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Enhanced Performance of Vapor Compression Air Conditioners Using TiO_2 Nanoparticle-Oil Additives

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ABSTRACT

In this paper, two different refrigerants (R22 and R410) were used, and TiO_2 nanoparticles were mixed with pure oil used for the compressor not to directly with the Freon of 1-Ton split Air Conditioners a/c unit. Power consumption inside room temperature and Coefficient of Performance (COP) with oil mixed TiO_2 nanoparticles were better than pure oil for both refrigerants. R410 has better performance than R22. The a/c system used R410 and operated with oil mixed TiO_2 nanoparticles saved a maximum of 28.4% in power consumption, and maximum COP of 4.55. Consequently, the a/c system that utilizes TiO_2 nanoparticles is recommended to save power consumption and improve thermal performance.

1. INTRODUCTION

The application of the AC system is increasing day by day in numerous industrial and domestic sectors. Khaleel and Khalefa [1] claimed that the values of the Ozone Depletion Potential (ODP) and Global Warming Potential (GWP) are significant necessary indices for constructing a refrigeration system employing alternatives to chlorofluorocarbons (CFCs) (GWP). The AC system regulates indoor temperature, air quality, and flow rate of air for a building and or for a designated room by removing the existing heat and moisture. The AC systems are generally categorized in central AC system, split type, and window type. However, a particular kind of AC system can be selected based on a particular application, designated room or chamber, and specific range. Further, the vapor compression AC systems have numerous applications for providing thermal comfort in terms of cooling and can obtain a broad range of temperature regulations. However, critical issues are still to be addressed and settled for the AC system. Firstly, AC systems consume a considerable amount of electricity as other thermal systems do state by Soliman et al. [2]. Second, how well they operate during times of high demand [3]. Thus, improving their performance in minimal energy consumption is critical in recent research and to obtain substantial savings for the organizations and end-users.

Bi and Shi [4] conducted an experimental investigation to find the energy consumption of the refrigeration system. They used TiO_2 mixed with R134a to prepare nan fluids. According to the experimental findings, utilizing nan fluids lowered the refrigeration system's energy consumption by 7%, (R134a with TiO_2). Bi et al. [5] investigated the energy usage of the system using various concentrations of TiO_2 combined with R600a in a residential refrigerator. According to the experimental data, 0.1 concentration of TiO_2 combined with R600a resulted in a minimum energy consumption of 5.94% and an increase in the refrigeration system's freezing rate of 9.6%. Sabareesh et al. [6] employed various TiO_2 concentrations (0.05%, 0.1%, and 0.15%) to examine the effectiveness of the vapor compression cycle. According to the experimental findings, the vapor compression refrigeration system's compressor work dropped by 11%, its coefficient of performance (COP) increased by 17%, and its average heat transfer rate increased by 3.6% at 0.1% TiO_2. To examine the energy savings of the residential refrigerator system and to lower CO_2 emissions in Malaysia, different weight concentrations of Al_2O_3 and TiO_2 nanoparticles (0.06% and 0.1%) were combined with R134a [7]. The findings showed that the largest energy savings for the refrigeration system of roughly 25% were achieved with 0.1% of TiO_2 nanoparticles to mineral oil R134a. Furthermore, their research indicated that utilizing nan refrigerant would result in a greater CO_2 reduction. Additionally, they claimed that combining mineral oil and R134a with 0.1% TiO_2 can reduce carbon emissions by more than 7 million tons. Another study [8] looked into the viscosity and thermal conductivity of heated iron oxide and aluminum oxide Nano fluids. According to the experimental findings, the viscosity of nan fluid increased by 15%-25% and the thermal conductivity of iron oxide by 3%-12%, respectively. In order to emphasize the experimental and numerical investigations completed to compile the impact of nan fluids on the functionality of evaporating and condensing systems, Rashidi et al. [9] conducted a review study. According to their review work, many AC and refrigeration systems can benefit from the usage of nan fluids as major and effective heat transfer fluids to boost their thermal performance. A TiO_2 nanoparticles and polyethylene glycol were employed in an experimental investigation by Sanukrishna and Prakash [10] to examine the thermal conductivity and viscosity of Nano lubricant. Tests were conducted using various volume fractions (0.07 to 0.8%) and temperature ranges of 20 to 90 0C. According to the findings, raising the mixture's volume fraction led to an increase in the thermal conductivity and viscosity of the Nano lubricant. The same pattern of results with increasing temperature was also found. External pipes were connected to the condenser part during an experimental study by Nakkaew et al. [11]. Through extra heat pipes and air moving at a speed of 5 m/s, they were able to dissipate 240 W of heat. Additionally, based on their findings, it has been suggested that using a total of 6 heat pipes will optimize the refrigeration system's power usage and provide the best performance. In their investigation, they modified the refrigeration system's geometrical design. The condenser and evaporator parts of the conical tube design have coil torsion (pitch ratio) ranges of 0.07-0.13 and taper angles ranging from 0-135° [12]. They discovered that raising coil torsion and taper angle increased the coefficient of performance (COP). Many experts are also concentrating on utilizing nan fluids to enhance the effectiveness of the refrigeration system. TiO_2 Nano fluids were used in an experimental investigation by Jiang et al. [13] to determine how they would affect an ammonia absorption refrigeration system. TiO_2 was employed in various mass fractions (0.1%, 0.3%, and 0.5%), and the maximum COP was around 27%. Sanukrishna and Prakash [10], and Adelekan et al. [14] conducted an experimental investigation to look into the COP of TiO_2-based refrigeration systems. R600a and TiO_2 were combined to create the Nano refrigerant. According to the experimental findings, the system's COP (TiO_2 with R600a) improved by up to 78%. Babarinde et al. [15] carried out this research further and calculated the refrigeration system's COP using two different Nano refrigerant concentrations (TiO_2 in combination with R600a): 0.4 g/L and 0.6 g/L. The results showed that 0.4g/L of TiO_2 Nano lubricant boosted the refrigeration system's coefficient of performance by 52%. Kamel and Najm [16] investigated different kinds of conventional fluids and Nano fluids to analyze the heat transfer and fluid movement in tubes bank heat exchangers. The results showed that compared to the base fluid, introducing Al_2O_3 and SiO_2 nanoparticles at a constant concentration enhanced heat transfer performance. These early investigations supported the use of nan fluids in air conditioning and refrigeration systems. The use of nan fluids is advantageous since it lowers energy consumption and enhances the system's thermal performance. As a result, in this research project, R22 refrigerant was combined with TiO_2 nanoparticles. For this research, a split air conditioner was used, and R22 and TiO_2 nanoparticles were combined to create the nan fluid. Calculations were made and comparisons were made between the density and viscosity of pure oil and oil combined with TiO_2 nanoparticles. Also computed and compared were the thermal performance (at room temperature) and the COP of the system using pure oil and oil mixed with TiO_2. The immiscible kerosene-water two-phase flows in a T-junction micro channel were numerically investigated using the Lattice Boltzmann (LB) method [17]. The experimental results were quantitatively and qualitatively confirmed by this result [18-20].

In recent years, desiccant dehumidifiers have drawn increased interest from the air conditioning sector. Although secondary 123 refrigeration design's thermal efficiency is lower than that of conventional direct refrigeration systems, it has been found to be a good strategy for reducing refrigerant charge. Use two nanofluids and test the plate heat exchanger's thermal efficiency in the range of 0 and 10°C. Their findings demonstrated that the use of nanofluids boosted convective heat transfer. They also mentioned the link between pressure drop and thermal performance [21, 22].

These systems have the ability to reduce the amount of energy required for humidity control as compared to conventional compression refrigeration devices by utilizing low-temperature waste heat [23-26].

The general format of this paper is organized in a way that Section 1 describes the research background related to the title of the paper. This section discusses a small discussion about the AC system, nan fluids, and previous research. Further, in this section, the objective of the paper has been highlighted. Section two discussed the preparation of the nan fluids in which the methods of mixing TiO_2 nanoparticles and R22 have been discussed. Further, the experimental setup is presented, and methods of calculating thermal comfort (inside room temperature) ad COP were also highlighted. Section 3 depicts the result and discussion section, where the results, arguments, and discussion have been carried out. Finally, section five describes the Conclusion and Future Recommendations that have been set for future work.

Mate this study adds (TiO_2 nanoparticles) to the oil of these systems with a capacity of 1 ton and two units working with freon gas (R22) and (R410) in order to increase the (cop) of air conditioning unit units (a/c) and decrease their energy consumption. the findings are then compared.rials and methods.

1.1 Preparing nano oil

The TiO_2 nanoparticles were suspended in type 4GS as shown, and the technical parameters were determined to create the Nano oil. Using Eqs. (1) and (2), the amounts of oil and TiO_2 nanoparticles were computed [22].

$$m_p = \frac{\emptyset \times \rho_p \times \left(\frac{m_f}{\rho_f}\right)}{(1-\emptyset)} \quad (1)$$

$$\rho_P = (1-\emptyset)\rho_f + \emptyset\rho_n \quad (2)$$

where:

m_p is the amount of an oil; ρ_P is the theoretical density of an oil, ϕ is mass fraction; mf is the mass of pure oil; ρ_f is the density of pure oil; ρ_n is nano oil density.

1.2 The density of nano-oil

The quantity of nanoparticles (solid) was calculated and mixed with cooling oil through two methods as described below:

1.2.1 Mechanical method

Figure 1(a) shows an electric mixer, and it was used to mix the oil with nanoparticles. However, the number of nanoparticles was calculated according to Eq. (1). The oil and nanoparticles were mixed for a certain time ranging from 30 to 45 minutes, for proper and homogeneous mixing.

1.2.2 Ultrasonic method

After mechanical mixing, the mixture (oil and TiO_2 nanoparticles) was poured into a flask and placed on an ultrasonic machine, as shown in Figure 1(b). The machine ran for 45-60 minutes to complete the whole process as suggested [24].

(a) (b)

Figure 1. Nano-oil density measurement: (a) Electric mixer (b) Ultrasonic machine

1.3 Viscosity

After preparing the Nano fluid (oil with TiO_2 nanoparticles), Eq. (3) was used to calculate its viscosity of it using equation used [20].

$$\mu_{nf} = \mu_{pf}(1 + 2.5\emptyset) \quad (3)$$

where:

μ_{nf} is Nanofluid viscosity; μ_{pf} is pure oil viscosity.

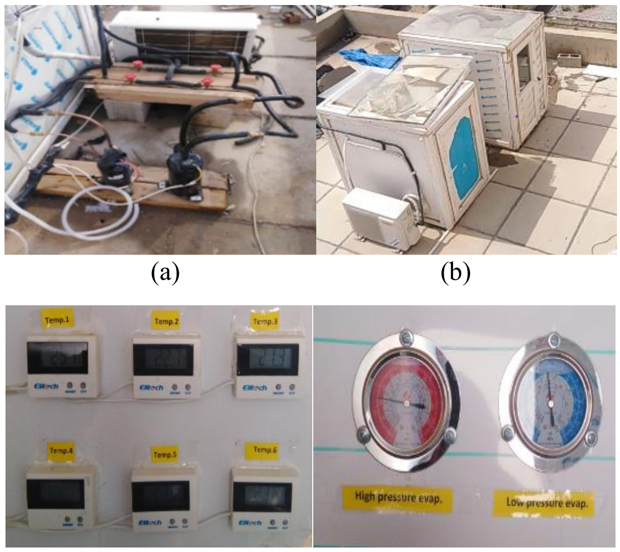
Additionally, Figure 2 displays a digital rotating viscosity meter that was used to gauge the viscosity of pure oil and nanoparticle TiO_2.

Figure 2. Viscosity measurement for nano-oil (Ø=0.001) and pure oil

Temperature readings in rooms one and two as well as the amount of electrical current used by the compressor in systems one and two were taken throughout various time periods. After that, the amount of energy saved was calculated using the following formula: the ratio of saved current equals the rate of current of a compressor using pure oil minus the rate of current of a compressor using oil mixed with nanoparticles.

1.4 Experimental setup

In this study, power consumption, interior room temperature, and COP of the systems were calculated for 1-Ton split AC units using R22 and R410. Additionally, two alternative oils were employed for the compressor of the AC units, including pure oil and oil combined with TiO_2 nanoparticles. Additionally, two identical rooms with identical external dimensions—1.5 m×1 m×1.5 m (length, breadth, and height) and similar technical parameters as those in Figure 3 were used for the experiment. Both rooms were constructed using metal panels and insulated foam as a means of insulation, with the exception of the south side. A layer of aluminum with a thickness of 1 mm was used to construct the south side. The north side of the door was installed, and the glass was 4 mm thick. To evaluate the thermal efficiency of both split AC systems, a separate arbitrating system with two high and two low pressure gauges, six thermocouples, and positions in both rooms, was installed. Additionally, the arbitrating system has a voltage meter, and the voltage difference was established to track each system's operating capability for comparing power discharge. There were no modifications made to the split AC system in one room because it was deemed to be basic. At the same time, mixed oil was added to the compressor of the other split AC system.



(a) (b) (c) (d)

Figure 3. Air conditioning system: (a) Inner section (b) Outer section (c) Temperature and (d) Pressure measuring setup

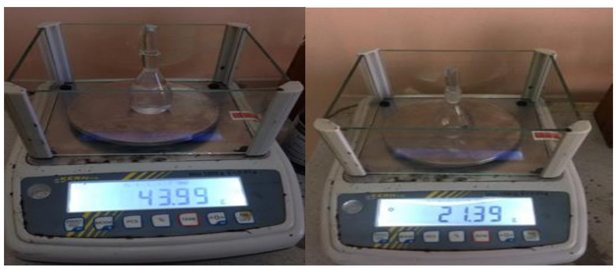


Figure 4. Density measurement of oil

1.5 Computational method

Eq. (4) was used to compute the density of pure oil used in the device of system one as depicted in Figure 4.

$$\rho_f = \frac{m_f}{v_f} \quad (4)$$

where:

v_f is the volume of pure oil.

1.6 Coefficient of performance (COP)

The efficiency of compressors and cooling systems is known as the COP. It can also be described as the proportion between the amount of adequate cooling in the evaporator and the power of the compressor. Let the device function more effectively whenever the COP percentage rises. Utilizing mixed oil and nanoparticles, the device's COP was estimated using Eq. (5).

$$C.O.P = \frac{Q}{W} \quad (5)$$

where: "W" refers to the work performed by the compressor, and "Q" refers to "the heat provided to or evacuated from the reservoir".

2. RESULTS AND DISCUSSION

1. As discussed earlier, there were 02-split AC units used to calculate theoretical and practical data collection. Pure oil was used for split AC unit 01, and nan fluids (pure oil mixed with TiO_2 nanoparticles) were used for split AC unit 02. Further, both split AC units were operated in the same conditions and circumstances.
2. Results for pure oil and Nano fluids' theoretical and actual densities are shown in Table 1 and Figure 5. The findings demonstrated that the pure oil and Nano fluid theoretical densities were greater than their actual densities. Furthermore, pure oil and nan fluids both saw theoretical and practical density values increases of 0.22 and 0.1%, respectively. Lower practical values for the pure oil and nan fluids could be the result of experimental performance practical mistake. Based on the growing gap between theoretical and actual density values for pure and nan fluids, it is possible that a small calculation error is to blame.
3. Figure 6 illustrates the results of a viscometer calculation of the viscosity of pure oil and nan fluids. The viscosity of the pure oil and nan fluids is measured and displayed on the viscometer's display screen. The results for pure oil viscosity and oil containing nanoparticles are shown in Table 2. The findings showed that oil containing nanoparticles has a higher viscosity than plain oil. The obtained results also showed that the viscosity of the combined oil increased with the inclusion of TiO_2 nanoparticles.
4. The power usage of an AC system using pure oil and oil combined with TiO_2 nanoparticles is shown in Table 3. For the AC system, R22 was employed as the refrigerant, and oil was combined with 0.001 fractions of TiO_2 nanoparticles. Additionally, the system's power usage was determined using runtime (hours). It was computed the difference between the two scenarios, the system's power consumption, the rate of registered capacity, and the profit in percentage. Additionally, Figure 7 displays a graphic representation of the system's power consumption results. It is clear that the system running on Nano fluids used less power than the system running on pure oil. It suggests that employing Nano fluids can have a major positive impact on how much power the AC system uses. Additionally, the statistics on power usage revealed that an AC system running on nan fluids might save 15.5% more money than one running on pure oil.

Table 1. Theoretical and practical pure oil density and oil with nanoparticles

Density	*Theoretical g/cm³*	*Practical g/cm³*
Pure Oil	0.905	0.903
Oil with Nanoparticles (Ø = 0.001)	0.907	0.906

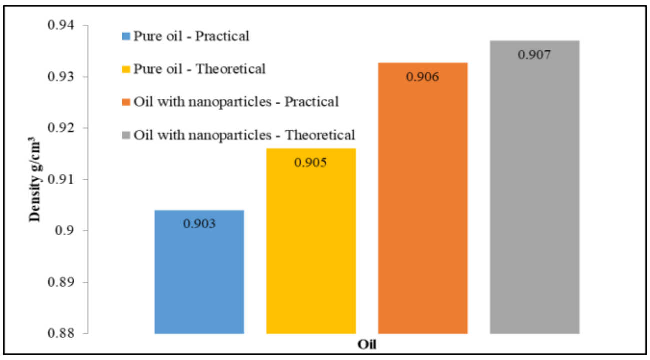


Figure 5. Theoretical and practical density of pure oil and oil with nanoparticles

Figure 6. Viscometer

Table 2. Pure oil viscosity and oil with nanoparticles

Viscosity of Pure Oil (mPa.s)	**319**
Viscosity Oil with Nanoparticles (mPa.s)	320.5

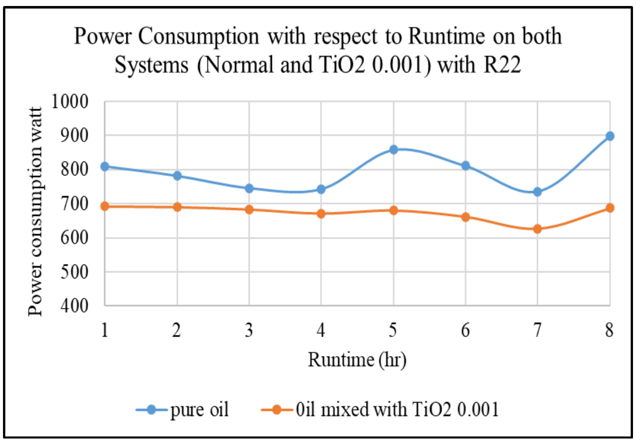


Figure 7. Power consumption for both oils with R22

Table 3. Power consumption for pure oil and TiO_2 0.001 with R22

Power Consumption with Respect to Runtime on Both Systems (Normal and TiO2 0.001) with R22		
Runtime (hr)	***Pure Oil (Watt)***	***Oil mixed with TiO2 0.001 (Watt)***
1	810	693
2	782	691
3	746	684
4	743	672
5	858	681
6	811	662
7	736	626
8	898	687
Total	6384	5396
Rate of Registered Capacity	798	674.5
The Ability Difference between the Two Cases	123.5	
Percentage of Profit Obtained by Capacity	15.5%	

5. The power usage of the AC system when using pure oil and oil combined with TiO_2 nanoparticles is shown in Table 4. Additionally, oil was combined with 0.001 fractions of TiO_2 nanoparticles and refrigerant R410 for the AC system. The AC system's power usage was calculated based on time (hours). Figure 8 shows the power consumption figures graphically. The findings showed that the TiO_2 nanoparticle-infused oil-operated AC system consumed less power than the pure oil-operated system. These findings suggested that using nan fluids can reduce the amount of energy needed to run AC systems. Additionally, using nan fluids increased the AC system's capacity-based profit by 28.4%.

Table 4. Power consumption for pure oil and TiO_2 0.001 with R410

Power Consumption with Respect to Runtime on Both Systems (Normal and TiO₂ 0.001) with R410		
Runtime (hr)	***Runtime (hr)***	***Runtime (hr)***
1	1364	1034
2	1364	990
3	1342	1034
4	1298	924
5	1254	726
6	1232	858
7	1188	990
8	1188	770
Total	10230	7326
Rate of Registered Capacity	1278.75	915.75
The Ability Difference Between the Two Cases	363	
Percentage of Profit Obtained by Capacity	28.4%	
The Amount of the Increase in Efficiency	0.235	

6. In order to test for thermal comfort, the AC system ran on both oil (pure oil and oil combined with TiO_2 nanoparticles) and both refrigerants (R22 and R410). The internal room temperature was determined using thermocouples installed at various times and locations across the space. However, each system was kept in their symmetrical positions for the room (both oils and refrigerants). Figures 9(a) and (b) provide a graphic representation of Table 5 results for the interior room temperature (b). The findings showed that as the period increased, the temperature inside the room fell. However, compared to the system that used oil combined with TiO_2 nanoparticles, the AC system that used pure oil worked for a shorter period of time and produced a lower interior temperature. Additionally, the AC system using refrigerant R410 provided better thermal comfort than R22 for both cases (pure oil and oil mixed with TiO_2 nanoparticles).

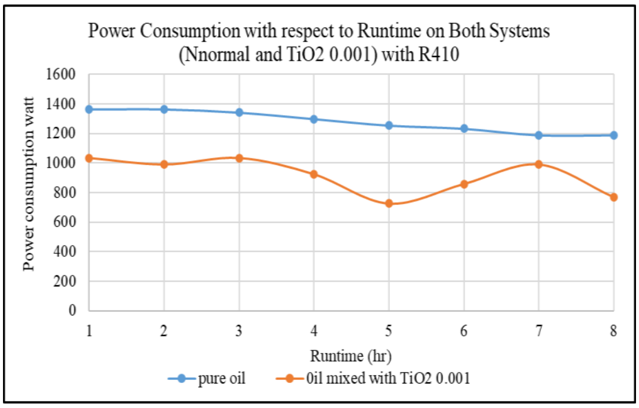


Figure 8. Power consumption for both oils with R410

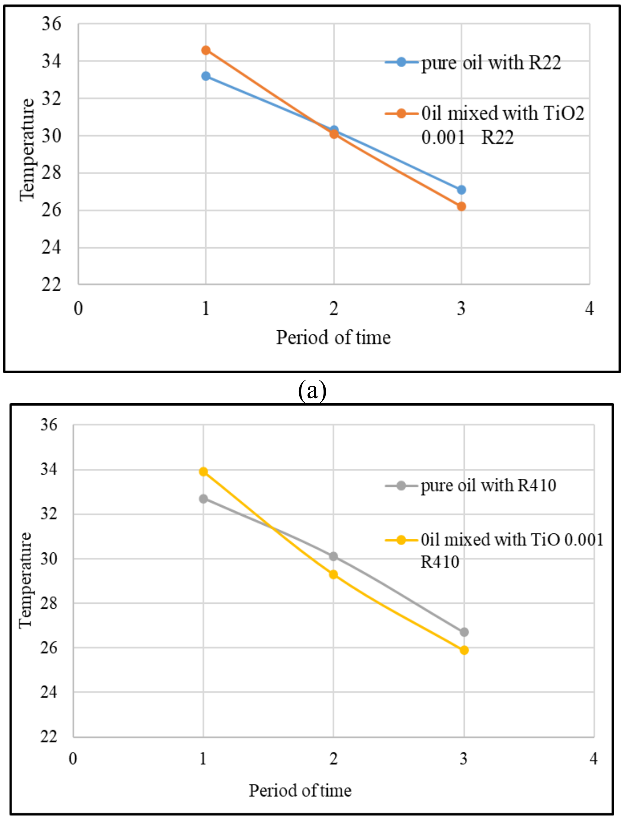


Figure 9. (a). Inside room temperature for pure oil and oil mixed with TiO_2 0.001 for R22, (b). Inside room temperature for pure oil and oil mixed with TiO_2 0.001 for R410

7. Figure 10 depicts the COP of an air conditioning system using both pure oil and oil mixed with TiO_2 as refrigerants (R22 and R410). For employing pure oil and Nano-oil, R22 with TiO_2, and R410 with TiO_2, the COP results were 3.26, 3.85, and 4.55, respectively. Additionally, the actual COP of the AC system was determined once the room's minimum temperature was reached (at the steady state). In other words, it was determined by dividing the amount of cold air (air conditioning) in the evaporator by the entire amount of power used by consumption.

Table 5. Theoretical and practical pure oil density and oil with nanoparticles

Time Period	Inside Room Temp. Pure Oil with R22	Inside Room Temp. for Oil Mixed with TiO_2 0.001 R22	Inside Room Temp. for Pure Oil with R410	Inside Room Temp. for Oil Mixed with TiO_2 0.001R410
1	33.2	34.6	32.7	33.9
2	30.3	30.1	30.1	29.3
3	27.1	26.2	26.7	25.9

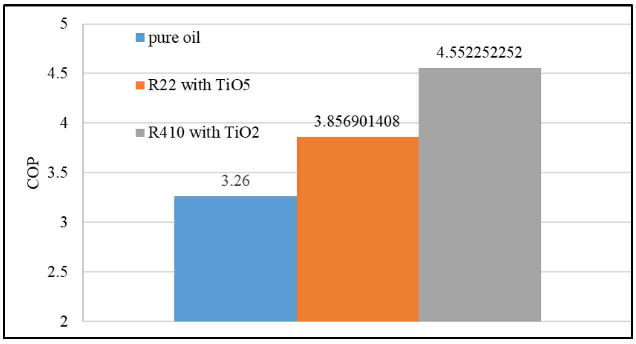


Figure 10. COP for the system

3. CONCLUSIONS

The continuous change of environmental situation and increase of temperature reveals that the utilization of AC systems is increasing substantially. The increase in the use of AC causes more consumption of electrical energy and cost for the users and or organizations. Thus, the newest research in refrigeration and AC systems is focused mostly on lowering the electrical energy consumption for the AC system. Using nan fluids for AC and refrigeration systems is one of the most results for such a system. The nan fluids reduce the consumption of electrical energy and improve thermal performance. Therefore, TiO_2 nanoparticles were mixed with oil in this research to prepare nan fluids and were used for the AC system. Further, two different refrigerants R22 and R410, were used for the AC system. The density, viscosity, power consumption, inside room temperature, and COP were calculated experimentally. The following conclusions were drawn from the experimental data:

1. The density and viscosity of the nan fluids (oil mixed with TiO_2 nanoparticles) were higher than the pure oil.
2. Using oil mixed with TiO_2 nanoparticles in the AC system reduced the power consumption.
3. The AC system operated with oil mixed TiO_2 nanoparticles and used R22 provided 15.5% power savings.
4. The AC system operated with oil mixed TiO_2 nanoparticles and used R410 provided 28.4% power savings.
5. The AC system used oil mixed with TiO_2 nanoparticles resulted in higher COP than the AC system that used pure oil for both refrigerants (R22 and R410).
6. Finally, the AC system using refrigerant R410, and oil mixed with TiO_2 nanoparticles resulted in higher COP.

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NOMENCLATURE

AC	Air Conditioner Coefficient of Performance
COP	Coefficient of Performance
CFC	Chlorofluorocarbon
ODP	Ozone depletion potential
GWP	Global warming potential
Q	Heat supplied to or removed from the reservoir
W	Work done by the compressor

Greek symbols

$\emptyset$	optical penetration depth (m)

Subscripts

m_p	Amount of an oil
P_P	Theoretical density of an oil
m_f	Mass of pure oil
p_f	Density of pure oil
p_n	Nano oil density
v_f	Volume of pure oil
μ_{nf}	Nano fluid viscosity
μ_{pf}	Pure oil viscosity