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Evaluation the Performance of Chilled - Water Air Conditioning Unit Using Alumina Nano Fluids

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Abstract: One of the important contributions to the application of nanotechnology is the nanofluids technique in which will be become a good alternative to the conventional heat transfer medium. This is done by addition of nano particles of high thermal conductivity to the base fluid of the low thermal conductivity.
In the present paper, the performance of chilled-water air conditioning unit with and without alumina nanofluids has been experimentally investigated. The first method technique was used to prepare Al_2O_3- water nanofluids.Al_2O_3 nano particles was added with water in the cooling tank through using different concentrations by weight varies from 0.1,0.2,0.3, and 1% wt. and the alumina nanofluids have been continuously supplied to the cooling coil. The experiments have been performed under operation conditions include a variation of flow rate of chilled water/ alumina nanofluids and the air through the cooling coil. The experimental results have been shown a less time is achieved to obtain the desired child fluid temperature for all the different concentrations of nanofluids (Al_2O_3- water) compared with pure water. Also, the results revealed an increasing in the COP by about 5%, and17% for alumina nanoparticles concentration 0.1, and1% by weight respectively.
Keywords: Nano fluids, Alumina, Chilled water, Air conditioning, Nanotechnology, COP.

1 Introduction

Nano fluids basically consist of a base fluid blended with nano sized particles (1-100nm) formed a colloid material. Common base fluids include water, organic liquids (e.g. ethylene, tri-ethylene-glycols, refrigerants, etc.), oils and lubricants, bio-fluids, polymeric solutions and other common liquids. Materials commonly used as nano particles include chemically stable metals (e.g., gold, copper), metal oxides (alumina, silica, zirconia, Titania), oxide ceramics (e.g. Al_2O_3, CuO), metal carbides (e.g. SiC), metal nitrides (e.g. AIN, SiN), carbon in various forms (e.g., diamond, graphite, carbon nano tubes, fullerene).
Nanofluids have a unique feature which is quite different from those of conventional solid-liquid mixtures in which millimeter and/or micro metre-sized particles are added. Such particles settle rapidly, clog flow channels, erode pipelines and cause severe pressure drops. All these shortcomings make the applications of nanofluids to be a good alternative compared to the conventional solid-liquid mixtures .Nano materials can be classified as: Carbon based nano materials (e.g.: Carbon nano tubes), Metal based nano materials (metal oxides such as aluminum oxides), Dendrimers (nano sized polymers) and composites (nano sized clays) [1]. When these nano particles are suspended in conventional fluids (water, oil, ethylene glycol) called “nano fluids”. Nanofluids clearly exhibit improved thermo-physical properties such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer coefficient. The property change of nano fluids depends on the volumetric fraction of nano particles, shape and size of the nano materials.

According to the application, nano fluids are classified as heat transfer nano fluids, tribologicalnano fluids, surfactant and coating nano fluids, chemical nano fluids, process/extraction nano fluids, environmental (pollution cleaning) nano fluids, bio- and pharmaceutical nano fluids and medical nano fluids (drug delivery, functional and tissue-cell interaction).
By suspending nano particles in conventional heat transfer fluids, the heat transfer performance of the fluids can be significantly improved. Due to improved properties, better heat transfer performance is obtained in many energy and heat transfer devices as compared to traditional fluids

which open the door for a new field of scientific research and innovative applications. [1].

Accordingly, nano fluids can be used in broad range of engineering applications due to their improved heat transfer and energy efficiency in a variety of thermal systems.

Routbort et al.[2] employed nano fluids for industrial cooling and showed great energy savings and resulting emission reductions. They showed that replacement of cooling and heating water with nano fluids has the potential to conserve about 300 million kWh of energy for industries. For the electric power industry using nano fluids could save about 3000-9000 million kWh of energy per year which is equivalent to the annual energy consumption of about 50,000-150,000 households.

It is well known fact that conventional fluids such as water, ethylene glycol (EG) and engine oils have low thermal conductivity and the efficiency of heat transfer with a very small temperature difference is limited. There is a need for energy efficient working fluids to improve the energy conversion system. However, the coefficient of convective heat transfer depends on thermal conductivity of the fluid. The thermal conductivity of fluid is improved by adding nano sized solid materials to the base fluids. The solid additives improve the thermal conductivity of the base fluid.

One of the most applications of nano fluids has been taken researchers attentions in the field of vapor compression system and it is considered one solution to the crises of energy [4-6].Since the performance of the vapor compression system is measured by the coefficient of performance, COP, therefore the improvement of COP has been taken more attention from researchers through the reduction of work input or increasing the heat transfer rate in the evaporator. Nano particles played a vital role to improve energy efficiency in refrigeration and air conditioning systems (HVAC&R) and thus to raise the performance of refrigeration and air conditioning systems. In vapor compression systems, the nanoparticles of different materials can be added to lubricant oils (called nano lubricants) or refrigerants (called nano refrigerants) or both called nano fluids which have been proved significantly improved in the thermal physical of the base fluids and they turned improved the heat transfer rate [7-17]
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Sabareesh et al.[6] have been tested experimentally improvement the performance of vapor compression system (using R22 as the working fluid) by adding nano particles of TiO_2 to the base fluid oil mineral lubricant. They noted that an enhancement in the COP of the refrigeration system has been observed and the existence of an optimum volume fraction noticed, with low concentrations of nano particles suspended in the mineral oil. They have been concluded that 0.01% volume fraction increased the average heat transfer rate by about 3.6%, and reduced the average compressor work by about 11%, which in turn of increases the COP with 17%.

Soliman et al. [5] conducted theoretical and experimental work to study the performance a vapor compression cycle with nano materials additives to the working fluid. They have been used a Polyester (POE) oil with Al_2O_3nanomaterials additives to enhance the performance in the vapor compression cycle with R-143a refrigerant. Theoretical analysis shows that the heat transfer coefficient in the evaporator with nano refrigerant increases by 50% and exergy loss decreases by 28 % when nanorefrigerant is used. The experimental results indicate that R- 134a and Polyester (POE) oil with Al_2O_3 nano particles enhance the vapor compression cycle performance by 10.5 % with 13.5 % lees energy consumption. These results were obtained with 0.1% mass fraction of nano-lubricant oil. Kotu et al. [7] have been performed an experimental study to compare the heat transfer performance in domestic refrigerator using Nano refrigerant and double pipe heat exchanger. The performance of the domestic refrigeration system with HFC134a/mineral oil system was compared with mineral oil/Nano refrigerant and HFC134a/mineral oil/double pipe heat exchanger. They found that the HFC 134a/mineral oil/DPHE system reduced the energy consumption by 30% and mineral oil/Nano refrigerant system reduced the energy consumption by 26 % when compared with the HFC134a/mineral oil system. Kawade et al. [8] have performed an experimental work to study the effect of nano particles in vapor compression refrigeration system. In this study the nano particles of SiO2 (15-20 nm) are to be used as additive in refrigerant and lubricating oil. Nano particles of SiO2 are to be added in the refrigerant and in lubricant to prepare the nano refrigerant and mineral oil with volume fraction 0.1, 0.2 and 0.3% by mass. Experimentation results shows that COP for 0.1 %, 0.2% and 0.3% of refrigerant are increased by 3.77%, 6.70% and 9.86% respectively while COP for 0.1 %, 0.2% and 0.3% of lubricant are increased by 6.97%, 9.90% and 12.68% respectively.

Wang et al. [10] have been conducted a new mineral –based nano-refrigeration oil (MNRO) , formed by blending some nano particles (NiFeO4) into naphthene based oil B32 which was employed in the RAC using R410a as refrigerant. The findings have been shown the solubility of the MNRO in R134A, R407C, R410A and R425A were experimentally validated to be good enough for RAC using these HFC refrigerants. Papade et al. [12] have been studied the performance of an air conditioning system with and without a nano refrigerant. It is found that the coefficient of performance is increased by 14% and the power consumption reduces nearly by 20% when POE oil is reduced by a mixture of POE oil and AL2O3 nano particles**.**

Hailong Li et al. [9] have been conducted an experimental work to study the system performance of a heat pump with nano fluid as refrigerant, which was prepared by mixing 5wt% TiO2 with R22. The findings show that adding the nano particle TiO2 didn't changed the heat absorbed in the evaporator clearly but increase the heat released in the

condenser. As a result, by compared to using pure R22, when using R22 + TiO_2, the COP of the cooling cycle was decreased slightly, however, the COP of the heating cycle was increased significantly.
The present paper will study experimentally the effect of adding alumina nano particles to the pure water on the performance of chilled water air conditioning unit. It is also investigated the elapsed time for cooling the heat transfer fluid to be required to cool the incoming air over the surface of cooling coil. Also, different concentrations of alumina nano particles are tested by adding them to the pure water and compared to the pure water. Measuring the coefficient of the performance without alumina nano particles and with alumina nano particles will be done.

2 Experimental Work

This section introduces the description of the experimental unit, the materials used, its specifications and preparation of nano fluids as well as the instrumentation to be used and procedure.

2.1 Experimental Unit Description

The experimental unit of chilled water air conditioning has consisted of two loops for circulation of two base fluids (refrigerant and nano fluids/chilled water) in which the evaporative (cooling tank) is the intermediate element for the two loops. The first loop, defined by the dotted line in figure 1, is the circulation of nano fluids/chilled water (the first base fluids) and it composes of the cooling tank and the cooling coil at which the incoming air to be cooled. The second loop is the vapor refrigeration compression system at which the refrigerant (second base fluid) was circulated through the evaporative (cooling tank) causing the cooling effect.

2.1 Nanofluids

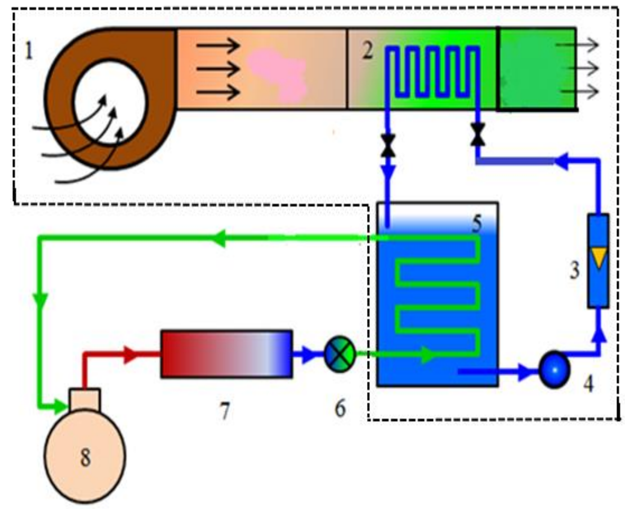
Nanofluids are a mixture of alumina, Al_2O_3, nanoparticles of different weight fraction with the water base fluid (chilled water). Different concentrations by weight of alumina nano particles are prepared and added to the water base fluid to study the effect of variation of concentration in each case on the performance of the systems with and without adding to the water base fluid.

2.1.1 Alumina Nano Particles

The source of Alumina nano particles particle used in the experiments was from Aluminum Company of Egypt and is a type of sandy alumina and contains a 98.5% of Al_2O_3. This type of alumina is re-grind them again several times in a ball mill to obtain nano sizes and this check by scanning microscopic of grinding samples. Figure 2 shows an image of TEM has been done in the National Center of Research at Cairo city. It is found that the size of alumina nano particles ranges of 20-70 nm. Samples of alumina nano particles were prepared at five different concentrations: 0.1,0.2, 0.3, 0.6, and 1% by weight fraction.

2.1.2 Preparation of Alumina Nanofluids

The technique of the first method is used to prepare alumina a nanofluid with different concentrations of alumina varies from 0.1, 0.2, 0.3, 0.6, 1% by weight.



1. Blower 2. Cooling coil 3.Rotameter 4. Water pump
5. Evaporative (or cooling tank) 6. Expansion valve
7. Condenser 8. Compressor

Fig.1: A schematic of the experimental unit.

2.2 Instrumentation

Various measurements have been performed to obtain the performance of the chilled water air conditioning unit under different operating conditions. These measurements have been included measuring the temperatures using mercury thermometers at locations inlet, T_3, and outlet, T_4, of the evaporative (the cooling tank) of the chilled water and inside the cooling tank, T_5, for the cooling water, inlet and outlet of the air at cooling coil T_1, T_2, and the temperature of the refrigerant at the inlet and outlet of the evaporative, T_{R1}, T_{R2}. The volume flow rate of air is measured by using anemometer and the volume flow rate of inlet water to the cooling coil using rotameter. The measurements at different locations in the chilled water are shown in Fig.3.

2.3 Procedure

First, to test the unit for operation with no load, then the unit operates by supply the evaporative (cooling tank) with the working fluids (nanofluids or pure water) and the vapor compression system is running at the same time where the flow of refrigerant is coming to the evaporative to cooling the working fluids.

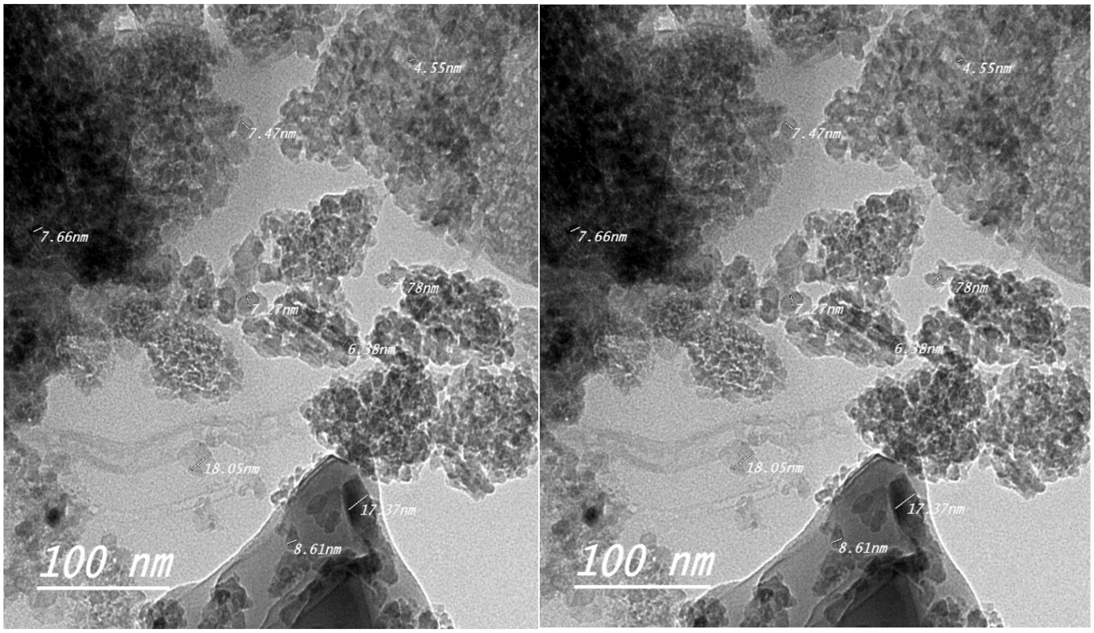


Fig. 2: TEM image of Al_2O_3 nano particles used in the experiments.

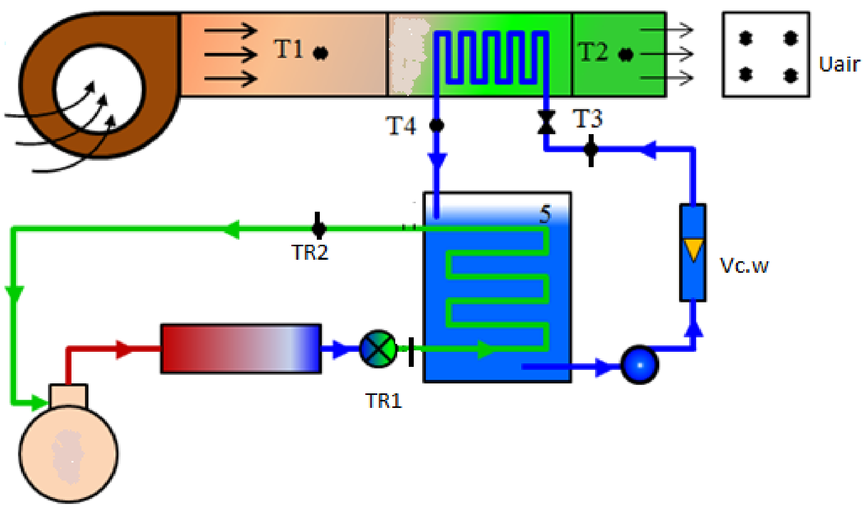


Fig. 3: A schematic of the locations of different measurements.

The temperatures at different locations from time at 8 am to 2pm are recorded. The run was performed at constant volume flow rate of chilled working fluids to the cooling coil with a constant volume flow rate of coming air to the cooling coil. The experiments have been conducted by variation the volume flow rate of chilled w water working fluids ranges from 2, 3, 5Lit/min and variation the volume flow rate of incoming air with rate of 80, 160, and 250 CFM and recording the reading of temperatures in each run. Figure 3 shows a schematic of the whole system of chilled water air conditioning unit. The whole system is mainly composed from the chilled working fluids (referred to the dotted line at figure 1), cooling coil and the system of vapor compression system.

The alumina nano particle of a specified concentration was mixed with the water inside the cooling tank (evaporative) after starting the unit to ensure good mixing of nano particles of alumina with water during the operation of the cycle. To maintain a continuously colloidal of nano fluids, the return chilled water from the cooling coil to the evaporative is poured at the bottom of the cooling tank. The experiment was repeated at different concentration of nano particles of alumina varies from 0.1, 0.2, 0.3, 0.6, 1 % by weight and different operating conditions of volume flow rates of each alumina nanofluids and the incoming air for 2, 3, 5Lit/min and 80, 160, and 250 CFM respectively. For each run, the different reading is recorded to calculate the performance of the chilled water air conditioning unit.

3 Coefficient of Performance

The coefficient of performance, COP $_{wf.,}$ is defined as a function of the cooling medium (chilled water or alumina nanofluids). The COP_{wf} is calculated using the experimental data based on the power input and the cooling load by reducing the temperature of heat transfer 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 and the power consumed by water pump as shown by the dotted line of the first loop (figure 1).

Accordingly,

$$COP_{w.f} = \frac{\dot{m}_{wf} C_{pwf}(T_{wf,in} - T_{wf,out})}{W_{comp} + W_{blower} + W_{pump}}$$

Where:

$\dot{m}_{wf}$ = mass flow rate of chilled working fluid

$Cp_{w.f}$ = specific heat of water, W/kg.^{o}C

$T_{w,in}$ = inlet temperature of water or alumina fluids,^{o}C

$T_{w,out}$ = outlet temperature of water or alumina fluids,^{o} C

W_{comp} = power consumed by compressor, Watt

W_{blower} = power consumed by blower, Watt

W_{pump} = power consumed b water pump,Watt

4 Results and Discussion

The following experimental results are focusing on the cycle of chilled working fluids which previously defined as the first loop, figure1. The data obtained from the experimental results will be stated about the comparison of the elapsed time without adding nano-alumina and with nano-alumina. Also, the discussion introduces the gain of COPc.w. using alumina nanoparticles.

4.1 Effect of Adding Alumina Nano particles on the Elapsed Time for Cooling the Working fluids

Experiments have been conducted with and without alumina nano fluids to follow the time elapsed for temperature drop of heat transfer fluid. The heat transfer fluid for the two cases (alumina nano fluids or pure water) is the cooling medium to be circulated in the cooling coil using to cool the incoming air passing over the cooling coil. The experiments have been performed without alumina nano particles (i.e. with pure water) and with alumina nano particles of different concentrations vary from 0.1, 0.2, 0.3% by weight. The experiments have been performed under constant conditions of volume flow rate 5Lit/min and volume flow rate of air ranging at 80 and 250 CFM. The concentration of alumina nano particles is varied between 0.3, 1% b weight. Figures 4a and 4b show the variation of temperature drop for 0.3% and 1% alumina nano fluid and pure water during the initial period for cooling the heat transfer fluid required to cool the incoming air. It is noticed that the time of cooling the heat transfer fluid for the 0.3% and 1% alumina anano fluid is less than the time elapsed for the pure water. This is due the enhancement for heat transfer to base fluid by adding alumina nano particles where the thermal conductivity of alumina higher than the thermal conductivity of pure water. The higher concentration of alumina particles relatively, the less time for cooling the nano fluids as shown in figure 4 up to a period of 75min, where a further thermal conductivity added to the base fluids.

4.2 Hourly Variation of Alumina Nano Fluids Temperature Drop at Constant Condition of Volume Flow Rate of Alumina Nanofluids: V_w = 2Lit/min

Figures 5a,b ,and c show the temperature drop of nano fluids for two concentrations 0.1and 0.2% b weight of alumina nano particles at the period from 8 am to 2pm. It is noticed that for the three cases of volume flow rates up to the ten o'clock, a remarkable temperature drop of nano fluids then almost a constant value of temperature for the two concentrations of alumina nano particles. But the elapsed time of temperature drop for concentration 0.1 is less than the time of concentration of 0.2% although the variation in flow rate of air. This may be occurring of occurring agglomeration for the concentration of 0.2 which reduces the heat transfer rate. With an increased airflow rate, 250 ppm, causing reduction the agglomeration of the 0.2 concentration and approximates the elapsed time for 0.1% concentration as shown in Figure 5c.

4.3 Hourly Variation of Alumina Nano Fluids Temperature Drop at Constant Condition of Volume Flow Rate of Alumina Nanofluids: V_w = 3Lit/min

Figures 6a,b, and c show the temperature drop of nano fluids for two concentrations 0.1and 0.2% b weight of alumina nano particles at the period from 8 am to 2pm. It is noticed that for the three cases of volume flow rates up to the ten o'clock, a remarkable temperature drops of nano fluids then almost a constant value of temperature for the two concentrations of alumina nano particles. But the elapsed time of temperature drop for concentration 0.1 is less than the time of concentration of 0.2% although the variation in flow rate of air. This may be occurring of occurring agglomeration for the concentration of 0.2 which reduces the heat transfer rate. With an increased airflow rate, 250 ppm, causing reduction the agglomeration of the 0.2 concentration and approximates the elapsed time for 0.1% concentration as shown in Figure 5c.

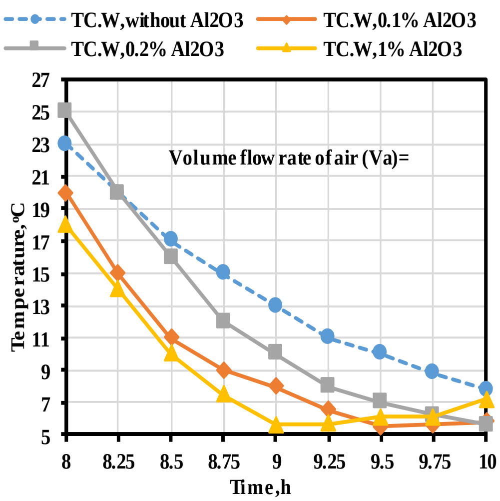


Fig.4a

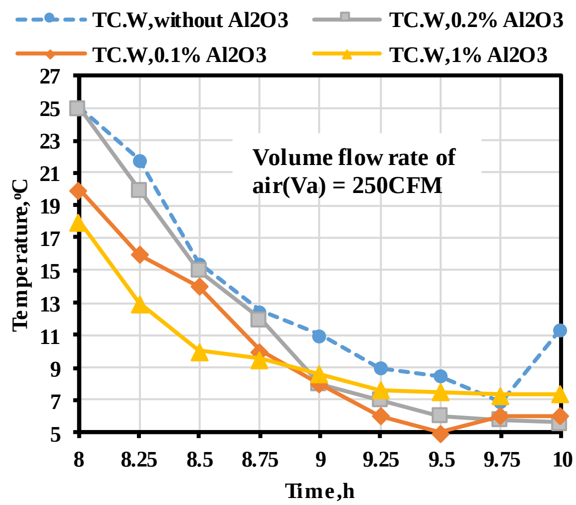


Fig.4b

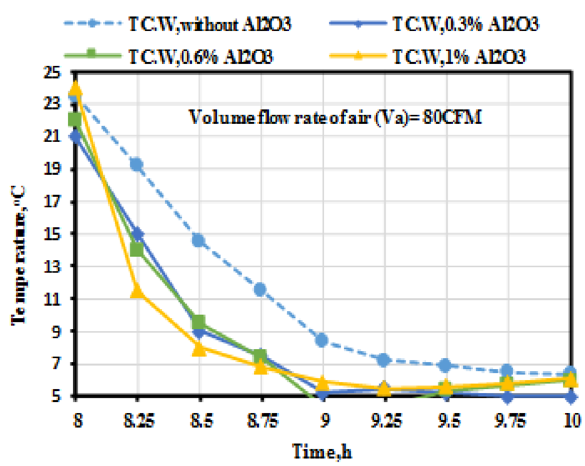


Fig.4c

Fig. 4: Elapsed time for temperature drop of cooling water with and without alumina nano particles

4.4 Comparison of Coefficient of Performance

Figure 8 shows the columns histogram of coefficient of performance ($COP_{c.w.}$) for pure water and for alumina nano fluids of alumina concentrations 0.1, and 1% by weight. It is noticed that the $COP_{c.w.}$ for all alumina nano fluids concentrations is higher than the $COP_{c.w}$ .for pure water. This is due the advantages of adding alumina nano particles which in turn increases the heat transfer rate and probably reduces the power consumption compared to pure water. Also, it is noticed that the $COP_{c.w.}$ of 1% concentration of nano alumina is the highest value than the other concentrations and pure water. The gain in $COP_{c.w.}$was17% and 5% for alumina concentration 1% and 0.1 respectively

compared with pure water.

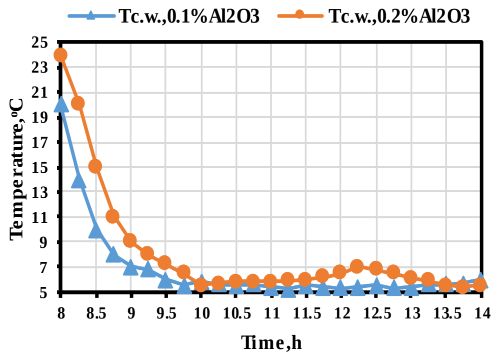


Fig. 5 a

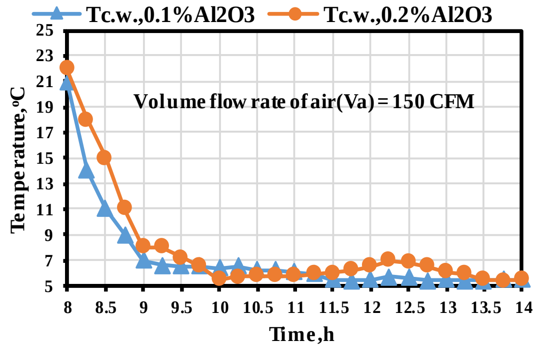


Fig.5b

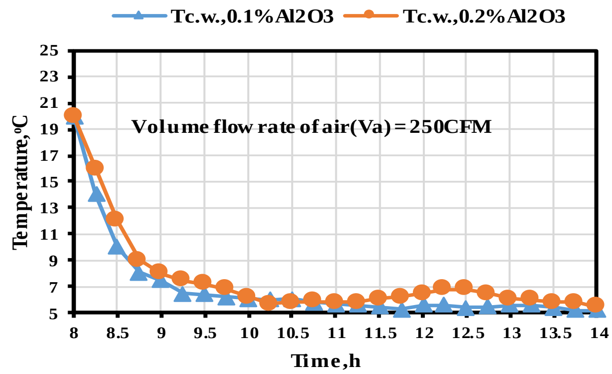


Fig.5c

Fig .5: Hourly variation of temperature drop of alumina nano fluids for alumina nano particles with different concentration at working conditions: volume flow rate = 2 Lit/min

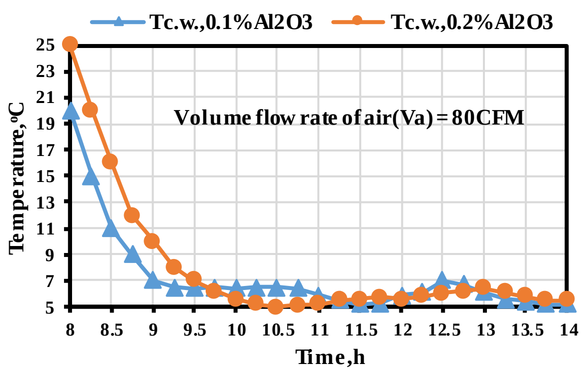


Fig.6a

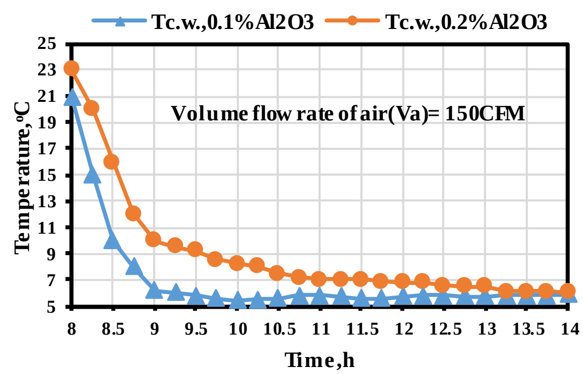


Fig6 b

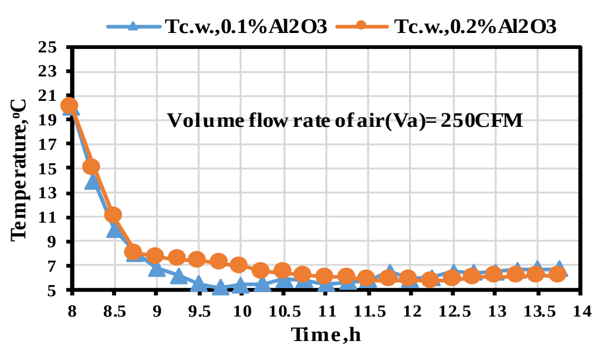


Fig.6c

Fig. 6: Hourly variation of temperature drop of alumina nano fluids for alumina nano particles with different concentration at working conditions: volume flow rate = 3 Lit/min

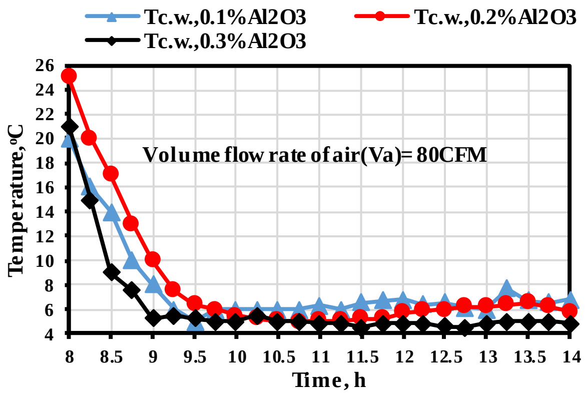


Fig.7a

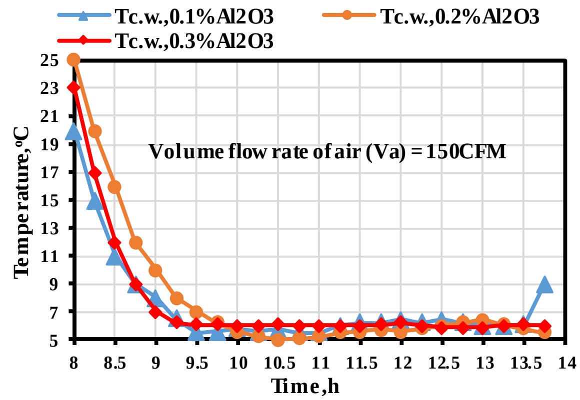


Fig.7b

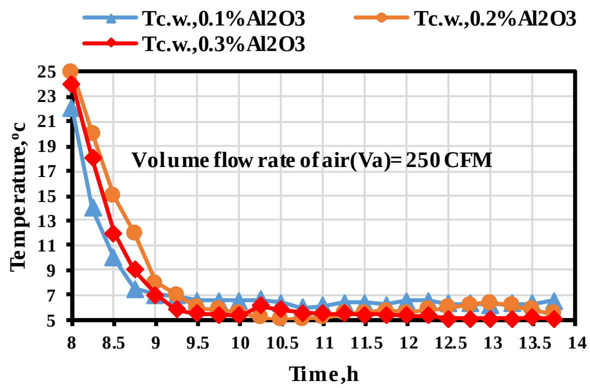


Fig. 7c

Fig.7: Hourly variation of temperature drop of alumina nano fluids for alumina nano particles with different concentration at working conditions: volume flow rate = 5Lit/min

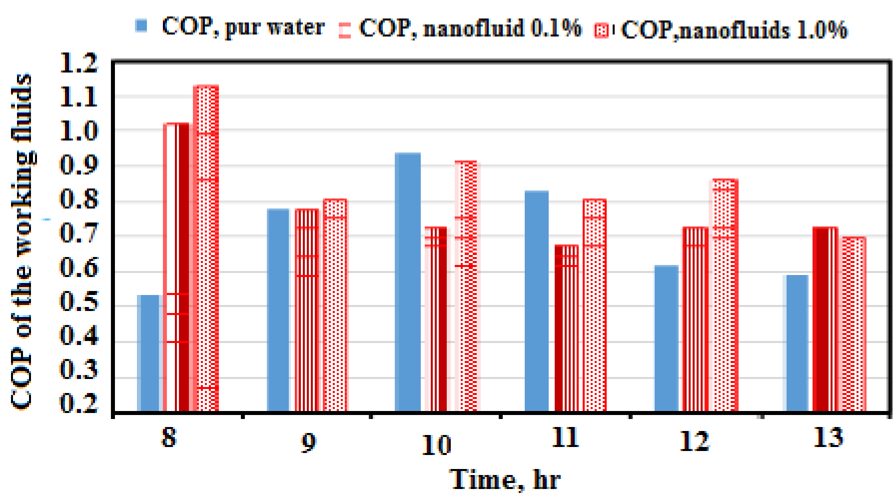


Fig. 8: Effect of adding different concentration by weight of alumina nano particles on COP

5 Conclusions

The thermal performance of chilled water air conditioning unit has been investigated with alumina nano fluids of different concentration (0.1, 0.2, 0.3,0.6 and 1% by weight) and pure water. The experiments have been performed through variation the flow rate of the working fluids (alumina nano fluids and pure water) ranging from 2, 3, and 5 Lit/min and variation of the incoming air which be cooled and ranging from 80, 150, and 250 CFM.
An improvement of the heat transfer characteristics of the working fluids (pure water) has been achieved by addition of alumina nano particles to the pure water. This is revealed from the results of reduced the elapsed time required to cool the alumina nano fluids comparing to the elapsed time of the pure water by about half hour for most the concentrations of alumina nano particles.
With increasing the flow rate of the working fluids (alumina nano fluids), the elapsed time also reduced to the required temperature to be recirculated.
Also, it is noticed that with increasing the concentrations of alumina nano particles, the elapsed time has been reduced. Preparation of homogeneous suspension of nano particles and base fluids is still a technical challenge to obtain a continuous colloidal during the cycle of nanofluids. The flow rate of base fluids (alumina nano fluids/chilled water) and the incoming air to be cooled have been a significant effect on elapsed time for cooling the base fluids.
It is also noticed that the cycle of cooling the air using alumina nano particles operates with normal manner like the cycles with pure water only.

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