

2. Literature review

In an effort to lessen the negative effects of air conditioning on the environment and increase energy efficiency, hybrid systems have been created. In order to minimise energy consumption and environmental effect, these systems integrate several cooling technologies, such as sensible cooling and vapour compression refrigeration systems, to provide efficient cooling. Research shows that hybrid AC systems are more efficient and produce less greenhouse gas emissions than their conventional counterparts.

Researchers have looked at using nanofluids, which are suspensions of nanoparticles in a base fluid, to improve cooling fluids used in air conditioners. Nanoparticles, when added to a base fluid, may enhance the fluid's heat transfer properties, leading to better air conditioning system performance and energy efficiency. There is evidence that using nanofluids in HVAC systems may enhance system sets' coefficients of performance (COP), increase cooling capacity, and decrease energy consumption.

Nanofluids have been the subject of several investigations on their potential use in HVAC systems. Ajayi et al. [1] looked at how R134a/Al2O3 nanofluid affected a home vapour compression refrigeration system and discovered that it improved the efficiency of the refrigeration process and that nanolubricants had an influence on the capacity to consume energy. In their experimental investigation of SiO2/PAG nanolubricants in an AAC, Sharif et al. [2] discovered that these lubricants may boost COP by up to 24 percent and by an average of 10.5 percent. F. Ahmed [3] conducted experiments on an Al2O3 and water nanofluid refrigeration system's secondary fluid and found that a COP of 6.5 was possible at 40°C for the nanofluid's input temperature, 80g/s for its mass flow rate, and 15% for its volume concentration. For three different mass charges of R134a—150 gm, 180 gm, and 200 gm—D. S. Kumar and Elansezhian [4] studied the effectiveness of a vapour compression refrigeration system using a nano-refrigerant with a volume concentration of 0.2% Al2O3-PAG oil. The findings demonstrated a decrease in energy usage of 10.32%. Nanofluid flow using refrigerant in a vapour compression refrigeration system was studied by Coumaressin et al. [5] in terms of its properties and efficiency. They used TK Solver to examine a mixture of nanoparticles of aluminium, copper, titanium, and zinc oxide with the basic refrigerant R1234yf at concentrations ranging from 0% to 1%. Experiments have shown that nanofluids including refrigerant have a greater heat transfer coefficient than pure refrigerant, and that nanofluids made of aluminium oxide have a 28% higher coefficient of performance (COP) and a 7% lower power consumption than other nanofluids. In their experimental investigation, Chauhan et al. [6] examined the effects of several concentrations of TiO2 in the ice plant test rig, ranging from 0.1% to 0.3% by volume, in conjunction with R134a refrigerant. The POE/TiO2 nanolubricant combination was also tested. To acquire the refrigerant's characteristics, the NIST-developed REFPROP 9.1 software was used. Based on the testing results, a nanolubricant/R134a combination (POE/TiO2) reduced the input power of the compressor by 15.7% and enhanced the coefficient of performance (COP) by 29.1% at a concentration of 0.2% TiO2, in comparison to a system employing only lubricant (POE).

Using nanofluid (water+TiO2) in the shell side of the chiller at different volume concentrations (0.05 %, 0.075 % and 0.1%), Mahdi et al.[7] tested two alternative refrigerants, R-407c and R-134a, to enhance the performance of a water chiller system. Research indicates that compared to the same system operating with R407c, one employing R134a results in a COP that is almost 28% greater. Sunu et al. [8] tested the efficacy (ε) and total heat transfer of the fan coil unit (FCU) of an AC water chiller with 0.2% nanoparticles added to the chilled water, as well as the effects of an Alumina-water nanofluid on heat transfer. According to the results, the heat transmission improved with increasing bulk flowrate of chilled water. The heat transfer improvement of nanofluid chilled water is about 8.0 to 11.1% higher than that of no nanofluid chilled water at a given mass flowrate. The thermal performance of a chilled water air conditioning unit was studied by Abdel Hady et al. [9] using pure water and varying concentrations of alumina nano fluids (0.1, 0.2, 0.3, 0.6, and 1% by weight). The working fluid flow rates (2, 3, and 5 Lit/min) and the incoming chilled air flow rates (80, 150, and 250 CFM) were varied to conduct the tests. The working fluids consisted of alumina nano fluids and clean water. The experimental findings reveal that for all concentrations of nanofluids (Al2O3-water), it takes less time to obtain the necessary chilled fluid temperature as compared to pure water. In addition, the findings showed that alumina nanoparticle concentrations of 0.1 and 1% by weight increased the COP by about 5% and 17%, respectively. Six typical active chilled beam systems were tested in a full-scale laboratory by Nam & Zhai [10] to determine their air-side and water-side cooling capacities and related impact factors.

The energy performance of active chilled beams was specifically examined in relation to the impacts of supply airflow rate and cooling coil water supply temperature. The investigation also verified that the cooling performance is affected by the diameters of the active chilled beam air supply nozzles. According to the results, the overall cooling capacity—which is determined by the dominant water cooling capacity—rises as the main airflow rate or water input temperature increase or decline, respectively. The capability for cooling the air side increases when the main airflow rate or water intake temperature both go up. The air-to-water cooling capacity ratio increases as the main airflow rate and water intake temperature rise. In their study, M. S. Ahmed and Elsaid [11] evaluated the efficiency of a chilled water air conditioning system (CWACS) that used a combination of pure water as a working medium base fluid and hybrid nanofluids comprising several kinds of nanoparticles, including Al2O3 and TiO2. According to the findings, a single Al2O3/H2O nanofluid reduced the amount of time it took to cool the fluid in a chiller system and increased the coefficient of performance. Al2O3/H2O had a greater refrigeration effect value of around 5.3% and a lower compression ratio of about 4.1% when compared to TiO2/H2O. In a trans-critical CO2 refrigeration cycle, Purohit et al.[12] evaluated the efficiency of a water-cooled gas cooler against that of an alumina nanofluid-cooled double-pipe gas cooler with 0.5, 1.5, and 2.5% particle volume fractions. Based on their findings, alumina nanofluid cooled systems perform better than water cooled systems at the same Reynolds number.

Overall, the literature suggests that the use of nanofluids in air conditioning systems can improve the energy efficiency and performance of these systems. However, further research is needed to investigate the optimal concentration of nanoparticles for different air conditioning systems. This research work aims to contribute to this area of research by investigating the performance of a hybrid air conditioning system with different concentrations of nanofluids.

3. Experimental Set Up and methodology

3.1 Experimental Set Up

The experimental setup used in this research work consists of a hybrid air conditioning system with and without Al_2O_3 nanofluid. The system includes air precooling or sensible cooling with car radiator and cooling and dehumidification by chilled spray water. The chilled spray water was cooled by closed loop nanofluid obtained by a vapor compression refrigeration unit. The nanofluid used in the study is a mixture of Al_2O_3 nanoparticles and a base fluid (water).

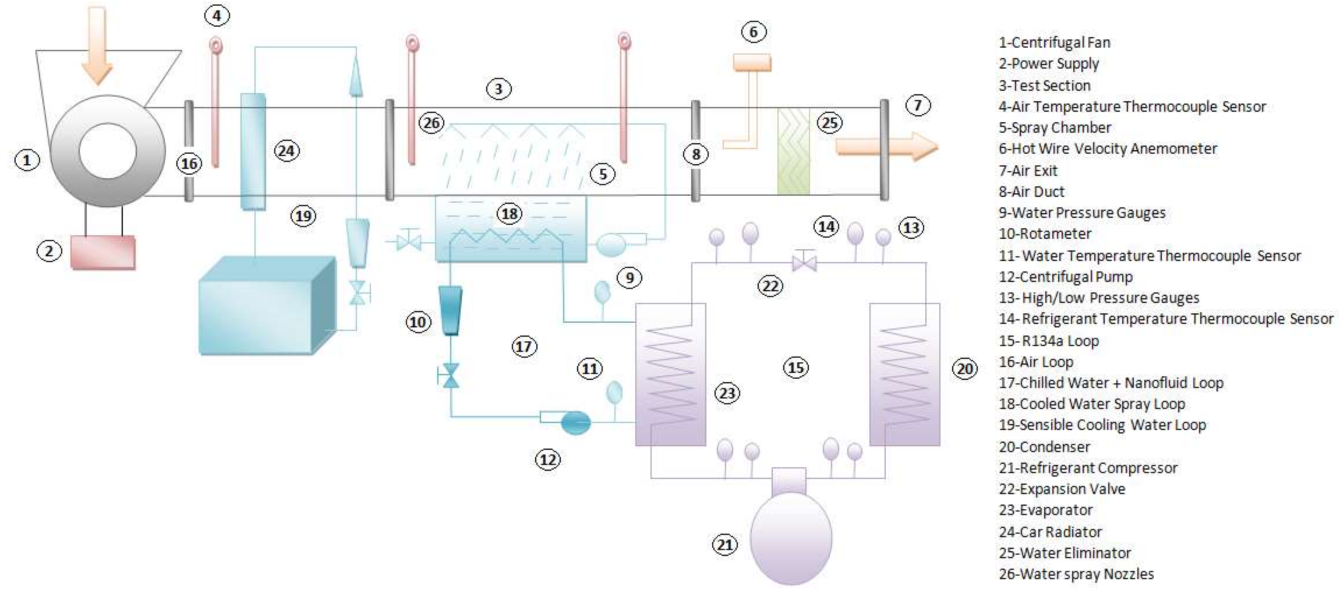

Fig.1 Experimental setup of the analysis process.

The experimental apparatus will consisted of five loops, as shown in above Fig.

Vapour compression refrigeration systems, such as Loop-A, are industry standards. The various components of a VCRS include an R-134a working refrigerant fluid reservoir, a capillary tube, a closed-type reciprocating compressor, a fin-and-tube condenser, and a shell-and-helical coil evaporator.

The Plexiglass air side duct known as Loop-B measures 0.25 x 0.25 m2 and extends for 1.6 m. Its sections include an inlet for air, a pre-cooling, a chilled water spray, and an air section downstream. The propeller fan (120W-2500 RPM-420m3/hr) is coupled to the 0.5 m long air intake portion. In the test segment, the controlled face air velocity varied between 0.6 and 2 metres per second. The air flow rates used in the experiments ranged from 0.15 to 0.25 m3/s. A automobile radiator (0.4x0.35x2.5mm) serves as an indirect evaporative cooler in the pre-cooling portion, which is 0.3 metres long. There is a water tank with a cooling coil, a spray pump, and spray nozzles that make up the 0.4-meter-long chilled water spray portion. Part of the water eliminator is located in the 0.4 m downstream segment. The cross-section of the air duct is square. A cross flow of air is created by fixing the spray nozzles through the spray portion. Cooled water spray and a finned and tubed radiator are driven by a variable-speed centrifugal fan. A thermocouple grid and a hot wire velocity anemometer, among other required measurement instruments, are set up in accordance with the standards.

For the purpose of conducting experiments, the test area has a regulated and variable face air velocity.

As part of a vapour compression refrigeration system (VCRS), Loop-C is a closed loop of chilled water/nanofluid circuit that includes an insulated tank with a helical evaporator coil. The VCRS may be adjusted by adjusting a thermostat to the temperature at which water is supplied to the spray nozzles in the air/spray portion. In order to conduct experiments, the cooling coil in the water tank is used to pump the working fluid (water or nanofluid) at a flow rate ranging from 2LPM to 6LPM. Within the insulated shells, there is a fixed helical coil tube that carries the refrigerant. The coil is submerged in water or nanofluid for cooling.

For indirect evaporative cooling of air types, Loop-D is an open/close loop that supplies the automobile radiator in the pre-cooling part of the air duct with normal water at ambient temperature.

Using an enhanced set of temperature controls, the refrigeration system produces the chilled working fluids (water or nanofluids) and brings them to the necessary set point temperature.

Under varied settings, including changes in air and working fluid flow rates and concentrations of alumina nanoparticles, we compare the effects of various nanoparticle concentrations with those of pure water, the base fluid. From the insulated shell, a centrifugal pump transfers the chilled working fluid—which may be water or nanofluids—to the spray water tank. A rotameter was used for measurement, while a ball valve was used to regulate the volumetric flow rate. In order to measure the temperatures, thermocouples will be used.

Loop-E is open/close loop of chilled water spray loop consisting of spray water tank, spray pump and an augmented set of spray nozzles.

Table 1

Parameters used for the evaluation process

Component	Ratings
Compressor	Hermetically Sealed Reciprocating compressor 1/6 HP
Evaporator	Shell and tube type (Water Capacity 20L)
Expansion Valve	Capillary tube(Length 10ft)
Condenser Tube and Fin type Air cooled condenser	
Primary Refrigerant	R134a
Refrigerant Charge Mass	200gm
Secondary Refrigerant	Water+Al2O3Nanoparticles
Battery Spray motor	12V DC; Pressure (100psi); Flow rate (0.66 l/min)
Propeller Fan RPM	2700; Flow rate: 120 m3/hour; Power:65 watt

Fig.2(a). Front View of experimental setup done in our labs

Fig.2(b). Side View of experimental setup done in our labs

3.2 Experimental Methodology

To evaluate the performance of the hybrid air conditioning system with and without nanofluid, the following experimental procedure was conducted:

1. First, the experimental setup was assembled and configured according to the design specifications.
2. Test the unit for operation with no load
3. Al2O3 nanoparticles were scattered in distilled water in varying ratios to create nanofluid. The weight-based concentrations of Al2O3 were created, with a range of 0.2%, 0.4%, 0.6%, 0.8%, and 1%. Every concentration sample was made independently and then mixed into the water-based solution. Each nanofluid concentration was homogenized for 15-20 minutes using a mechanical stirrer before being exposed to a high-speed mechanical stirrer.

   Steps of 0.2% were used to adjust the Al2O3 nanofluid's concentration from 0% to 1%. The system was run for three hours at each concentration in order to achieve steady-state conditions.
4. During the experimental period, various parameters such as working fluid temperature, temperature drop, dry bulb temperature, wet bulb temperature, refrigeration effect and COP were measured and recorded.
5. The experimental results were analyzed and compared to evaluate the performance of the hybrid air conditioning system with and without Al_2O_3 nanofluid.

Measurement and Data Collection: Several instruments were used to measure and record the performance parameters of the hybrid air conditioning system. These instruments include:

1. Thermocouples: To measure the temperature of the fluid at different points in the system.
2. Flowmeters: To measure the flow rate of the fluid at different points in the system.
3. Pressure gauges: To measure the pressure of the fluid at different points in the system.
4. Power analyzer: To measure the power consumption of the system.

Data Analysis: The experimental data collected from the hybrid air conditioning system with and without nanofluid were analyzed using statistical software. The data analysis involved comparing the performance parameters of the system with and without nanofluid, as well as analyzing the effect of nanofluid concentration on system performance.

To compare the performance of the hybrid air conditioning system with and without nanofluid, working fluid temperature, temperature drop, air temperature refrigeration effect and COP were analyzed. To evaluate the effect of Al_2O_3 nanofluid concentration on system performance, working fluid temperature, temperature drop, air temperature refrigeration effect and COP were plotted against the nanofluid concentration. The data analysis was performed to identify the optimal concentration of nanofluid that provides the best performance enhancement for the hybrid air conditioning system.

Coefficient of Performance (COP) is a ratio used to indicate the performance a HVAC system offers. The COP is calculated using the experimental data based on the power input and the cooling load by reducing the temperature of heat transfer cooling medium (water or alumina nano fluids). The power input includes the power consumed by compressor in the vapor compression refrigeration cycle, the power consumption by blower in air duct, the power consumed by water pump in precooling section and the power consumed by nanofluid pump in chilled water spray section.

Accordingly,

$$COP = \frac{\rho Q(h_1 - h_2)}{W_c + W_b + W_{p1} + W_{p2}}$$

Where,

ρ= density of air, kg/m^3
Q= flow rate of air, m^3/s
h_1= Enthalpy of Ambient air, KJ/kg (from Psychometric Chart)
h_2= Enthalpy of conditioned air, KJ/kg (from Psychometric Chart)
W_c= Power consumed by compressor, Watt
W_b= Power consumed by blower, Watt
W_{p1}= Power consumed by precooling water pump, Watt
W_{p2}= Power consumed by nanofluid pump, Watt

4 Measurements uncertainties and accuracy

The experiment's error analysis exposed the measurement apparatus's consequent inaccuracy and the data's uncertainty. A comprehensive study of various experimental uncertainties was carried out using the error analysis differential approximation approach. [12]. Table 2 lists the experiment's measurement device accuracy and experiment outcome uncertainty.

Table 2

Accuracy of the measurement parameters and the computed uncertainty of the variables

Instruments	Unit	Accuracy	Uncertainty
Rotameter	kg/s	0.5%	± 1.43
Thermocouple	°C	0.01%	± 0.14
Digital temperature indicator	°C	0.1%	± 0.32
Hot wire velocity anemometer	m/s	0.1%	± 1.55
Pressure gauges	PSI	0.1%	± 1.88
Refrigeration effect	kJ/kg	-	± 2.65
Compressor specific work	kJ/kg	-	± 2.46
COP	-	-	± 5.1

5 Results and Discussion

This research work aimed to investigate the performance of a hybrid air conditioning system with and without nanofluids. The objectives were to compare the performance of the hybrid air conditioning system with and without nanofluid, and to evaluate the refrigeration effect and Coefficient of Performance (COP) of the hybrid air conditioning system using different concentrations by weight varies from 0 to 1% in steps of 0.2% of nanofluids. Experiments were carried out with flow rates of air varied by 0.15-0.25 m^3/s.

5.1 Effect of Al_2O_3 based water nanofluid on the coefficient of performance of hybrid air conditioning system.

Figures 3a, 3b, and 3c illustrate how the performance coefficient of a hybrid air conditioning system is affected by the concentration of Al2O3 water-based nanofluid at varying volumetric flow rates. The main conclusion that can be drawn from the figure's brief observation is that the coefficient of performance rises as both the concentration and volume flow rate of the nanofluid increase.

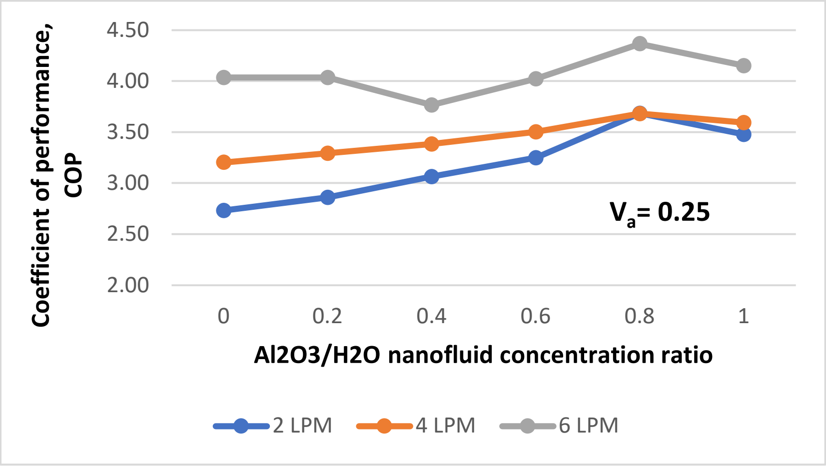

Fig. 3a Coefficient of Performance versus nanofluid concentration ratios

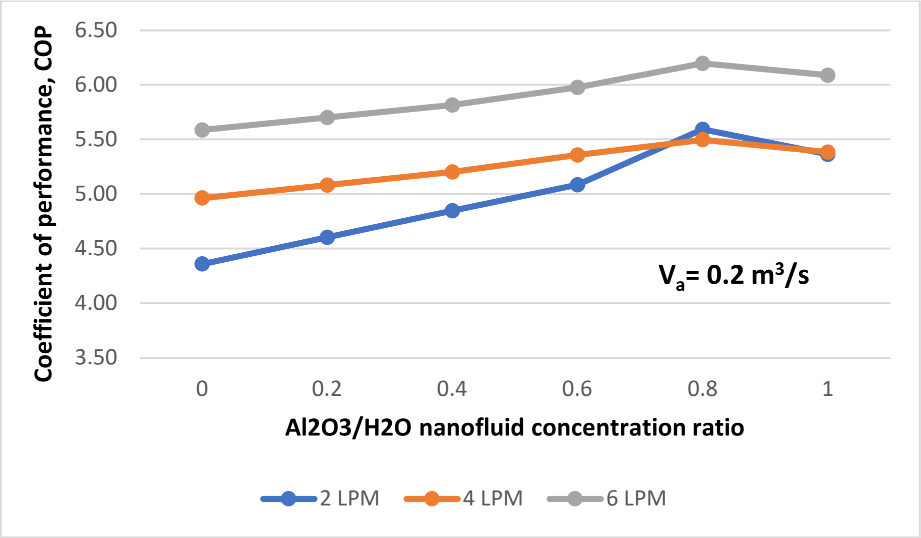

Fig. 3b Coefficient of Performance versus nanofluid concentration ratios

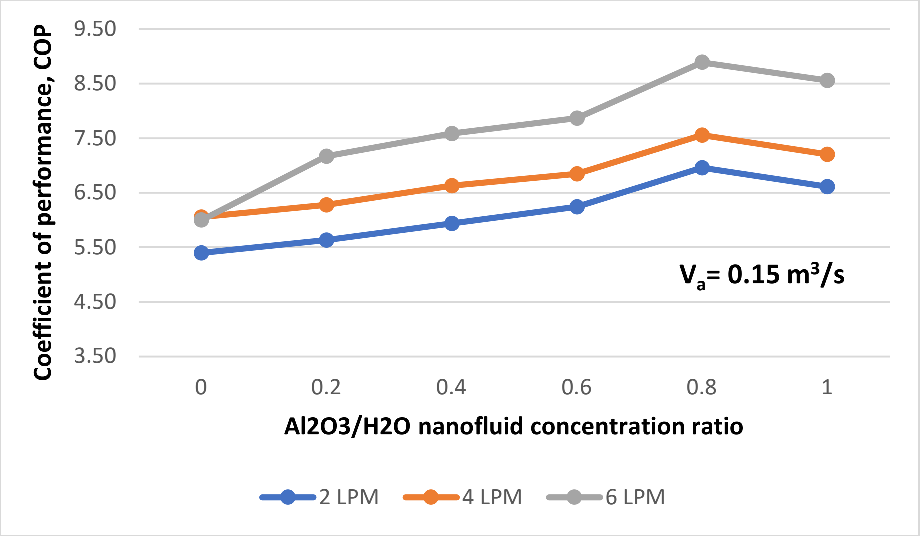

Fig. 3c Coefficient of Performance versus nanofluid concentration ratios

At volume flow rate of 2LPM, coefficient of performance increases by 27% as the alumina nanofluid concentration rises from 0% (pure water) to 1%. For a 0.8% concentration at a 2LPM volume flow rate, the coefficient of performance rises by 34%. This could be because of the 1% concentration of nanoparticles aggregating.

5.2 Effect of Al2O3 based water nanofluid on the refrigeration effect of hybrid airconditioning system

The cooling effect is shown to vary depending on the concentration of alumina nanofluid and pure water in Figures 4a, 4b, and 4c.

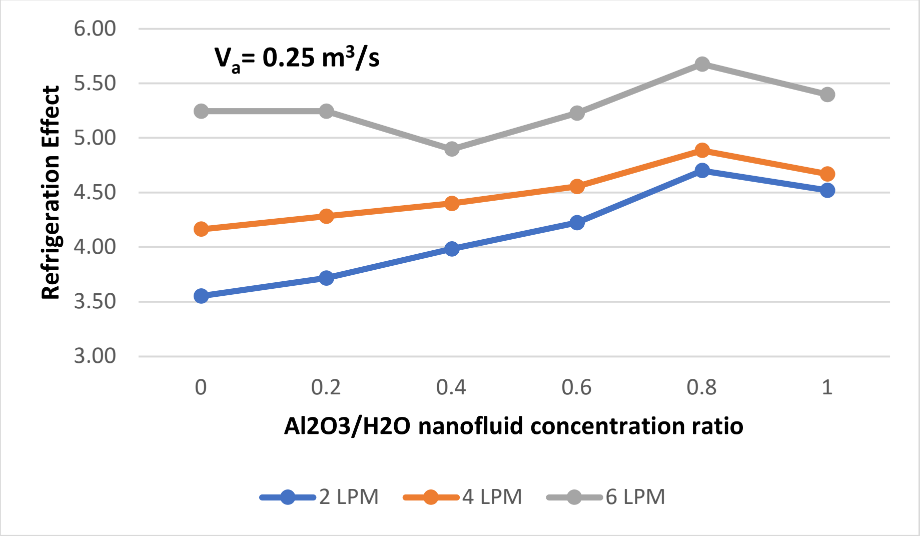

Fig. 4a Refrigeration effect versus nanofluid concentration ratios

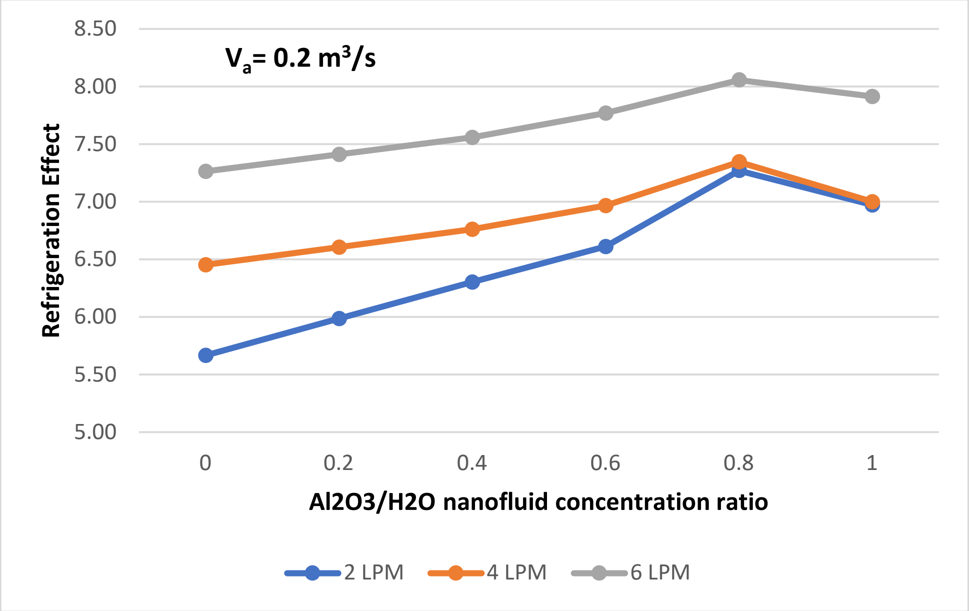

Fig. 4b Refrigeration effect versus nanofluid concentration ratios

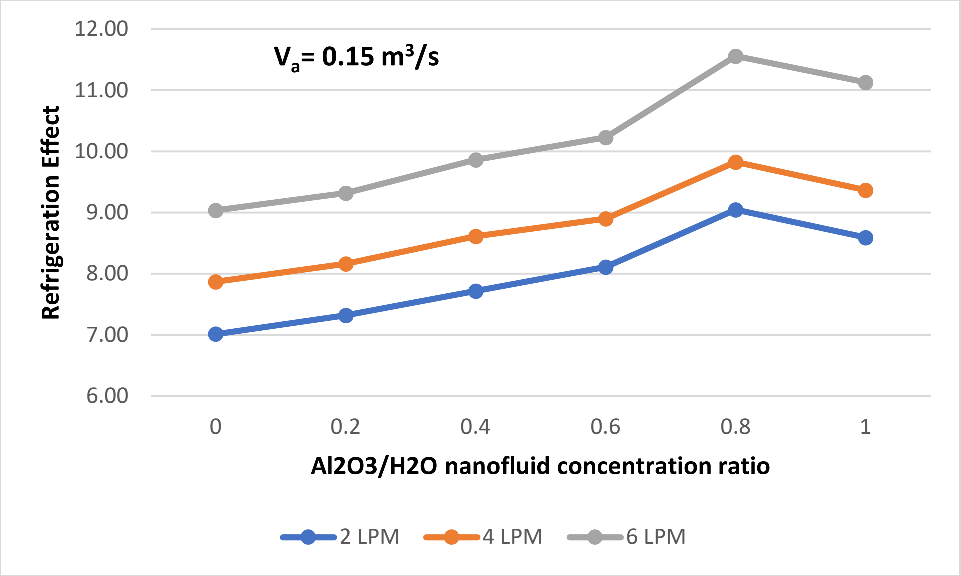

Fig. 4c Refrigeration effect versus nanofluid concentration ratios

Furthermore, it was observed that the 0.8% Al2O3 nanofluid concentration had the greatest cooling effect when compared to all other concentrations of Al2O3 nanofluid and pure water. At concentrations of 0.8% and 1% Al2O3 nanofluid, respectively, the increase in refrigeration effect was 32% and 27%.

5.3 Hourly variation of Coefficient of Performance

Figures 5a, 5b, and 5c show the coefficient of performance (COP) against elapsed time for various volume flow rates of nanofluid. The COP decreases with the elapsed time, according to the results.

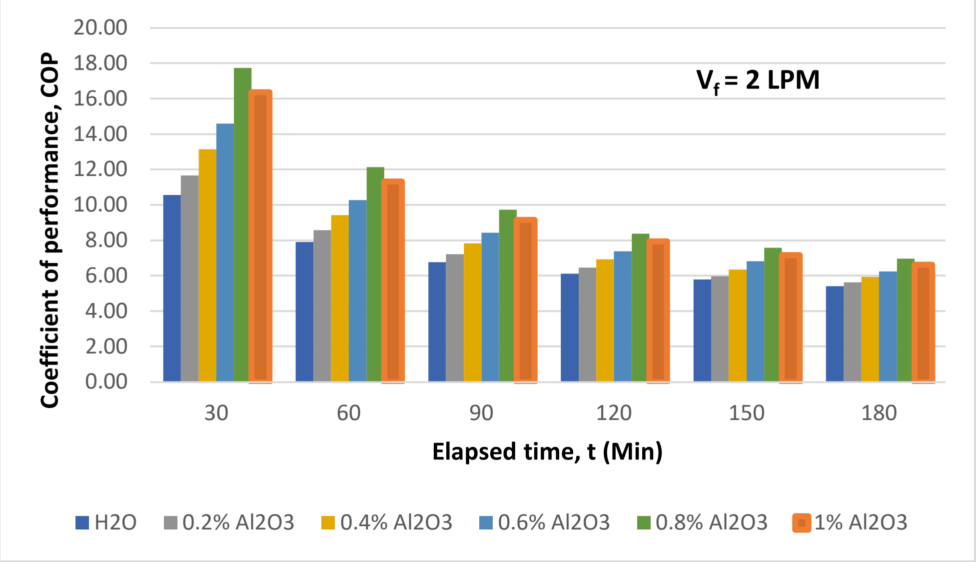

Fig. 5a Coefficient of performance versus elapsed time

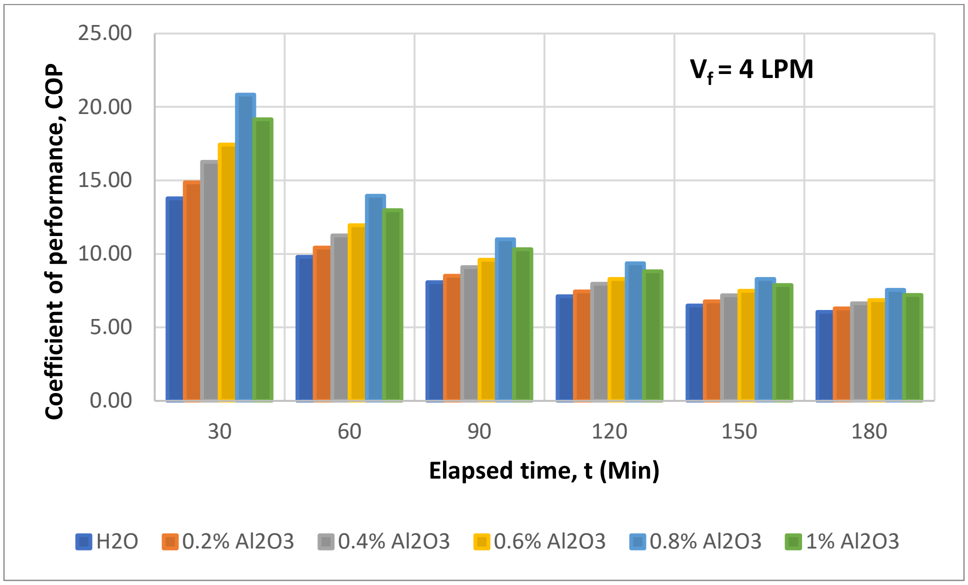

Fig. 5b Coefficient of performance versus elapsed time

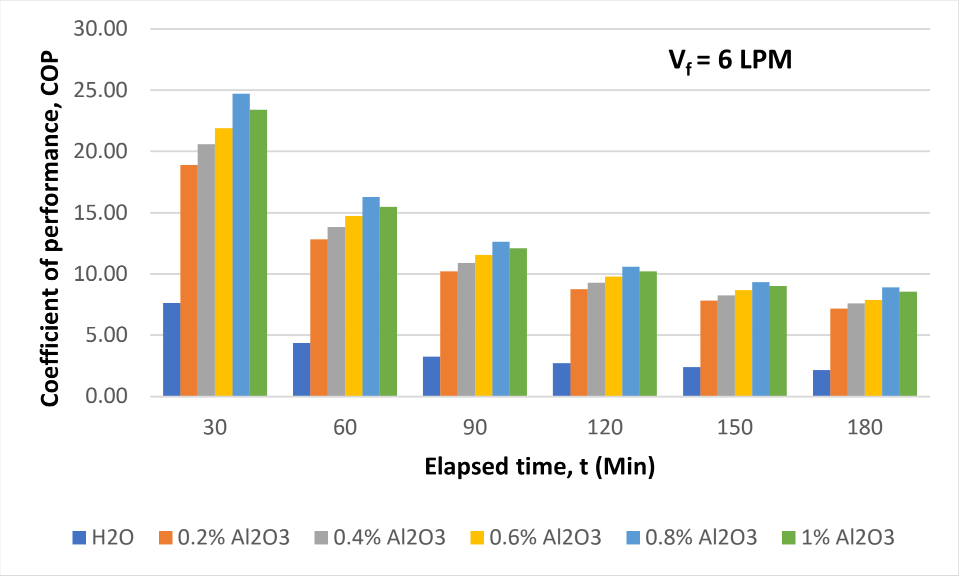

Fig. 5c Coefficient of performance versus elapsed time

5.4 Hourly variation of Nanofluid/working fluid outlet temperature

The decline in working fluid/nanfluid outlet temperature for pure water and various nanofluid concentrations at volume flow rates of 2LPM, 4LPM, and 6LPM is depicted in Figs. 6a, 6b, and 6c. The studies are conducted between the hours of 10 a.m. and 13 p.m. The figure showed that, in comparison to pure water and all other nanofluid concentrations, the elapsed duration of working fluid temperature was lower for 0.8% nanofluid concentration.

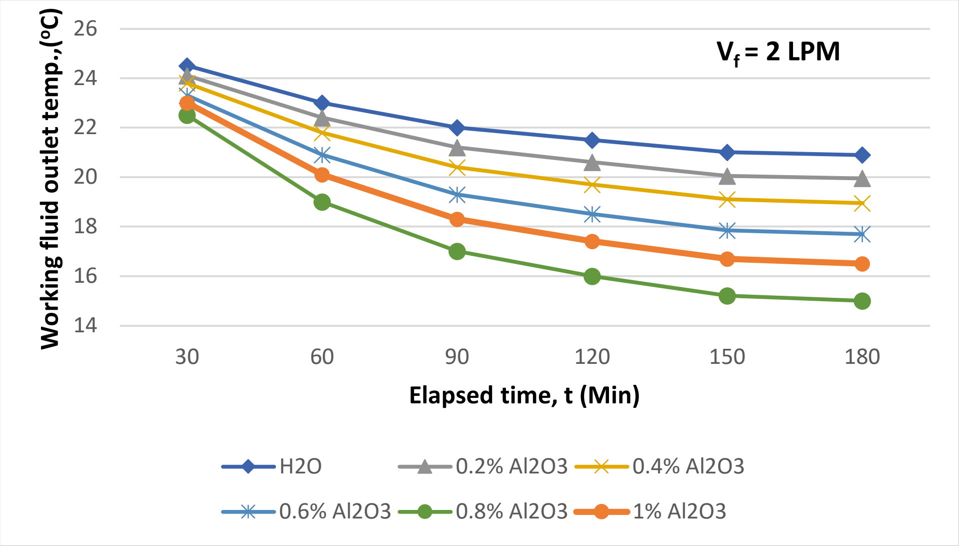

Fig. 6a Working fluid outlet temperature versus elapsed time

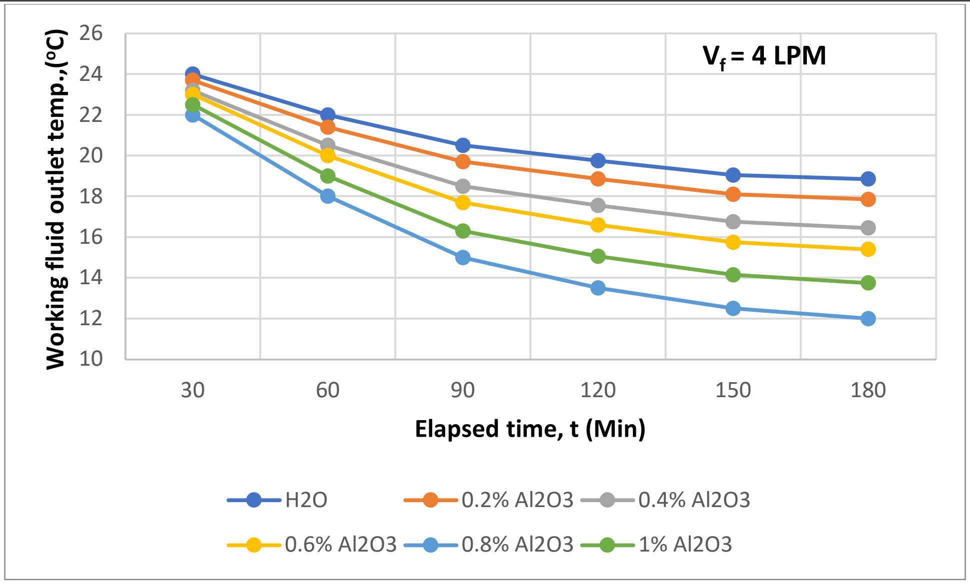

Fig. 6b Working fluid outlet temperature versus elapsed time

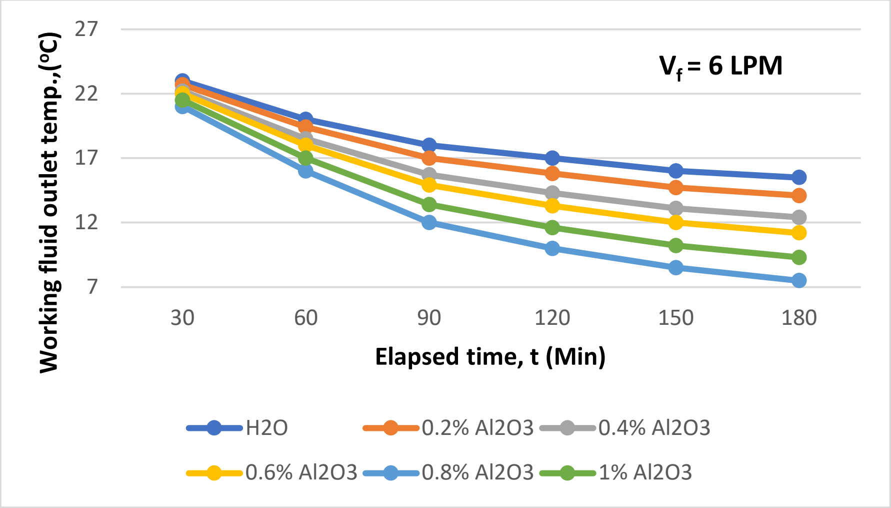

Fig. 6c Working fluid outlet temperature versus elapsed time

5.5 Hourly variation of temperature drop

With volume flow rates of 2LPM, 4LPM, and 6LPM, Figs. 7a, 7b, and 7c illustrate the decrease in the working fluid/nanfluid outlet temperature for pure water and for various concentrations of nanofluid. Between the hours of 10 a.m. and 13 p.m., the trials are conducted. As seen in the figure, the concentration of 0.8% nanofluid showed a greater temperature decline with respect to elapsed time than all other concentrations of nanofluid and pure water.

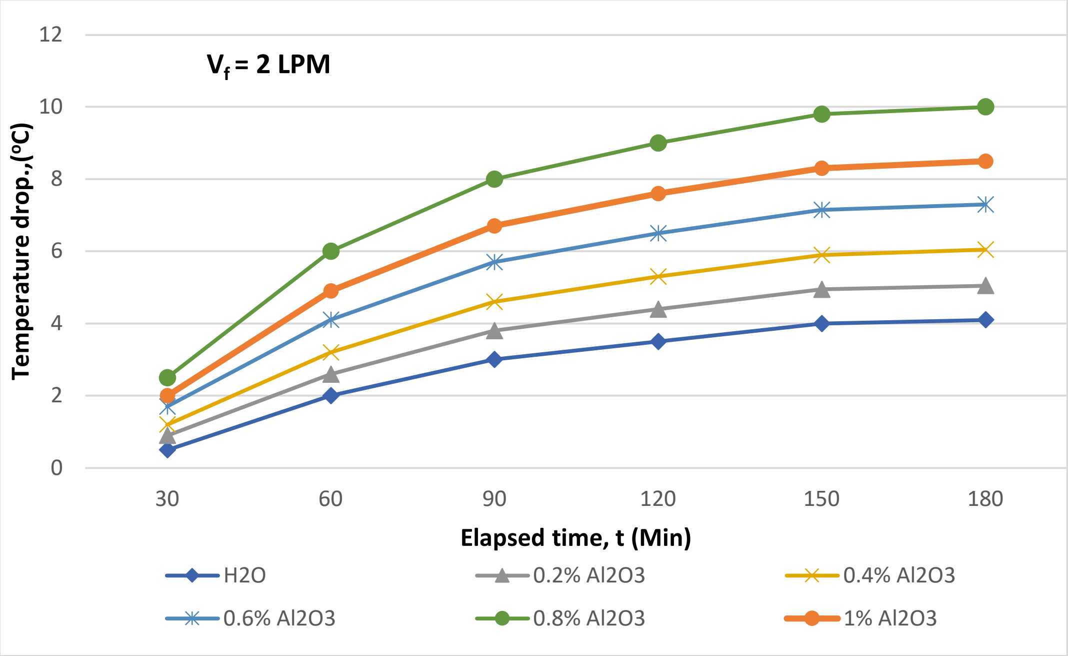

Fig. 7a Temperature drop versus elapsed time

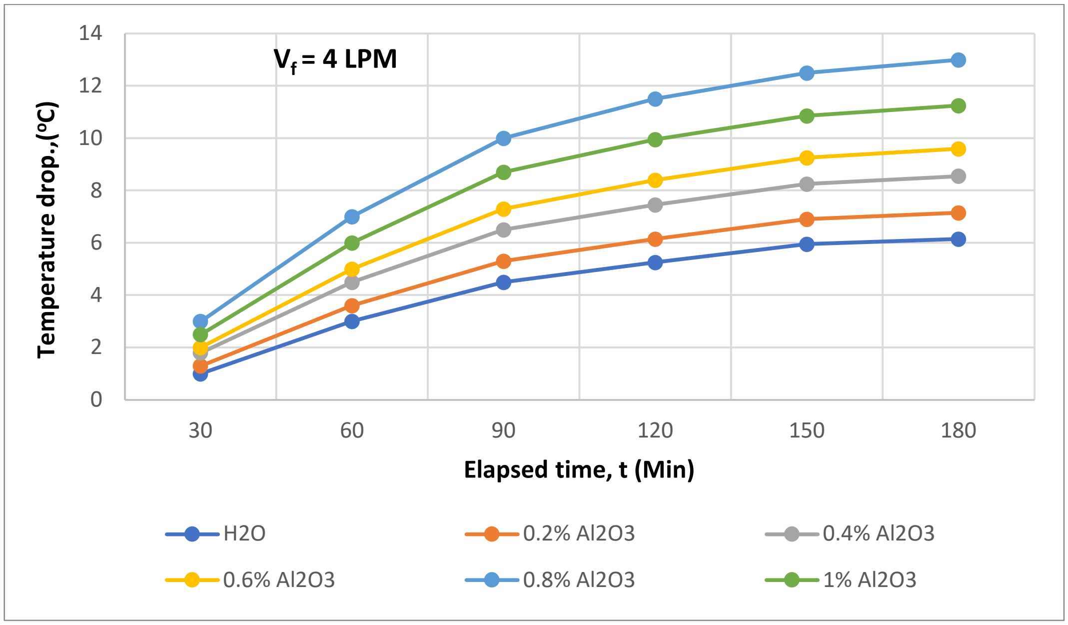

Fig. 7b Temperature drop versus elapsed time

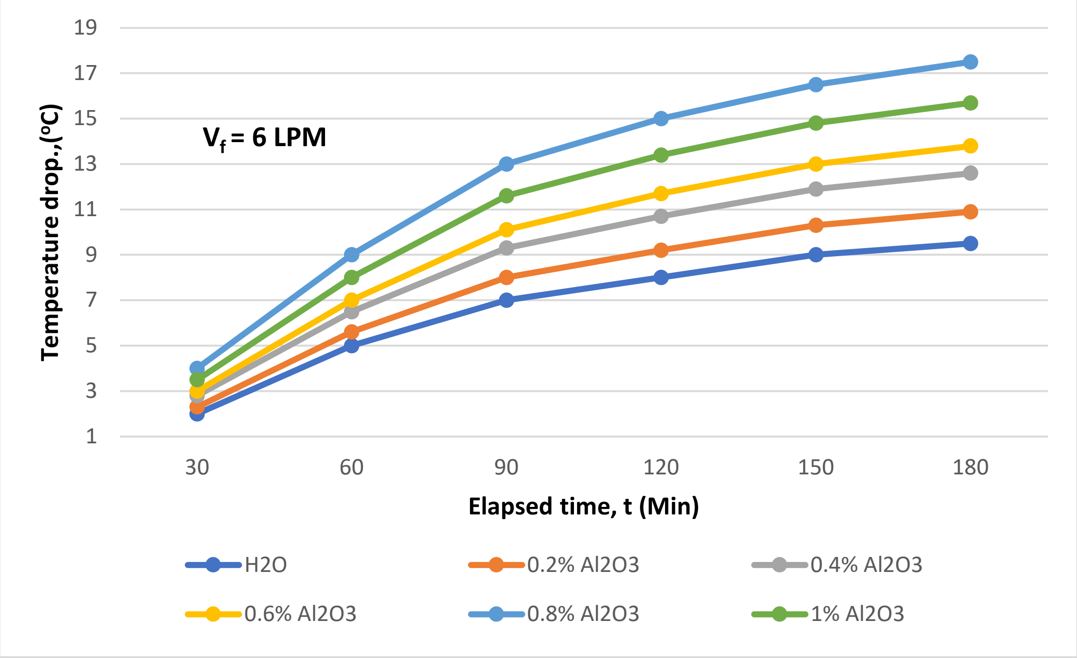

Fig. 7c Temperature drop versus elapsed time.

5.5 Hourly variation of Conditioned air temperature

The conditioned air temperature for pure water and various nanofluid concentrations with volume flow rates of 2LPM, 4LPM, and 6LPM is displayed in Figs. 8a, 8b, and 8c with regard to time. The studies are conducted between the hours of 10 a.m. and 13 p.m. The figure showed that the temperature of the conditioned air decreased with time and was lower at 0.8% nanofluid concentration than it was at pure water and all other concentrations.

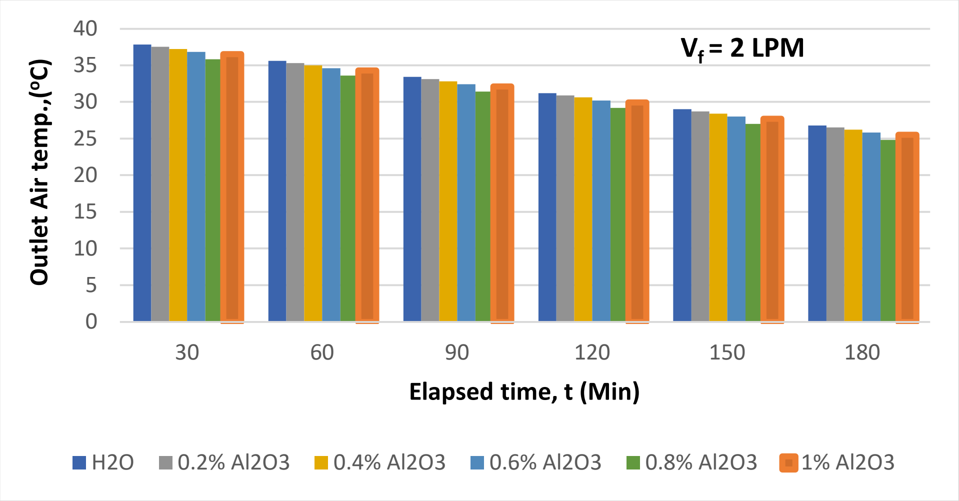

Fig. 8a Conditioned air temperature versus elapsed time

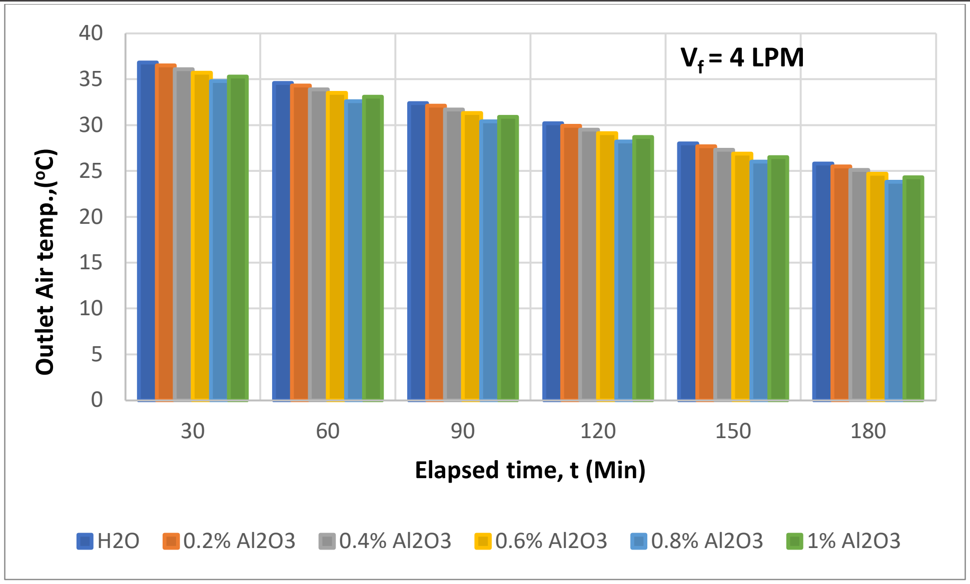

Fig. 8b Conditioned air temperature versus elapsed time

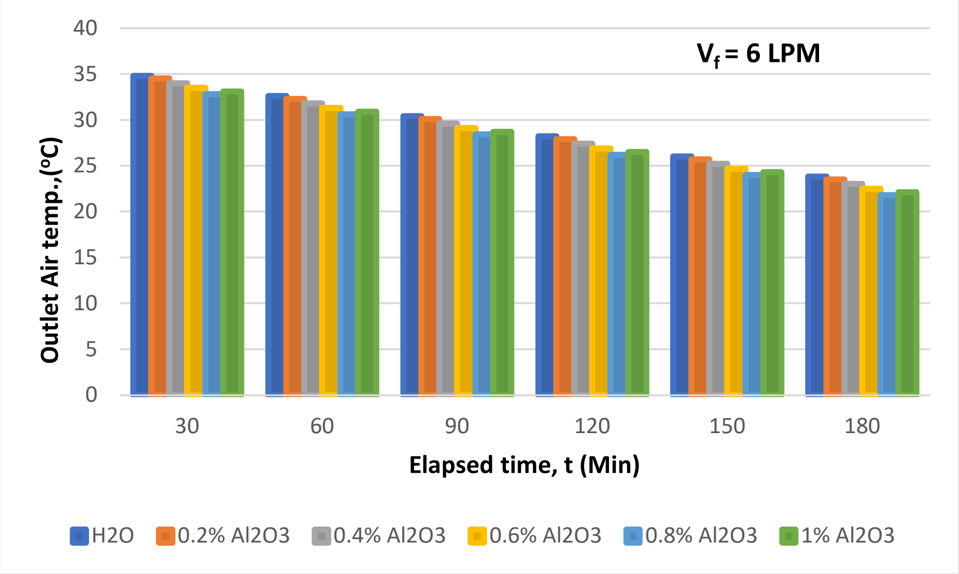

Fig. 8c Conditioned air temperature versus elapsed time

6 Conclusions

In this study, the performance of a hybrid air conditioning system with and without nanofluid was compared and evaluated for different concentrations of nanofluid. The experimental results show that the addition of Al_2O_3 nanofluid can significantly improve the performance of the hybrid air conditioning system. The following conclusions can be drawn from the study:

1. The addition of Al_2O_3 nanofluid to the hybrid air conditioning system resulted in a significant improvement in the system's performance. The refrigeration effect increased by up to 32% and the COP increased by up to 34% compared to the system without nanofluid. The power consumption of the system with Al_2O_3 nanofluid was also reduced compared to the system without nanofluid.

2. The performance of the hybrid air conditioning system with Al_2O_3 nanofluid was found to be dependent on the concentration of the nanofluid. The optimal concentration of Al_2O_3 nanofluid was found to be 0.8%, which resulted in the highest performance improvement.

3. At lower air volume flow rates and greater chilled water spray nanofluid flow rates, higher hybrid air conditioning system coefficient of performance values were achieved.

4. The experimental results are consistent with previous studies that investigated the use of nanofluids in air conditioning systems. The improvement in COP and refrigeration effect observed in this study is comparable to the improvement reported in previous studies.

5. The results of this study can contribute to the development of more efficient and environmentally friendly air conditioning systems.

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