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Original Article

The Effect of Compressor Speed on Residential Air Conditioning Systems Using R407c and R32 Refrigerant

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ABSTRACT

The demand for residential air conditioning (RAC) systems is expected to increase in the future owing to rising ambient temperatures resulting from global warming. Therefore, it is important to develop and study refrigerants that can improve energy efficiency and thermodynamic performance. This study compares R32 and R407c refrigerants in RAC systems, with an emphasis on the coefficient of performance (COP) and cooling capacity. The research methodology used an experimental approach by testing compressor speeds of 2400, 2700, and 3000 rpm. Based on the test results, R32 consistently performed better than R407c at all compressor speed variations. The COP and cooling capacity of R32 increased significantly by 15.53% and 35.90%, respectively. The stability of R32 performance operated at different compressor speed variations showed an increase in operational adaptability. Finally, R32 was proven to be a more effective and efficient refrigerant than R407c in the RAC system.

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1. Introduction

The demand for residential air conditioning (RAC) systems has been increasing annually. This is due to changing environmental conditions influenced by rising global temperatures, which trigger an increased demand for air conditioning systems [1]. In contrast, the use of refrigerants contributes to global ozone depletion owing to the increasing use of synthetic chemicals in refrigeration technologies. These chemicals, such as hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs), and hydrocarbons (HCs), are widely used in refrigeration systems, such as refrigerators, automotive air conditioning (AAC), and RAC systems. CFC-type refrigerants are significant contributors to ozone depletion potential (ODP) and global warming potential (GWP), raising environmental concerns. Therefore, international agreements have restricted the use of CFCs and encouraged a shift to environmentally friendly refrigerants, such as HFCs [2]. Furthermore, the use of RAC systems is predicted to increase dramatically with global population growth, particularly in warmer regions. An estimated 4 billion units will be installed by 2038, with India emerging as a major player

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in the EV market. While this growth helps people live better lives in warmer regions, it also poses environmental concerns owing to its potential impact on the global climate [3]. Therefore, RAC systems are designed to utilize environmentally friendly and sustainable refrigerants with low ODP and GWP to minimize their negative impacts on the environment and global warming.

Refrigerants were selected based on the ODP and GWP criteria established in the international agreement outlined in the Montreal Protocol [4]. In summary, the increase in global warming is partly attributed to the release of carbon dioxide (CO_2) into Earth's atmosphere; the higher the GWP value of a refrigerant, the greater its contribution to global warming over time [5]. A high GWP value can potentially affect the surrounding air. This assertion was noted by [6], who noted that the increased use of refrigerants with high GWPs results in accelerated global warming and increased energy consumption. Consequently, the GWP and ODP factors should be considered when selecting future refrigerants. Currently, the commonly used refrigeration systems include R22, R410a, R407a, R407c, and R32 refrigerants. However, refrigerant R22, which has an ODP and GWP of 0.05 and 1.810 [7], respectively, is being gradually phased out in accordance with F-GAS regulations and the international community [8-10]because its permissible ODP is zero and its GWP must not exceed 2.500. Refrigerants R410a, R407a, R407c, and R32 have GWP values of 2,100, 2,107, 1,530, and 675, respectively [11-14]. Owing to the relatively high GWP values of R410a and R407a, their gradual phase-out is concerning. In addition to having relatively favorable ODP and GWP values, R32 and R407c were utilized as alternatives because they are new refrigerants that meet international standards; therefore, both were employed in this study. Notably, to the best of our knowledge, a comparison between R32 and R407c remains limited in the literature; thus, this study presents a novelty in terms of refrigerant selection.

Furthermore, the refrigerant interacts with the lubricant during the refrigeration cycle. Both interact clearly in the compression process, where the lubricant is indirectly carried along with the high-pressure refrigerant flow owing to shear forces and turbulence, particularly on the exhaust side of the compressor. Therefore, lubrication is crucial in mechanical systems, where the main function of the lubricant is to prevent wear of sliding components and ensure that the compression process in the compressor operates smoothly [15]. Because a compressor is a sliding component that actively moves to produce compression energy, the lubrication system plays an important role in maintaining the continuity of the refrigeration system. In addition to the characteristics of the lubricant, the flow rate, phase change process, and operating conditions affect the distribution of the lubricant equilibrium [16]. This evaluation shows that the refrigerant and lubricant have interrelated functions that meet the criteria in experimental testing on the RAC system tester. However, in practice, comparing the performance of R32 and R407c in RAC systems under single, unvarying parameter conditions produces limited information and does not fully represent the operating characteristics of the system. Therefore, the performance of the RAC system was evaluated based on varying compressor speeds.

Compressor speed is one of the factors that affect the performance of an RAC system during the refrigerant cycle. Sharif, et al. [17], Zawawi, et al. [18] validated this statement through experiments on an AAC system, where the experiments were conducted at speed variations between 900 and 2100 rpm. The results showed that the coefficient of performance (COP) decreased as the compressor speed increased. Matsumoto, et al. [19] argued that compressor speed affects energy efficiency, resulting from observations of R32, R1234yf, and R1234ze compared to R410a. In contrast, Tian, et al. [20] stated that the COP increased with the use of an R32/R290 mixed refrigerant compared to R410a. Recently, Al-Badri and Al-Hassani [21] reported that the resulting COP was higher at lower speeds; however, this study was limited to speed variations using R410a. It is concluded that the exploration of alternative refrigerants with low GWP, such as R32 and R407c, combined with variable-compressor-speed technology, shows promising potential for sustainable RAC systems. However, a comprehensive study of their comparative performance at various compressor speeds is still limited and constitutes a critical research gap. This places research under urgent scientific and engineering challenges. Therefore, this study aims to investigate the compressor work, COP, and cooling capacity against variations in compressor speed for two different types of refrigerants, which are operated at compressor speeds of 2400, 2700, and 3000 rpm.

2. Methods

2.1. Characteristics of refrigerant and lubricant

Refrigerant characteristics, including the chemical formula, molar mass, critical pressure, and critical temperature, are typically used to select the type of refrigerant. The molar mass affects the mass flow rate, the critical pressure affects the operating limits of the system, and the chemical formula indicates the type of refrigerant [22]. The performance of an RAC system is not determined by its ODP or GWP. Therefore, further experimental research is required to investigate the performance of refrigerants in RAC systems. R32, also known as difluoromethane (CH_2F_2), is a single refrigerant. R407c is a mixed refrigerant consisting of $CH_2F_2/CHF_2CF_3/CH_2FCF_3$ containing a combination of R134a (52%), R125 (25%), and R32 (23%).

The PVE lubricant was obtained from Idemitsu Kosan Co., Ltd., as listed in Table 1. This lubricant is frequently used in RAC systems paired with HFC-type compressors. A literature review revealed that polyol esters (POEs), polyalkylene glycols (PAGs), and PVEs have been evaluated for their performance. The performance of POE lubricants in terms of the friction coefficient showed relatively good results at temperatures below their transition point. However, the friction coefficient increased and durability decreased when operating at temperatures above this point, in contrast to PVE and PAG, whose durability increased at temperatures above the transition point. In contrast, PVE has a higher viscosity coefficient and pressure resistance than PAG and POEs. This indicates that PVE produces lower friction and wear coefficient values compared to POE lubricants [23].

Table 1. Characteristics refrigerant and lubricant properties [24-26]

Refrigerant and lubricant properties	R32	R407c	PVE
Chemical formula	CH_2F_2	$CH_2F_2/CHF_2CF_3/CH_2FCF_3$	
Critical temperature (°C)	78.1	86.74	
Critical pressure (MPa)	5.78	46.2	
Critical density (kg/m³)	429.77	527.30	
Molar mass	52.0	86.2	
Boiling point at 1 atm (°C)	-51.7	-43.56	
Dynamic viscosity at 40°C (mm²/s)			68.1
Viscosity index			84
Density at 15°C (kg/m³)			0.9369

Another advantage of PVE lubricants is their high resistance to hydrolysis, which allows them to maintain their properties under varying conditions of viscosity [27]. Therefore, PVE was used in this study because it has been shown to be effective in lubrication systems. In addition, PVE was chosen because it is compatible with R32 and R407c, according to Kaneko, et al. [28], Zeng, et al. [29], and is soluble, according to Matsumoto, et al. [19], Jia, et al. [30]. Therefore, a PVE lubricant was used in this study to operate with R32 and R407c in the RAC system.

2.2. *Experimental test rig and procedure*

Figure 1 shows the RAC system test rig used in this experiment. The RAC system using the FTV-P series was obtained from Daikin Malaysia Sdn. Bhd. The outdoor and indoor unit codes were RV28PBV1M and FTA-28PBV1MF, respectively. This system uses a rotary compressor with unit code 9RS102DAA21, and its speed can be precisely controlled using a variable frequency drive (VFD). The experiment was conducted at 0.865 kW and 86 A, the outdoor air temperature was set to 33.3 °C, and the indoor air temperature was set to 27 °C according to the MS1525 standard [31]. Before the experiment was conducted, all equipment, such as the electrical system, piping system, and other supporting equipment, were ensured to be in good condition and checked. A VE115N model vacuum pump was used to suck air and water vapor before filling with R32 and R407c. To ensure that there are no leaks in the piping system, it must be vacuumed for at least 30 min. Subsequently, the RAC system was filled with 450 g of refrigerant charge using R32 and R407c. The experimental data were collected after the system reached (ideal) conditions. Data were collected for 30 min at compressor speeds of 2400, 2700, and 3000 rpm. At the refrigerant change transition stage, the RAC system was flushed with an SP-888 flushing machine for 30 min or three times.

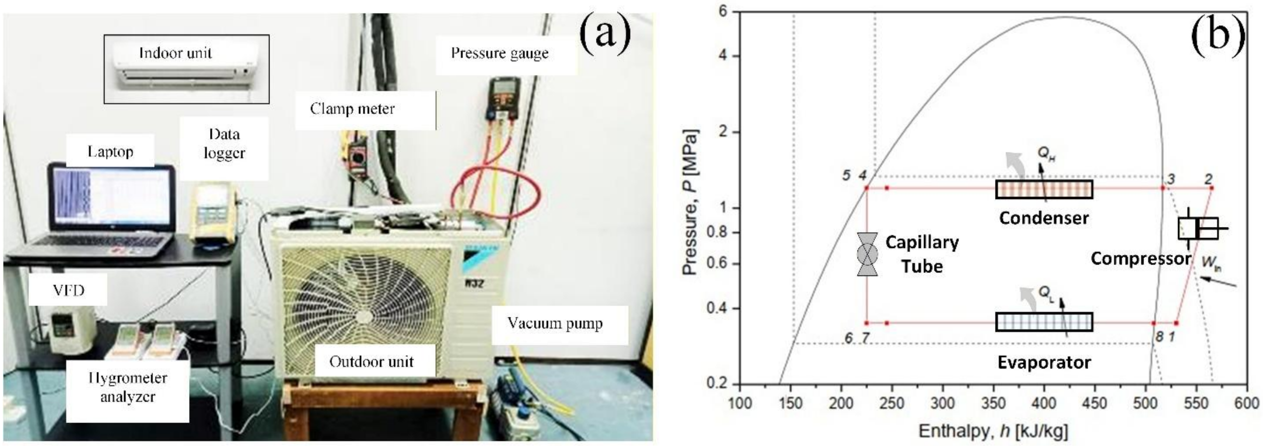

Figure 1. Experimental setup and thermodynamic representation of the RAC system: (a) experimental setup including the indoor unit, outdoor unit, sensors, and measurement instruments; (b) pressure–enthalpy (P–h) diagram of the vapor-compression refrigeration cycle indicating the thermodynamic state points (h_1–h_6).

The collected data outputs, such as the compressor suction enthalpy (h_1), compressor exhaust enthalpy (h_2), condenser intlet enthalpy (h_3), condenser outtlet enthalpy (h_4), expansion inlet enthalpy (h_5), and expansion outlet/evaporator inlet enthalpy (h_6), were determined from the measured temperature and pressure data to evaluate the refrigeration performance parameters, including the refrigerant effect, compressor work, coefficient of performance (COP), and cooling capacity. Energy consumption data were collected using a clamp meter to calculate the energy used during the experimental process. Equation (1) is used to obtain the refrigeration effect value (q_e), and Equation (2) is used to determine the compressor work (W_{in}), and equations (3) and (4) are used to determine the COP value and cooling capacity (Q_L). Assuming that the evaporator inlet enthalpy (h_5=h_6) is caused by isentropic expansion in the capillary tube.

$$q_e = (h_1 - h_6) \tag{1}$$

$$W_{comp} = \dot{m}(h_2 - h_1) \tag{2}$$

$$COP = {}^{q\;L}/{W_{in}} \tag{3}$$

$$Q_L = \dot{m}(h_1 - h_6) \tag{4}$$

In the experiment, the instruments used were first calibrated, and the uncertainty of the equipment was evaluated. A Testo 550 was used to measure the pressure in the range of -0.1 to 6 MPa, resulting in an uncertainty of ±0.5%. A thermocouple (type K) was used to measure the temperature in the range of -50 to 250 °C, with an uncertainty of ±0.1 °C.

This study used a measurement error calculation based on the percentage of the relative standard error (RSE), an approach also proposed by Sharif, et al. [32]. The consistency of the measurement data was used in Equation (5), and the standard error (SE) was calculated using Equation (6). The number of samples *(n)*, the standard deviation of the calculated data *(σ)*, and the mean *(X)* represent the sample set. The average RSE percentage was generated from three trials for each parameter to improve the measurement accuracy.

The RSE calculation results showed varying results, with the highest value being 6.595%, which is considered realistic. This is due to the acc3°Cation of instrument errors, transient fluctu27°Cs, and limited sensor fluctuations [33]. The RSE percentages for each parameter are listed in Table 2.

$$RSE\ (\%) = \frac{S_{eer}}{X}\ x\ 100 \tag{5}$$

$$S_{eer} = \frac{\sigma}{\sqrt{n}} \tag{6}$$

Table 2. Relatif standard error eksperimental process

RSE	R32	R407c
Refrigerant effect, q_e (%)	0.549	0.391
Coefficient of Performance, COP (%)	3.916	6.595
Compressor work, W_{comp} (%)	3.056	5.543
Cooling capacity, Q_L (%)	0.551	3.530
Energy consumption, kW (%)	1.757	1.187

3. Result and Discussions

3.1. *Effect of compressor speed on refrigerant effect*

The variation in the refrigerant effect at different compressor speeds is shown in Figure 2. The results indicate that the refrigerant effect decreases slightly as the compressor speed increases. A similar trend was observed for both refrigerants, R32 and R407C.

For R407C, the refrigerant effect values at compressor speeds of 2400, 2700, and 3000 rpm were 154.40, 153.30, and 152.10 kJ/kg, respectively. In contrast, the refrigerant effect obtained using R32 was higher, resulting in an overall difference of approximately 6.47%. This indicates that R32 provides a greater heat absorption capacity in the evaporator.

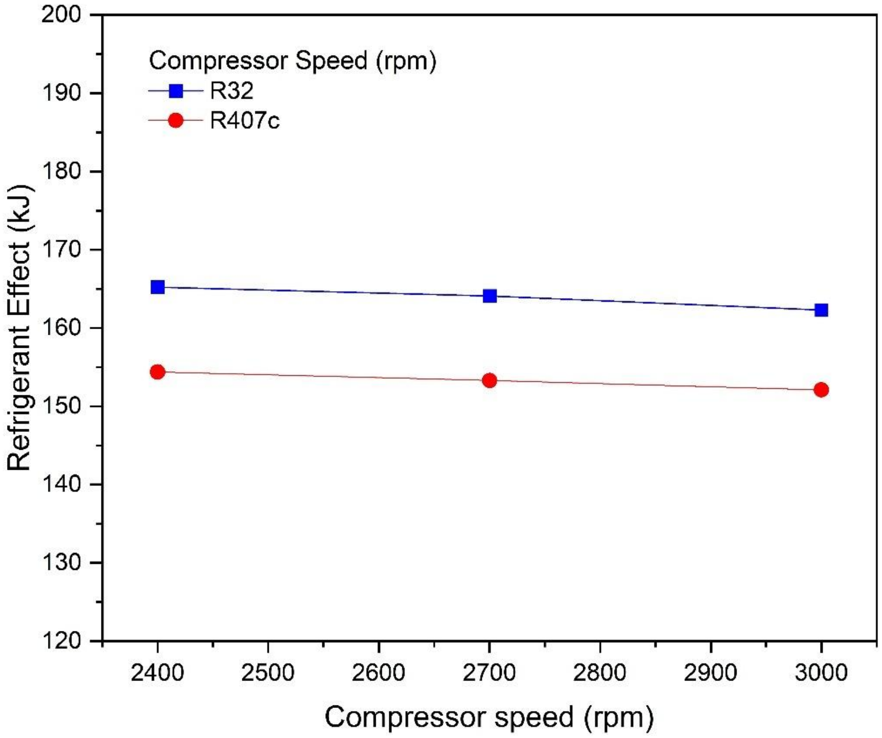

Figure 2. Evaluation of refrigerant effect with the compressor speed variations

From a thermodynamic perspective, the refrigerant effect is primarily determined by the enthalpy difference between the inlet and outlet of the evaporator. The lower refrigerant effect observed for R407C can be attributed to its relatively smaller vapor–liquid enthalpy difference, which limits the amount of heat absorbed during the evaporation process [34, 35]. Consequently, the cooling capacity of the system tends to be lower when using R407C compared to R32.

3.2. Effect on compressor work and power consumption

Figure 3 illustrates the variations in compressor work and power consumption at different compressor speeds. As shown in Figure 3a, the compressor work increases with increasing compressor speed. This trend is expected because higher rotational speeds increase the refrigerant circulation rate and compression load within the compressor.

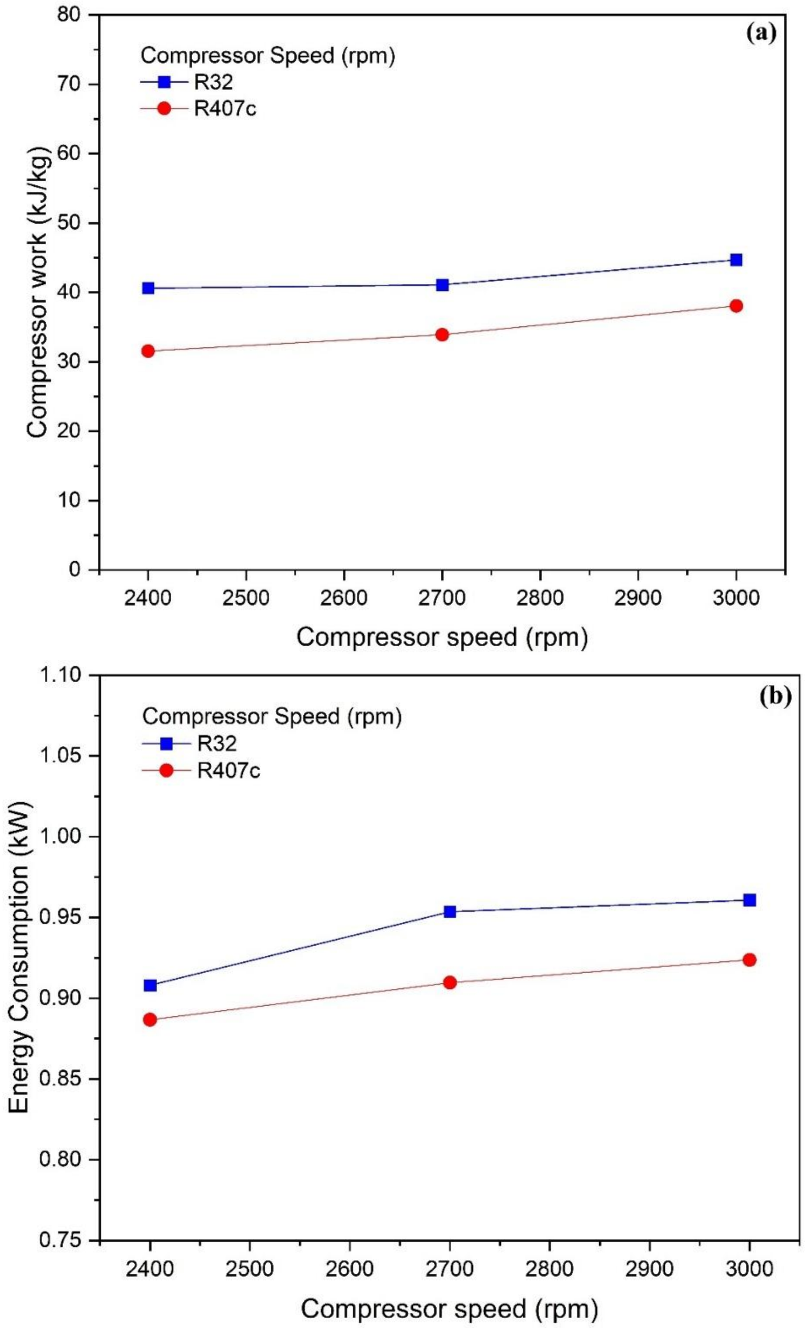

Figure 3. Effect of compressor speed on (a) compressor work and (b) power consumption for refrigerants R32 and R407C.

A comparison between the two refrigerants showed that the compressor work obtained using R407C was generally lower than that obtained using R32. On average, the compressor work of R407C was approximately 18.25% lower than that of R32, with the maximum reduction reaching 22.38% at a compressor speed of 2400 rpm. This behavior can be attributed to the relatively lower compression pressure associated with R407C, which results in a lower compression load and, consequently, lower compressor work [36]. The compressor work directly influences the overall system performance, particularly the coefficient of performance (COP) and cooling capacity, which are discussed in the following section.

The power consumption at various compressor speeds is presented in **Error! Reference source not found.**b**.** The results indicate that the power consumption increases with increasing compressor speed for both refrigerants. This trend occurs because higher compressor speeds require greater mechanical input to maintain the compression process, resulting in increased electrical energy consumption. Conversely, when the compressor work decreases, the required power input also decreases owing to the reduction in the pressure ratio and refrigerant mass flow rate.

Because R407C produces lower compressor work than R32, its power consumption is also slightly lower, with an average reduction of approximately 3.60%. These results demonstrate a strong correlation between compressor work and energy consumption, confirming that variations in the compression load significantly affect the overall energy requirement of the RAC system.

3.3. Effect of compressor speed on COP

The decreasing trend of COP with increasing compressor speed is a thermodynamic realization, as illustrated in Figure 4. For R32, the COP values obtained at compressor speeds of 2400, 2700, and 3000 rpm were 5.827, 5.285, and 5.621, respectively. The corresponding COP values for R407C were 4.889, 5.101, and 4.203, respectively.

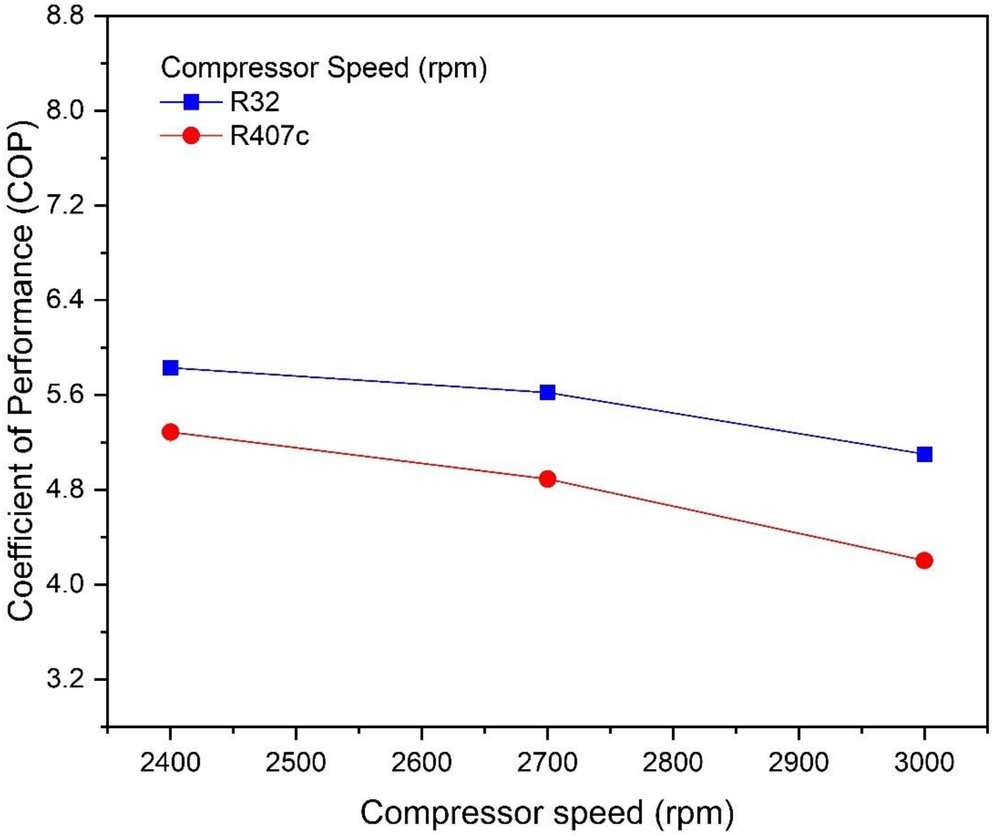

Figure 4. Evaluation of COP with the compressor speed variations

A comparison between the two refrigerants showed that R32 consistently provided a higher COP than R407C under most operating conditions. The maximum improvement achieved using R32 was approximately 17.60% at a compressor speed of 3000 rpm, with an average enhancement of 15.53%. This result indicates that R32 offers better thermodynamic performance in the tested RAC system.

From a thermodynamic perspective, increasing the compressor speed leads to a higher refrigerant circulation rate and an increase in compressor discharge pressure. Consequently, the compressor work increases more significantly than the refrigeration effect, resulting in a reduction in the system COP [37, 38]. In addition, higher compressor speeds increase mechanical and compression losses, which further reduce the overall system efficiency.

In contrast, at lower compressor speeds, the compressor work and energy consumption are reduced, thereby allowing the system to operate more efficiently and produce a higher COP. Under these conditions, the pressure rise during the compression process is relatively moderate, which helps maintain a favorable balance between the refrigeration effect and compressor work [39].

3.4. Effect of compressor speed on cooling capacity

The variations in cooling capacity as a function of compressor speed for different refrigerants are shown in Figure 5. The results indicate that the cooling capacity increased with increasing compressor speed for both refrigerants, R32 and R407C. This behavior is expected because higher compressor speeds increase the refrigerant circulation rate within the system.

A comparison between the two refrigerants indicates that R32 generally provides a higher cooling capacity than R407C, with an average improvement of approximately 35.90%. This result suggests that R32 exhibits better refrigeration performance under the tested operating conditions.

From a thermodynamic perspective, an increase in cooling capacity is primarily associated with an improvement in compressor volumetric efficiency and the resulting increase in refrigerant mass flow rate. As the mass flow rate increases, the amount of heat absorbed in the evaporator also increases, thereby enhancing the cooling capacity of the system. In addition, a higher refrigerant velocity improves convective heat transfer within the evaporator, which further contributes to an increase in cooling capacity.

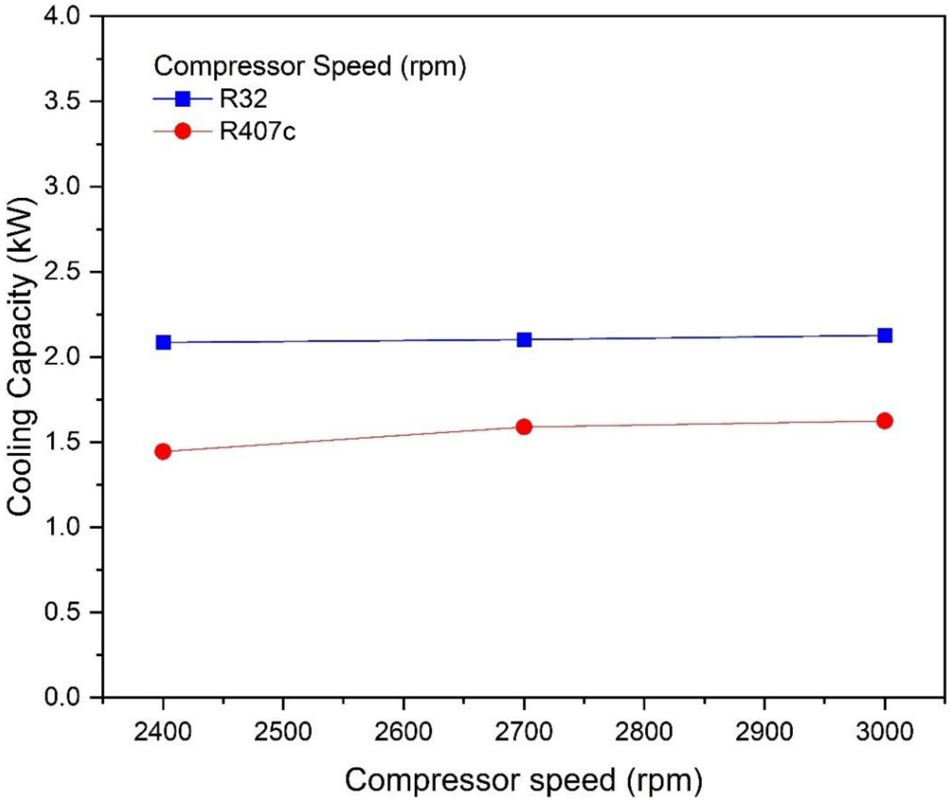

Figure 5. Evaluation of cooling capacity with the compressor speed variations

3.5. Discussion

The refrigeration performance of the system is strongly influenced by the compressor speed. An increase in the compressor speed leads to a higher refrigerant circulation rate; however, it may simultaneously reduce the effective refrigeration effect. At higher speeds, the refrigerant residence time in the evaporator decreases, thereby limiting the heat absorption process and potentially causing the refrigerant to exit the evaporator before reaching the fully saturated vapor state [40].

The compressor work exhibited an inverse trend, with the compressor work increasing as the compressor speed increased. This is consistent with the thermodynamic principle of energy balance, wherein increased energy leads to an increased mass flow rate, which ultimately increases the compressor work [2]. Mechanical motion plays a crucial role in generating the refrigerant pressure required to drive refrigeration cycles. Increasing the compressor speed increases the refrigerant mass flow rate and pressure ratio, resulting in simultaneous increases in the compressor work and energy consumption [41].

Furthermore, a higher COP was observed at low compressor speeds because of the decrease in compressor work and energy consumption. This condition occurs during the compression process, where low compressor speeds reduce the volumetric pressure in the compressor, resulting in an increase in the COP [39]. In addition, the experimental results indicate that refrigerant R32 provides a higher cooling capacity than R407C. This behavior can be attributed to the higher volumetric efficiency achieved when using R32, which enhances the refrigerant mass flow rate and improves the heat absorption process in the evaporator [42].

4. Conclusions

An experimental investigation was conducted on an air conditioning and refrigeration (RAC) system operating with refrigerants R32 and R407C at compressor speeds of 2400, 2700, and 3000 rpm. A comparative analysis was performed to evaluate the effects of compressor speed on compressor work, coefficient of performance (COP), and cooling capacity. The main findings can be summarized as follows:

- The compressor work obtained using R407C was lower than that using R32, with an average reduction of approximately 18.25%.
- The COP of the RAC system using R32 was higher than that using R407C, with an average improvement of 15.53%.
- The cooling capacity achieved with R32 was significantly higher than that achieved with R407C, with an average increase of approximately 35.90%.

Overall, the experimental results indicate that R32 provides better thermodynamic performance than R407C in the tested RAC system, particularly in terms of COP and cooling capacity across the investigated compressor speed range. These findings suggest that R32 is a promising alternative refrigerant for improving the energy performance of RAC systems. Future studies should investigate the influence of different lubricant types and operating conditions to further evaluate the long-term performance and practical feasibility of RAC systems using R32.

Author's Declaration

Authors' contributions and responsibilities

The authors contributed to every aspect of this paper's development, from conceptualization and literature review to experimentation and writing. They were responsible for the data analysis, interpretation of the results, and discussion. After reviewing the completed work, the authors approved it for publication

Acknowledgment

The data and materials described in the study are available from the authors upon reasonable request.

Availability of data and materials

The authors declare no conflicts of interest.

Competing interests

The authors declare no conflicts of interest related to this study.

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