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PERFORMANCE ANALYSIS OF R32/R600a BLEND WITH TiO_2/MO NANOFLUID FOR EXISTING RESIDENTIAL AIR CONDITIONING SYSTEM

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ABSTRACT

This experimental study investigated the energy and exergy performance of R32/R600a (50:50 by mass) with TiO2 nanofluid for a residential air conditioning system which was originally designed for R22. R32/R600a has been used along with 0.01%-0.02% volume concentration TiO_2 nanolubricant. Cetyl trimethylammonium bromide (CTAB) has been used as surfactant. Pressures and temperatures of different components have been recorded for measuring energy and exergy parameters. RERPROP 7 software has been used to determine the thermal properties of the refrigerants and the blend at different conditions. The results show that the R32/R600a has lower value of COP compared to R22. Numerically R32/R600a blend has 32%, blend with 0.01% nanofluid has 26% and blend with 0.02% nanofluid has 61% less COP than R22. However, refrigerating effect of the blend has increased by 10 percent compared to R22 while the blend with 0.01% and 0.02% has 20% and 9% more refrigerating effect respectively. Again, the blend without nanofluid and along with nanofluid (0.01%, 0.02%) have 25%, 7% and 3% more power consumption than that of R22 respectively. Exergy analysis shows R32/R600a blend and the 0.01%, 0.02% nanofluid have higher irreversibility compared to R22. Overall, R32/R600a blend is not suitable for retrofitting in R22 system.

Keywords: *Nanofluid, Exergy, COP, Alternate Refrigerant, Irreversibility, Stability*

NOMENCLATURE

COP	- Coefficient of Performance
ODP	- Ozone Depletion Potential
GWP	- Global Warming Potential
CFC	- Chlorofluorocarbon
HCFC	- Hydrochlorofluorocarbon
Blend	- R32/R600a (50/50 wt.%)
VCRS	- Vapor compression Refrigeration System
EER	- Energy Efficiency Ratio
RE	- Refrigerating Effect

1. INTRODUCTION

The usage of Air Conditioner is increasing day by day. Air conditioner demand growth in Bangladesh from 2013 to 2018.

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In Bangladesh, demand of air conditioner has been increased every year. From 2017 to 2018 air conditioner demanded Bangladesh has been increased by 14 thousand unit [1]. R22 is the most commonly used coolant in the air conditioning industry owing to its excellent thermal properties and availability compared to other coolants. R22 will, however, be phased out by 2020 in developed countries because of its high global warming potential (GWP) and by 2030 in developing countries under the Montreal Protocol [2-3]. Researcher are continuously searching for better alternative of R22 and many researches has already done on various types of refrigerants. Some authors choses hydrocarbon-based blend and refrigerant while other chooses Hydrofluoroolefin (HFO) as alternate refrigerant.

Again, many researchers have also suggested for hydrocarbon and HFC blend although high global warming potential (GWP) refrigerants has also been avoided in those researches [5-6]. R1234yf, R1234ze, R1234ze and their blend also shows less

GWP and have no ozone depletion potential (ODP). Researchers also try those refrigerants as an alternative of high GWP refrigerant as they possess good thermal performances[6]. Supermarket are nowadays adopting R404A and R507A in replacement of R22 but in European countries R744 and R134A and hydrocarbons are used in replacement oof R22 reported by Yang and Wu [7]. Although hydrocarbon like R600a and R290 has flammability issues. R32 has also been used as an alternative of R22 by some researcher shows better results [8]. Although R32 has flammability issue but through different experimental work between slow leakage rate and fast leak rate, Jia et al. [9] studied the leakage effect of R32. If there are still some electric sparks, the experimental work demonstrates non-flammability used in a scheme. The R32 cannot be ignited by light switches (contactors) in domestic appliances, based on the experiment. The cause of R32 combustion in the living room is most likely to be open fires such as a candle and a fire oven. Doiphode et al. [10] conducted a numerical and experimental analysis of an air conditioner using a mixture of R32 and R32/CO_2 instead of standard CFCs and HCFCs and found that it displays around 3-8 percent greater cooling effect than R32 if the mixture of R32/CO_2 by weight changes. Nattaporn and chaiyat [11] also demonstrated a technique using ultrasonic waves to boost the thermal efficiency of an R32 air conditioner. When using a standard R32 unit without ultrasonic generators, the installation of an ultrasonic generator at the evaporator of the R32 unit will increase EER by approximately 7.69 percent compared to the results. The test conditions also suggested that the improved system's cooling efficiency could be increased by approximately 7.69 percent. In addition, the convective heat transfer coefficient was approximately 17.36 percent higher for the adjusted ultrasonic R32 unit than for the standard R32 unit without the ultrasonic generators since the ultrasonic waves in the refrigerant flow will increase the turbulence and decrease the condensed water in the fan coil device. Sethi et al. [12] have also experimented with R407C and R444B replacing R22. R407C and R444B have been found to be effective at high ambient temperatures and to be 5% more efficient at all operating temperatures. Kapil et al. [13] also investigated R410A, R290, R1234yf, R502, R404A, R512A and R134A refrigerants in term of COP, exergy efficiency and results shows R152A better performance. Teng et al. [14] studied the feasibility of replacing R22 by R290 by varying the mass from 25 to 70 percent at different ambient temperature. Author also suggested that R22 can be replaced by R290 in his study. The effect of changing the R22 refrigerant to R22/R600a blend with nanoparticle was also studied by Razzak and Ahamed [15] shows that the blend saved energy and that the blend has better thermal properties than R22. Again, researcher also studied the exergy effect on various component of the air conditioner for various refrigerant.

Hydrocarbon (HC) exergy analysis was studied by Razzaq et al. [16], where the greatest exergy destruction was at the compressor and 50 percent of the overall exergy destruction. For different evaporator temperatures, the energy efficiency for R600a ranged from 10% to 16%. With the rise in evaporator temperature, total exergy loss was greatly reduced. Whereas, with the rise in condensing temperature for a given evaporator and ambient temperature, gross exergy losses have been increased. Gill et al. [17] studied the energetic and exergetic performance using R134a and LPG refrigerant with polyester oil and mineral oil where authors also added different nanoparticle. The result shows minimum power consumption and less irreversibility for LPG/TiO_2 with mineral oil of concentration of 0.2 g/L of TiO_2. In a vapor compression refrigeration cycle, Arora et al. [18] performed exergy analysis with R22, R407C and R410A. The research was carried out in the range of -38^0C to 7^0C and 40^0C to 60^0C respectively for evaporator and condenser temperatures. The outcome shows that for R22, the exergetic efficiency and COP were high compared to R407C and R410A. For R410A and then for R407C and then R22, respectively, the maximum energy destruction ratio was. Saravanakumar and Selladurai [19] studied the exergy analysis for R290/R600a refrigerant mixture in replacement of R134a and found that COP of blend was increased by 28.5 percent than R134a. In a vapor compression refrigeration system where R134a COP increased by 15.20 percent when Reddy et al. [20] carried out an exegetical analysis for R134a, R143a, R152a, R404A, R407C, R410A, R502 and R507A. Similarly, it was increased by 14.8, 15.57, 14.54, 12.98, 14.988, 14.91 and 14.70 percent for R143a, R152a, R404a, R407C, R410A, R502 and R507A, respectively and decreased by 1.04, 1.42, 0.73, 1.63, 3.02, 1.23, 1.33, 1.47 percent for exergy, respectively. Paula et al. [21] represented a steady state model of VCRS using R1234yf, R290 and R744 in replacement of R134a. Authors has found that R290 has better thermal performance as well as higher exergy efficiency. Ahmed et al. [22] summarized the information about the exergetic performance of different refrigerants such as R407a, R600a, R410a, R134a. In substitution of R134a in a VCRS. Sun et al. [23] also tested R513a for exergy analysis and found that the exergy was reduced by 14 percent compared to R134a. Again, Ahmad et al.

[24] conducted an exergy study in an R22 system with R290 and its mixture with R22 and shows that the exergy loss in the blend was higher than R22 in every case. Yataganbaba et al. [25] analyzed R1234yf and R1234ze as substitute of R134a about their exergy performance and they found that the exergy loss in the compressor is identical in both instances.

Nano particles are certain particles that have at least a dimension of 100 nm. The fluid in which nanoparticles are distributed in a base fluid used for various purposes is nanofluid. Nano particles are of various sizes, including nanowire, nanotube, nanorod, etc. Nanofluid is used to improve thermal properties such as conductivity, viscosity, thermal diffusivity compared to base fluid in heat transfer devices. Two methods can be used to prepare nanofluids: 1) One step method, 2) Two step Method. The preparation of these two approaches is different. Physical and chemical techniques are part of a single step process. Vapor deposition, laser ablation and submerged arc are used in the physical process. Chemical process uses chemical reaction to create nanofluids. In one step, nanoparticle preparation and suspension into base fluid is performed simultaneously where both methods are performed separately in two stages [26-27]. Two steps method include surfactant addition, PH adjustment, ultrasonication, magnetic stirrer-physical means etc. are used. Nanofluid stability check is an important characteristic for proper dispersion of nanoparticle into the nanofluid. The stability analyzed by sedimentation and centrifugal method, zeta potential analysis, spectral absorbency analysis, Dispersion can be improved through surfactant uses. Oleic acid, CTAB, SDS, SDBS, acetic acid is the common surfactant used for better dispersion of nanoparticle. Razzak and Ahamed [15] has also used TiO_2 nanoparticle with mineral oil in R22 air conditioner system and the performance shows increased. Babarinde et al. [28] analyze R600a with TiO_2 nanolubricant of 0.2, 0.4, 0.6 g/L where author shows better thermal performance with nanoparticle. Padmanabhan et al. [29] used a 0.1g/L concentration of TiO_2 nanoparticle with mineral oil in the R134a system and used a magnetic stirrer for proper dispersion to disperse the author. For about 6 months, the authors found the stability of the nanofluid. In our previous work the same result has been obtained [30]. Many researchers are nowadays trying to use hydrocarbon-based refrigerant so in order to find out the feasibility of R32 and R600a refrigerant blend, this work has been carried out.

So, in this work a blend of R32 and R600a has been used as an alternative to R22 to find out the performance. After that TiO_2 nanolubricant has also been used to find out the performance improvement than before.

2. REFRIGERANT SELECTION AND PROPERTIES OF REFRIGERANTS

Before phasing out of R22, alternative refrigerant should be well established for the replacement of existing R22 system. To analyze the thermodynamic performance of R32/R600a (50:50 by mass) with nanofluid experimental work has been carried out in this experimental work. So R32/R600a blend (B1) has been experimented to justify the use of those refrigerants. Properties of the selected refrigerant are shown in Table 1 [30-31].

Table 1. Thermo-physical properties of selected refrigerants [31-32]

Refrigerants	R22	R32	Blend 1 (B1)
Refrigerant Composition	$CHClF_2$	CH_2F_2	R32/R600a -(50:50)
Molar Mass (kg/kmol)	86.47	52.02	54.904
Critical Temperature (^{0}C)	96.2	78.1	87.225
Critical Pressure (MPa)	4.99	5.78	4.8974
ODP	0.050	0	0
GWP	1810	675	340

From James et al. [30] work, the properties of the selected base refrigerants have been taken, and the rest of the data is determined by the software REFPROP 7. Since the experimental setup was originally designed for R22 refrigerant, on the basis of experimental data, the best alternative must be found among these. There, the molecular mass of the blends is lower than R22, while the critical pressure is quite close to it. For optimal outcome, the charge of the blend needs closer observation in the experiment. Again, among all the refrigerants selected for this study, the Ozone Depletion Potential (ODP) is 0, while the Global Warming Potential (GWP) of the selected refrigerant blend is 82% percent lower than that of R22.

The vapor pressure at the saturation temperature is another important parameter for selecting the refrigerant. Vapor pressure at different temperatures at different saturation temperatures is shown in Figure 2. It can be described from this figure that R32 has a higher vapor pressure at different temperatures than R22, whereas at different saturation temperatures, the blend has lower vapor pressure than R22.

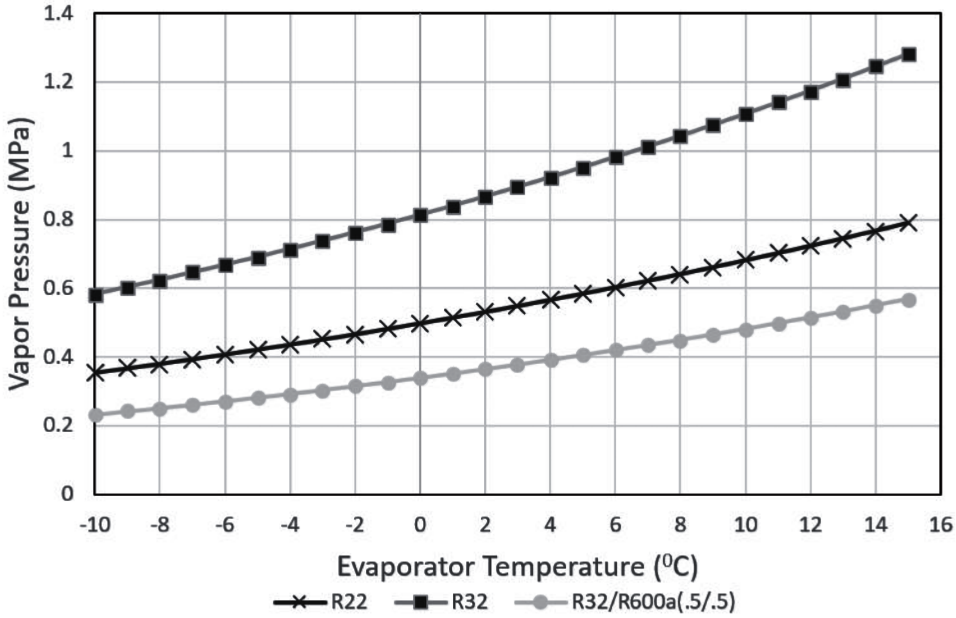


Fig. 1. Variation of vapor pressure at different evaporator temperature for different refrigerant and their blend

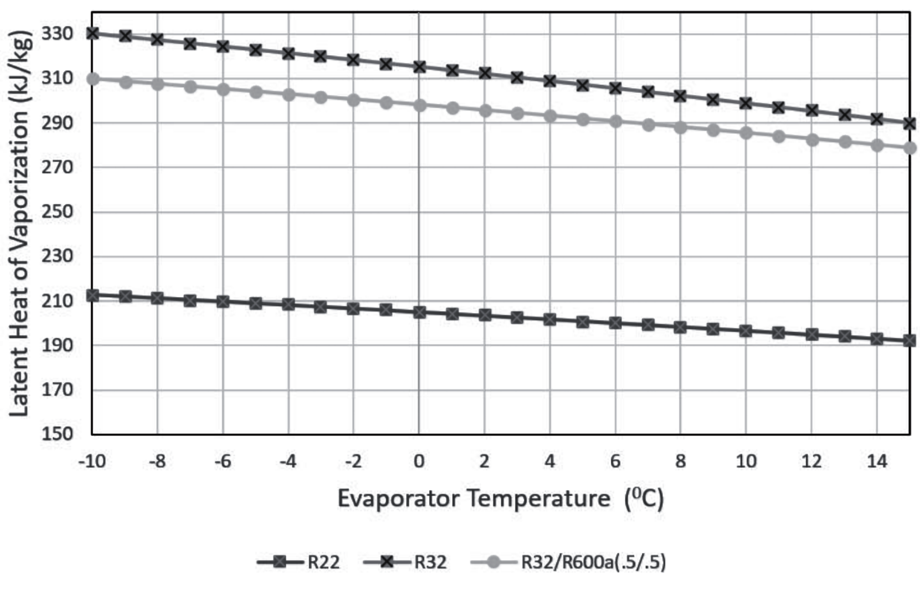


Fig. 2. Variation of Latent heat of Vaporization at different evaporator temperature for different refrigerant and their blend

Again, the efficiency of different alternatives depends to a large extent on the latent vaporization heat. Figure 3 shows the latent vaporization heat of different refrigerants at different saturation temperatures. It can easily be seen from this figure that all R22 alternate refrigerants have higher latent vaporization heat between R32 and the maximum latent vaporization. All required data has been determined using REFPROP 7 software [30].

3. EXPERIMENT

For this experimental work, a test facility has been set up. The indoor unit of the air conditioner was established in a space of 10 x 12 ft^2 which was selected. Others factors like room cooling load, humidity, solar radiation was tending to be uniform throughout the experiment. There was an outdoor unit on the outside of the room. The software package REFPROF 7 was used to determine the thermo-physical properties of refrigerant under different operating conditions. In different operating environments, the temperature of the refrigerant in the inlet and outlet of the evaporator, compressor and condenser, as well as the inlet and outlet pressures of the compressor and the pressure of the condenser were measured. For the experimental process, a General AOG12ASMC split air conditioner was used. In this experiment, rotary compressor has been used. To measure the different position temperatures four thermocouples were used in the pipe of the air conditioner and digital pressure gauge has been used to pressure measurement. Moreover, Power meter, clamp meter, thermometer has also been used in this experiment to take data. Instruments has been calibrated before using those. Still there are uncertainties in the measurement of the parameter which has been evaluated later on. The specification of the air conditioner is shown by Table 2

Figure 4 shows the system's schematic diagram. The figure showed the different inserted position of the thermocouple along with the measuring point of pressure. While only the suction and discharge pressure along the temperature is sufficient for energy and exergy analysis, the actual value of all points will not be given. In order to find the actual cycle value, four sectional values of temperature and pressure were taken along with the pressure.

Table 2. Air conditioner specification

Model	AOG12ASMC
Manufacturer	General
Capacity	3.40−3.45 KW (11600−11800 BTU/hr.)
Type	Split type air conditioner
Power type	220−240V, 50Hz
High pressure (Max)	390 psi
Low pressure (Max)	115 psi
Refrigerant	R22

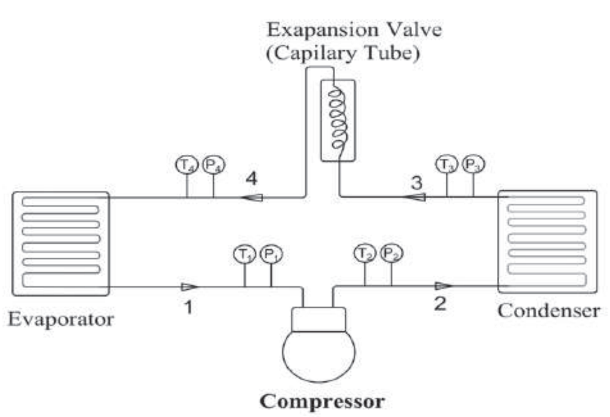


Fig. 3. Schematic Diagram of the Air Conditioner System

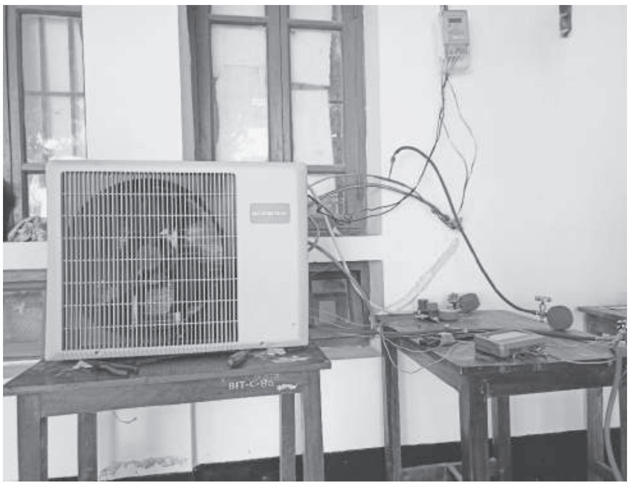


Fig. 4. Actual Experimental Setup

The p-h diagram of the VCRS is shown in figure 5.

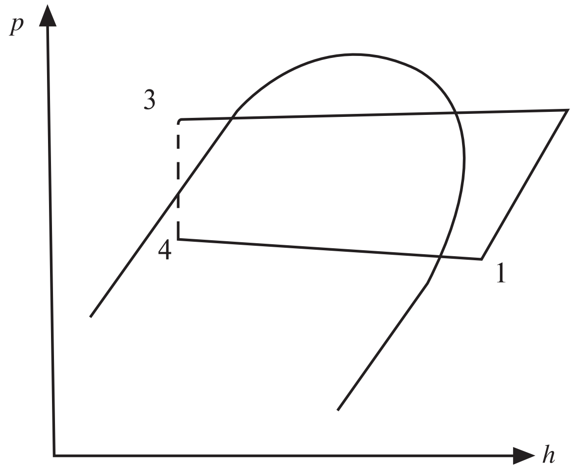


Fig. 5. P-h Diagram of simplified practical VCRS cycle

The two figures below comprise four processes in the four main parts of the air conditioner. 1-2 is the process of compression. 2-3 is the process of condensation. 3-4 is the process of expansion. 4-1 is the process of evaporation.

3.1 Nanolubricant Preparation

The TiO_2 nanoparticle was used in this experiment to disperse SUNISO 4S oil with mineral oil. 0.01 per cent and 0.02 per cent volume concentration were used in this study to disperse the nanoparticle. The following formula was used to get the weight value of 0.01 percent and 0.02 percent TiO_2 volume percentage. [32].

$$\% \text{ volume concentration}, \varphi = \left(\frac{\frac{w_{TiO_2}}{\rho_{TiO_2}}}{\frac{w_{TiO_2}}{\rho_{TiO_2}} + \frac{w_{MO}}{\rho_{MO}}} \right) \times 100 \qquad (1)$$

Where φ is volume concentration in %, ρ_{TiO_2} is the density of the TiO_2 Nanoparticles which is 4230 kg/m^3. The density of the mineral oil (ρ_{MO}) is 916 kg/m^3. W_{MO} represents the mass of the mineral oil in gram. In this experiment, 410 ml MO was required for the lubrication purpose in the compressor.

To obtain the anatase TiO_2 Nano particle, amorphous TiO_2 first calcinated in 580°C for 2 hours with a temperature increase of 15°C per minute for better performance over long range temperature, proposed by Juliete et al.[33]. The Two surfactants were used for the earlier study- SDS and CTAB to properly disperse the nanoparticle in the base fluid. But the surfactant was also suggested to be used in the application of low temperature heat transfer where the temperature is below 600°C as many surfactant effects are weakened at high temperatures. Thus, CTAB was chosen as a surfactant and many literature reviews indicate that the amount of surfactant used should be from (1/5) to (1/10) of the nanoparticle. So, surfactants (1/6) of the weight of the nanoparticle were used for this study. The surfactant was first added to the base fluid to be mixed in a beaker where the magnetic stirrer is on for nanofluid preparation. The TiO_2 nanoparticle was mixed with the base fluid in the beaker after some time, and the magnetic stirrer was held on for half an hour. The magnetic stirrer used to mix the surfactant and the nanoparticle is shown in the figure. After that, 120 kW 20 Hz ultrasonication was used for 1 hour to maximize the dispersion. [34]. Figure 7 shows the ultrasonic bath used for ultrasonication. Figure 8 shows magnetic stirrer used in this experiment. The stability analysis has been done on the basis of sedimentation and shows stability of 1 months. So further modification is necessary.

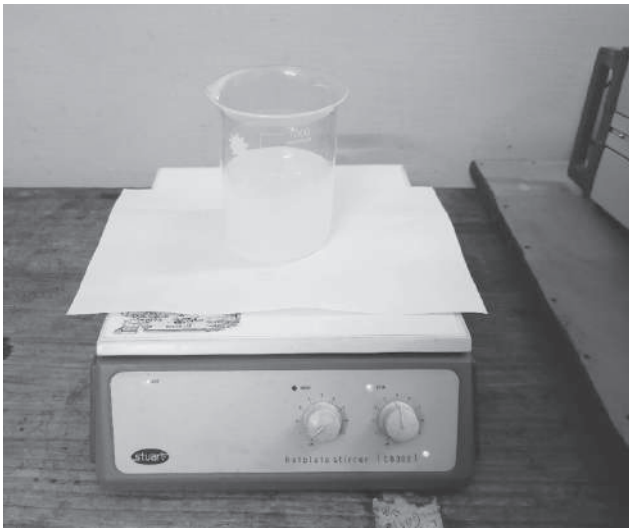


Fig. 6. Magnetic stirrer to mix the nanoparticle to base fluid

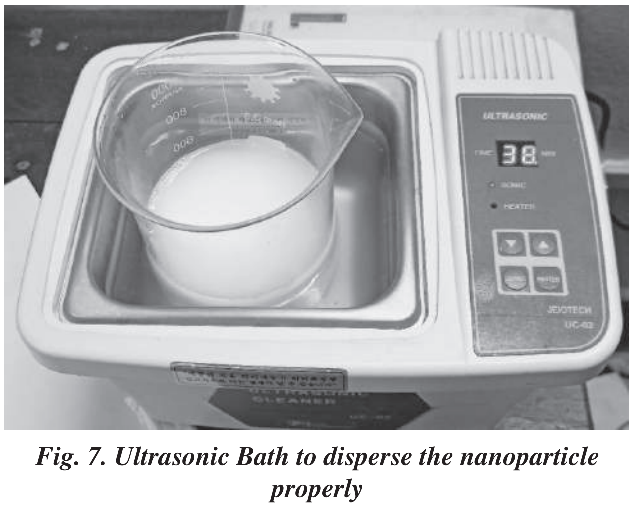


Fig. 7. Ultrasonic Bath to disperse the nanoparticle properly

3.2 Experimental Procedure

The air conditioner is first modified according to the schematic diagram of figure 4 and all the thermocouples and pressure gage are connected with the air conditioner system. Before charging any of the refrigerant into the system, the system must be made vacuumed by vacuum pump. The experimental setup first vacuumed at 30 mm Hg pressure for sufficient time so that any moisture, air particles or any other particles was evacuated from the system. Any presence of moisture or other particle may lead to damage the compressor and the system efficiency and lead to the failure of the system in long time. After that our original system refrigerant R22 which needs approximately 750 gm for this system are weighed by a digital scale and charged into the system by charging 100-150 gm per turn so that the compressor can easily compressed the refrigerant amount easily. There may be problem if the whole amount of refrigerant is poured into the system in one turn as the compressor may not be able to compress the large amount of gas at a time. After pouring the charge into the system and setting the thermostat temperature to 17^0C the air conditioner system should run for some time to get the steady results. All temperature and pressure values are recorded during the experiment to assess the performance of the system with the help of REFPROP 7 software. In this way, the system needs to be evacuated again by the vacuum pump for R32/R600a blend charging after taking the R22 refrigerant data values. Now, as the R32 is a high-pressure gas and R600a is a low-pressure gas, before the blend refrigerant has charged into the system, an empty cylinder is first kept in a cool ice bucket so that the empty cylinder inside temperature and pressure drops. After charging R600a by 50 percent of total mass, refrigerant R32 is then poured 75 percent of the total mass weighing in digital scale into that cylinder and kept for proper mixing for one day. The coolant was poured the next day by making the cylinder upside down so that the mixture of liquid coolant entered the system. After charging through blend 1 (B1), the data is recorded again. The data for blend B1 was further determined using the software REFPROP 7. All the data were taken keeping the interval of 30 s.

3.3 Experimental Data reduction

In this section, energetic and exergetic analysis of different parameter has been compared to evaluate the refrigerant. Energetic and exergetic analysis requires some formulas which are shown below [35].

Condenser duty can be described by:

$$q_c = (h_2 - h_3) \tag{2}$$

$$COP = \frac{m_r(h_1 - h_2)}{W_{el}} \tag{3}$$

There h1 and h2 are the enthalpies of compressor inlet and outlet and W_{el} is the electrical power consumed. W_{el} can be determined by the following equation:

Compressor Work can be determined by,

$$Wc = m_r (h_2 - h_1) \tag{4}$$

For exergy analysis at any point,

$$\psi_i = (h_i - h_{amb}) - T_{amb} (S_i - S_{amb}) \tag{5}$$

Where h_{amb}, s_{amb} are the specific enthalpy and specific entropy at an ambient temperature T_{amb}.

Exergy balance can be written as

$$X_{inlet} - X_{outlet} - I_{destroy} = 0 \tag{6}$$

Where, $X_{inlet} - X_{outlet}$ is the net exergy transfer by heat transfer, work transfer and mass transfer and $I_{destroy}$ is the exergy destroyed.

Exergy balance for evaporator is

$$I_{des,\,eva} = (h_4 - h_1) - T_{amb}(s_4 - s_1) + \left(1 - \frac{T_{amb}}{T_{eva}}\right) q_e \tag{7}$$

Exergy destroyed in the compressor,

$$I_{des,\,comp} = \dot{m}\,[(h_1 - h_2) - T_{amb}\,(s_1 - s_2)] + W_{el} \tag{8}$$

For condenser, exergy loss

$$I_{des,\,cond} = \dot{m}(h_2 - h_3) - T_{amb}\,(s_2 - s_3) - Q_{cond}\left(1 - \frac{T_{amb}}{T_{cond}}\right) \tag{9}$$

For throttling valve, exergy loss

$$I_{des,\,exp} = \dot{m}\,T_{amb}\,(s_4 - s_3) \tag{10}$$

Total exergy loss,

$$I_{total} = I_{des,\,eva} + I_{des,\,comp} + I_{des,\,Cond} + I_{des,\,exp} \tag{11}$$

3.4 Uncertainty analysis

Using some standard instrument, all the data has been measured yet all the instruments have some bias error and a probability of error. That's why analyzing uncertainties is important. This analysis was first used by Robert Moffat [36], in an outstanding article titled "Identifying the True Value-The First Step in Uncertainty Analysis Consider". Let's say, some primary measurement of an experiment is P1, P2, P3, P4, and X is the results of the measured data using a mathematical formula. The Uncertainty (U) can be measured as follows:

$$U = f(P_1, P_2, P_3, P_4 \dots\dots\dots\dots) \tag{12}$$

Two types of uncertainty exist. One is the single uncertainty of measurement that can be easily determined from the bias error and error of accuracy [37]. And the formula to assess this is

$$U_x = \sqrt{(B_x{}^2 + P_x{}^2)} \quad (13)$$

But the multiple measurement uncertainty still preferable for more reliability. From the analysis of Kline and Mc Clintock [38], total uncertainty (U) comes from the primary uncertainties (P1, P2, P3, P4 ....) can be determined as follows:

$$W^2 = [\left(\frac{\delta R}{\delta P_1} W_{p_1}\right)^2 + \left(\frac{\delta R}{\delta P_2} W_{p_2}\right)^2 + \left(\frac{\delta R}{\delta P_3} W_{p_3}\right)^2 + \cdots \ldots \ldots + \left(\frac{\delta R}{\delta P_m} W_{p_m}\right)^2] \quad (14)$$

Primary measured value uncertainty and multiple measurement uncertainty have been assessed through this formula in this work. The cooling effect, COP, Total irreversibility uncertainty was shown in the result section.

4. RESULTS AND DISCUSSION

After the steady state condition is reached, all possible pressure and temperature data, together with the power and hygrometer ambient temperature values, are taken. After all the required values for R22 and R32/R600a have been obtained, different properties are evaluated using Eqs. 2-15. In the later subsections, the outcome of those values is described. The pressure difference between R22 and blend have an effect in overall performance. R22 has lower compressor inlet and outlet pressure of about 75-80 psi and 260-280 psi whereas for the blend it increased to 90-100 psi and 315-325 psi.

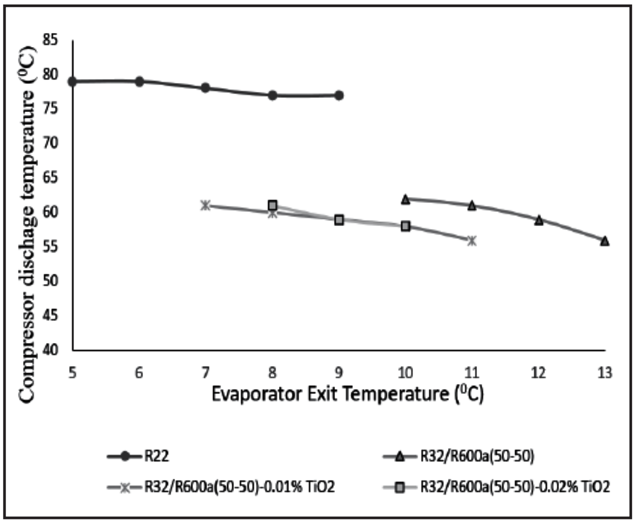


Fig. 8. Variation of Compressor Discharge Temperature at different evaporator exit temperature

4.1 Energy performance Analysis

Figure 10-14 shows the different refrigerant and blend along with the nanofluid coefficient of performance at different ambient temperature. Ambient temperature has been recorded though the hygrometer as well as thermometer at different day time condition. For different evaporator temperature different thermostat point was used and the pressure in the evaporator has less effect although there were some changes in the pressure. R22 refrigerant has maximum coefficient of performance. But the blend shows decreased COP at different ambient temperature. After applying nanofluid mineral oil still the COP has not improved. Numerically the average COP has decreased by 32%, 27%, 61% for the blend and with 0.01%, 0.02% nanofluid respectively. Although at lower ambient temperature the refrigerant blend shows good thermal performance but at higher ambient temperature COP falls. Generally, COP increased with the increase of evaporator temperature as the temperature difference of the evaporator and ambient becomes smaller which makes the system more efficient. Figure 15 shows the variation of refrigerating effect at different evaporator exit temperature where R22 has a maximum RE of 160.5 kJ/kg and the blend along with nanofluid has 185 kJ/kg, 208.5 kJ/kg, 183.9 kJ/kg respectively. Numerically average refrigerating effect has increased by 10%, 20% and 9% respectively for the blend with 0.01%, 0.02% nanofluid than R22. The refrigerating effect increased with the increase of evaporator temperature. Heat absorbed in the evaporator increases as the refrigerant's enthalpy increases at higher evaporator temperatures. As a consequence, the evaporator's heat absorbs power, or cooling effect, increases. Again, when the ambient temperature is higher, the air conditioner requires more refrigerant to trap heat from the room and cool it to the desired temperature. As a result, the refrigerant power per kilogram is reduced. When the ambient temperature is lower, the refrigerating effect is greater at all evaporator temperatures. Sabareesh et al. [39], Pattanayak et al. [40] also shows that COP increase with the nanoparticle use. Figure 16 shows the compressor work of the different refrigerant and blend. R22 has an average compressor work of 49 kJ/kg whereas blend has 89 kJ/kg, 0.01% nanofluid has 93 kJ/kg and 0.02% nanofluid has 140 kJ/kg of compressor work. At higher ambient temperatures, compression work appears to be greater. The difference between ambient and room temperature decreases as the temperature of the evaporator rises, meaning that less cooling is needed. As a result, less compression is required. Compression work is higher for higher ambient temperature. Figure 17 shows the condenser duty which also shows similar trend like compressor work. R22 has the lowest condenser duty and 0.02% nanofluid blend has maximum condenser duty. Blend has 23% more condenser duty whereas 0.01% and 0.02% nanofluid blend has 33%, 41% more condenser duty than R22.

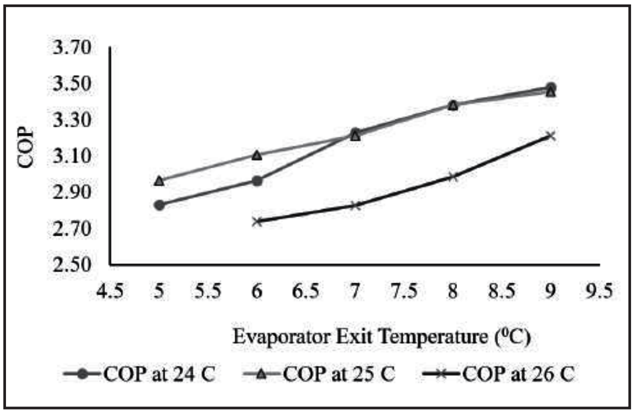


Fig. 9. Variation of COP at different evaporator exit temperature for R22 at different ambient temperature.

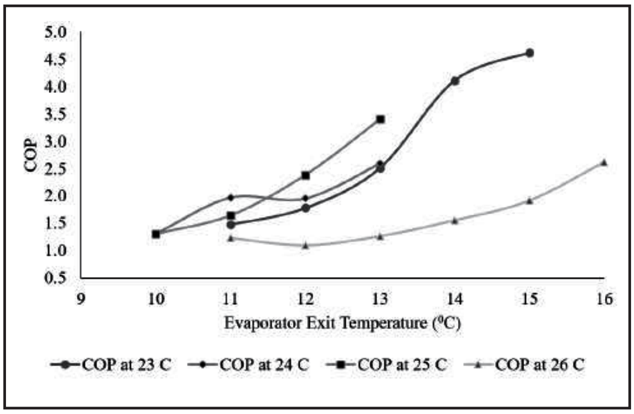


Fig. 10. Variation of COP at different evaporator exit temperature for R32/R600a at different ambient temperature

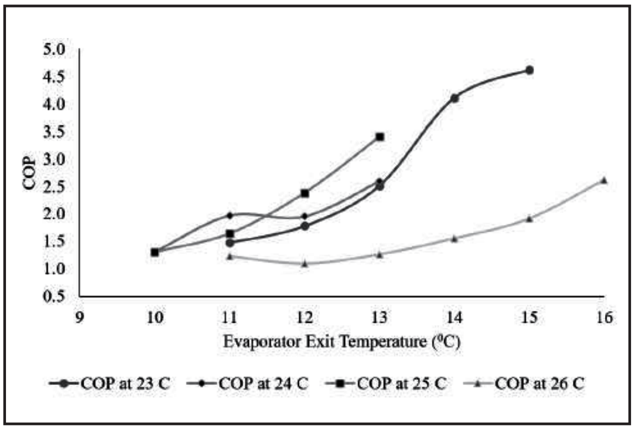


Fig. 11. Variation of COP at different evaporator exit temperature for R32/R600a-0.02% TiO_2 nanofluid at different ambient temperature

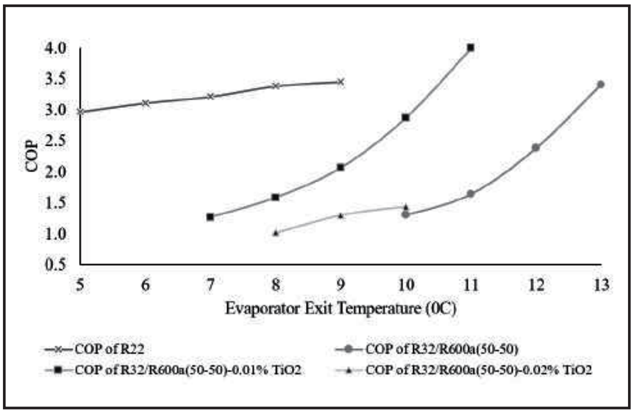


Fig. 12. Variation of COP at different evaporator exit temperature for different refrigerant and blend with nanofluid at 25°C ambient temperature

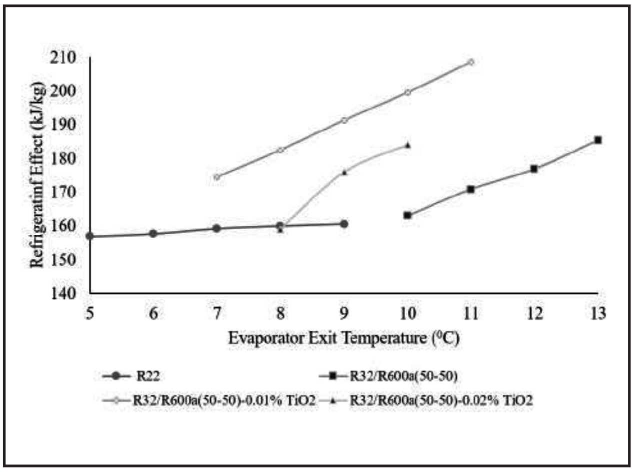
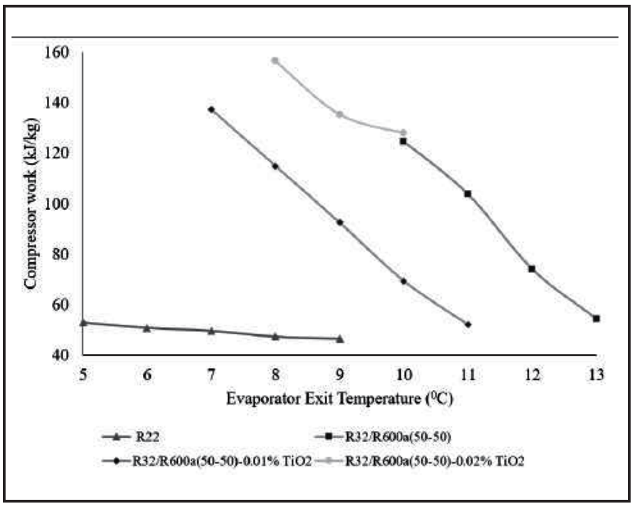


Fig. 13. Variation of Refrigerating effect at different evaporator exit temperature for different refrigerant and blend



14. Variation of compressor work at different evaporator exit temperature for different refrigerant and blend

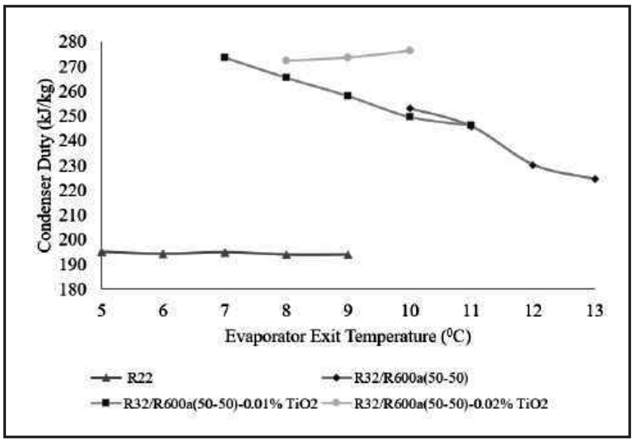


Fig. 15. Variation of condenser duty at different evaporator exit temperature for different refrigerant and blend

4.2 Exergy Performance Analysis

Analysis of energy is also essential, which shows how much energy during operation is destroyed in the entire system. Therefore, Figure 18 shows a comparison of total irreversibility with nanofluid for the coolant and blend. In this figure, R22 has the least irreversibility in the entire operation plotted against various exit temperatures of the evaporator. The relatively high irreversibility of the R32/R600a blend is then blended with 0.01 percent nanofluid. Among them, blending with 0.02 percent nanofluid has the greatest irreversibility. In addition, Figure 19 shows the exergy lost in the R22 components and most of the exergy destroyed was in the compressor than the evaporator. Exergy destruction was the minimum in the capillarity. The exergy loss in the compressor was greater in the compressor in all the figures.

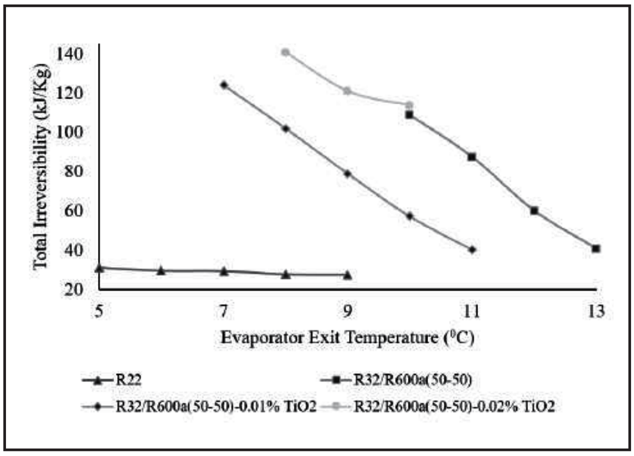


Fig. 16. Comparison of total irreversibility for different refrigerant and blend at different evaporator temperature

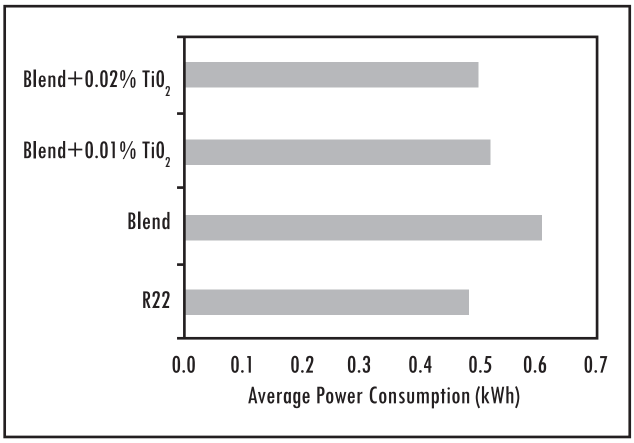


Fig. 17. Comparison of power consumption for daily 6 hours for different refrigerant and blend

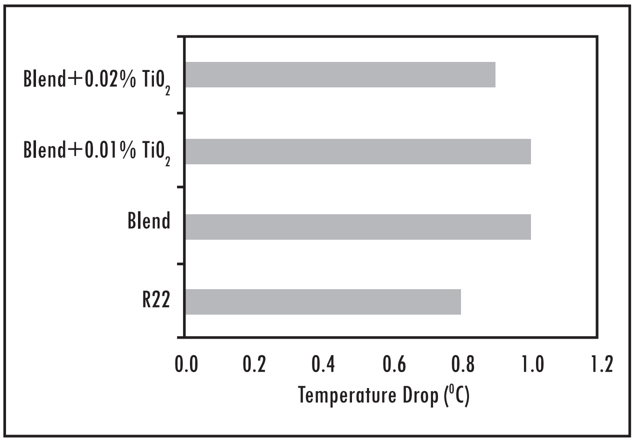


Fig. 18. Variation of temperature drop in the air-conditioned room in 3 minutes for different refrigerant and blend

Now consider about the energy consume by the refrigerant and blend which is shown by figure 17 where R22 refrigerant have a power consumption of 0.487 kWh for 6 hours a day starting from 10 AM to 4 PM. But the other blend and with the nanofluid application the power consumption are 0.610 kWh, 0.522 kWh and 0.500 kWh respectively which is 25%, 7% and 3% more than R22 respectively. Figure 18 considers the temperature drop in the air-conditioned room for a certain time which is 3 minutes to show how much temperature drop can be achieved using different refrigerant and blend. It shows that R22 can make 0.8^{0}C temperature drop in 3 minute and the blend with nanofluid can decrease 1^{0}C, 1^{0}C and 0.9^{0}C respectively.

After all the parameter analysis, result shows that refrigerating effect is higher for the blend compared to R22. Compressor needs to do more work for the blend. So, the coefficient of performance is less for the blend. Exergy destruction is also higher for the blend.

5. CONCLUSION

The experiment was done to examine the energetic and exergy performance of R22 and R32/R600a (50:50) along with nanofluid application of 0.01% and 0.02% volume concentration. The following conclusion can be drawn from the results

Energy performance shows that the 0.01% nanofluid concentration shows 20% more refrigerating effect than R22 whereas blend with 0.02% has 9% and 0.01% has 10% more refrigerating effect. Refrigerating effect is higher for blend. The refrigerating effect increased with the increase of evaporator temperature. Heat absorbed in the evaporator increases as the refrigerant's enthalpy increases at higher evaporator temperatures. As a consequence, the evaporator's heat absorbs power, or cooling effect, increases. Again, when the ambient temperature is higher, the air conditioner requires more refrigerant to trap heat from the room and cool it to the desired temperature. As a result, the refrigerant power per kilogram is reduced.

Blend shows less COP compared to R22. Blend with nanofluid also have less COP compared to R22. Numerically Blend has an average COP of 2.18 while R22 has 3.22. Blend with nanofluid with 0.01% and 0.02% concentration has 2.36 and 1.25 of COP.

Although the condenser duty is higher for all the alternate blend along with nanofluid application. Blend has 23 % more condenser duty compared to R22 while blend with 0.01% and 0.02% nanofluid has 33% and 41% more condenser duty respectively.

In case of compressor work R22 shows the least compressor work and blend with 0.02% nanoparticle shows maximum compressor work which is 183% more than R22. Blend has somewhat less compressor work of 89 kJ/kg. The difference between ambient and room temperature decreases as the temperature of the evaporator rises, meaning that less cooling is needed. As a result, less compression is required. Compression work is higher for higher ambient temperature.

Exergy analysis shows that the exergy destruction is lower in R22 where the blend has higher exergy destruction. Numerically blend without nanofluid and along with 0.01% and 0.02% nanofluid has 155%, 176% and 330% more irreversibility than R22 irreversibility. For R22, blend without nanofluid and along nanofluid has the maximum exergy destruction happened to be in the compressor.

Power consumption analysis shows that blend without nanofluid has the highest power consumption which is 0.610 kWh for 6 hrs. The analysis shows the blend along with nanofluid has 7% and 3% more power consumption compared to R22. In case of temperature drop the R32/R600a blend quite same temperature drop compared to R22.

6. ACKNOWLEDGEMENT

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