

Comparative Experimental Study of Grid and Helical Condenser Coils in a Vapour Compression Refrigeration System Using R-600a

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Abstract - The performance of a vapour compression refrigeration (VCR) system is significantly influenced by the design of its condenser. In the present work, a comparative experimental study is carried out to evaluate the performance of a conventional grid-type condenser and a modified helical coil condenser in a domestic refrigeration system. The system is operated using R-600a, an environmentally friendly refrigerant with low global warming potential.

Helical condensers of different coil diameters (200 mm and 250 mm) are fabricated and tested under identical operating conditions. The performance of the system is analyzed in terms of key parameters such as net refrigeration effect, work of compression, compressor power consumption, and coefficient of performance (COP). The experimental results indicate that the helical condenser configuration enhances heat transfer characteristics due to increased surface area and the presence of secondary flow effects.

Among the configurations tested, the 250 mm diameter helical condenser exhibits superior performance, with an increase in COP from 1.82 for the existing system to 2.40, along with a reduction in compressor power consumption from 1.92 kW to 1.65 kW. The results demonstrate that the use of a helical condenser significantly improves the energy efficiency of the refrigeration system. The study highlights the effectiveness of condenser geometry modification and supports the use of R-600a as a viable and eco-friendly alternative refrigerant.

Key Words: R-600a, Helical Condenser, Coil Diameter, COP, Heat Transfer

1.INTRODUCTION

Refrigeration systems play a vital role in modern society, with widespread applications in domestic appliances, food preservation, air conditioning, and various industrial processes. Among the available

refrigeration technologies, the vapour compression refrigeration (VCR) system is the most widely used due to its reliability, compactness, and high coefficient of performance (COP). The performance of a VCR system depends significantly on the efficiency of its primary components, namely the compressor, condenser, expansion device, and evaporator [14].

In recent years, environmental concerns associated with conventional refrigerants such as R-134a, which possess high global warming potential (GWP), have led to the exploration of eco-friendly alternatives. Natural refrigerants such as R-600a (isobutane) have gained considerable attention due to their negligible ozone depletion potential (ODP) and low GWP, along with favorable thermodynamic properties [1], [10]. Several experimental investigations have demonstrated that R-600a can achieve comparable or even improved performance in domestic refrigeration systems when compared to traditional refrigerants [1], [2].

The condenser is a critical component of the VCR system, responsible for rejecting heat from the refrigerant to the surroundings. Its design and geometry play a crucial role in determining the overall system efficiency, influencing heat transfer rates, pressure drop, and energy consumption [11], [12]. Conventional domestic refrigerators generally employ grid-type condensers; however, such configurations may not provide optimal heat transfer performance, especially under compact design requirements.

To enhance the thermal performance of condensers, various heat transfer augmentation techniques have been explored. Among these, the use of helical coil heat exchangers has emerged as an effective solution due to their compactness and superior heat transfer characteristics. The curvature of helical coils induces secondary flow patterns, which enhance fluid mixing and improve heat transfer rates [6], [7]. Additionally, studies on coiled tubes and modified condenser designs

have reported improved condensation heat transfer and reduced thermal resistance [5], [8].

Further investigations have focused on different condenser configurations such as serpentine and spiral coils, demonstrating noticeable improvements in system performance when compared to conventional designs [2], [3]. The use of enhanced surface geometries and inserts has also been shown to improve condensation heat transfer characteristics in refrigeration systems [8], [9]. Moreover, comprehensive reviews on heat transfer enhancement techniques highlight the importance of geometrical modifications in improving the efficiency of compact heat exchangers [15].

Despite these advancements, limited research has been conducted on the effect of geometric parameters such as coil diameter in helical condensers, particularly for systems operating with R-600a. The coil diameter significantly influences the heat transfer area, flow behavior, and pressure drop, thereby affecting the overall performance of the refrigeration system. However, systematic experimental studies addressing this aspect remain scarce.

Therefore, the present work focuses on the experimental investigation of a vapour compression refrigeration system by replacing the conventional grid-type condenser with a helical coil condenser of varying diameters using R-600a as the refrigerant. The system performance is evaluated in terms of parameters such as net refrigeration effect, mass flow rate, compressor work, and overall efficiency. The objective of this study is to analyze the influence of condenser coil diameter on system performance and to identify an optimal configuration that enhances efficiency while promoting the use of environmentally sustainable refrigerants.

2.LITERATURE REVIEW

The performance of vapour compression refrigeration (VCR) systems has been extensively studied with a focus on improving energy efficiency and reducing environmental impact. With the growing need for eco-friendly refrigerants, several researchers have investigated the use of hydrocarbons such as R-600a as a substitute for conventional refrigerants. Khaleel et al. [1] conducted an experimental study comparing R-600a and R-134a in domestic refrigerators and reported that R-600a exhibited comparable performance with lower environmental impact. Similarly, Kesavulu and Prahlada Rao [2] analyzed the performance of a VCR system using R-600a with different condenser configurations and observed improvements in system efficiency.

In addition to refrigerant selection, condenser design plays a significant role in determining the overall performance of refrigeration systems. Kulkarni et al. [3] investigated the use of spiral condenser configurations and found that such geometries enhance heat transfer characteristics, leading to improved coefficient of performance. Studies have also explored the influence of working fluids and lubricants; for instance, Senthilkumar et al. [4] demonstrated that the use of advanced lubricants in R-600a-based systems can further enhance system performance.

Helical coil heat exchangers have gained attention due to their compactness and enhanced heat transfer characteristics. The curvature of helical coils induces secondary flow, which improves mixing and increases the heat transfer coefficient. A study reported in the International Journal of Refrigeration [5] examined conical and coiled tube heat exchangers and highlighted their superior thermal performance compared to conventional straight tubes. Further experimental and numerical investigations [6] confirmed that helical coil heat exchangers significantly improve heat transfer efficiency in refrigeration and heat recovery applications.

The flow and heat transfer characteristics within helical coils have also been studied in detail. Research on condensation inside helical coiled tubes [7] revealed that the curvature affects both pressure drop and heat transfer rates, making geometric parameters crucial in system design. Similarly, studies involving enhanced tubes and inserts [8] showed that modifications in tube geometry can significantly improve condensation heat transfer performance.

Several works have focused on alternative condenser and evaporator designs to enhance system efficiency. Investigations on grooved tubes and modified evaporator geometries [9] indicated improvements in heat transfer rates and overall system performance. Moreover, performance evaluation studies on domestic refrigerators using R-600a [10] confirmed that system configuration and component design strongly influence energy efficiency.

Fundamental studies on heat exchangers emphasize the importance of proper design and optimization of thermal systems. Holman [11] and Kakac and Liu [12] discussed various heat transfer enhancement techniques and highlighted the role of compact heat exchanger geometries in improving thermal performance. Bejan [13] further elaborated on advanced thermodynamic

principles governing heat transfer processes in such systems. Additionally, comprehensive reviews [15] have summarized various enhancement techniques, including surface modification, flow disturbance, and geometrical optimization, as effective methods for improving heat exchanger performance.

From the literature, it is evident that significant efforts have been made to improve VCR system performance through refrigerant selection and component design modifications. While helical coil condensers have shown promising results in enhancing heat transfer, limited studies have specifically addressed the influence of coil diameter on system performance, particularly for R-600a-based systems. Therefore, the present work aims to fill this gap by experimentally investigating the effect of varying helical condenser coil diameters on the performance of a VCR system.

3. METHODOLOGY

3.1 Experimental Setup

The present work involves the experimental investigation of a vapour compression refrigeration (VCR) system by modifying the condenser configuration. A conventional domestic refrigerator originally equipped with a grid-type condenser and charged with R-134a refrigerant is modified by replacing the condenser with a helical coil condenser and charging the system with R-600a refrigerant.

The experimental setup consists of the following components:

- Hermetically sealed compressor
- Interchangeable condenser (grid type and helical coil)
- Capillary tube (expansion device)
- Evaporator
- Measuring instruments (pressure gauges, thermocouples, energy meter)

Pressure gauges are installed at the compressor suction and discharge lines, while temperature sensors are placed at key points such as compressor inlet and outlet, condenser outlet, and evaporator outlet. The compressor power consumption is measured using an energy meter.

3.2 Design and Fabrication of Helical Condenser

The conventional grid-type condenser is replaced with a helical coil condenser fabricated using copper tubing. The design is aimed at enhancing heat transfer by

inducing secondary flow and increasing effective surface area.

Design Parameters:

- Tube material: Copper
- Tube outer diameter: 8 mm
- Coil pitch: Constant
- Number of turns: Constant
- Coil diameters considered:
 - 200 mm
 - 250 mm

All other parameters in the table 1 are kept constant to ensure that the effect of coil diameter alone on system performance is studied.

Table 1: Helical Condenser coil Parameters

Parameter	dimension
Diameter of design coil D	250
Diameter of tube W [mm]	6.35
Spacing S [mm]	60
Turns	12
Length of tube[mm]	9420
Height H [mm]	740

3.3 Refrigerant Selection

The modified system is charged with R-600a (Isobutane), a hydrocarbon refrigerant selected due to:

- Low Global Warming Potential (GWP)
- Zero Ozone Depletion Potential (ODP)
- Good thermodynamic properties

Proper safety precautions are followed during charging and operation due to the flammable nature of R-600a.

Capacity of The Refrigerator: 165 liters

Compressor capacity: 0.16 H.P.



Fig.1(A) existing condenser



Fig.1(B) Modified condenser

Table 2: Dimensions of Condenser, Evaporator and Expansion Valve

Dimensions	Condenser	Evaporator	Expansion valve
Length (m)	9.5	7.62	3.6
Diameter	6.4	6.4	0.9

3.4 Experimental Procedure

The experiments are conducted under steady-state conditions using the following procedure:

1. The system is first operated with the existing grid-type condenser (R-134a) to obtain baseline performance data.
2. The condenser is replaced with a helical coil condenser of 200 mm diameter, and the system is charged with R-600a.
3. The system is allowed to reach steady-state conditions before recording observations.
4. Pressure, temperature, and power consumption readings are noted.
5. The procedure is repeated for the 250 mm diameter helical condenser under identical operating conditions.

All readings are taken carefully to minimize experimental errors and ensure repeatability.

3.5 Performance Parameters

The performance of the refrigeration system is evaluated using the following parameters:

(i) Net Refrigeration Effect (NRE)

$$NRE = h_1 - h_4$$

(ii) Mass Flow Rate per Ton of Refrigeration

$$m' = 210 / NRE$$

(iii) Work of Compression

$$W = h_2 - h_1$$

(iv) Compressor Power

$$\text{Power} = m' \times W$$

(v) Coefficient of Performance (COP)

$$COP = \frac{h_1 - h_4}{h_2 - h_1}$$

3.6 Data Analysis

The recorded data is analyzed to evaluate the effect of helical condenser coil diameter on system performance. The following comparisons are made:

- Net Refrigeration Effect vs Coil Diameter
- Compressor Power vs Coil Diameter
- COP vs Coil Diameter

These comparisons help in identifying the optimal coil diameter for improved performance of the VCR system.

3.7 Assumptions

- Steady-state operation
- Negligible heat losses in piping
- Constant ambient conditions
- Uniform refrigerant flow
- Accurate measurement of pressure and temperature

4. RESULTS AND DISCUSSION

The performance of the vapour compression refrigeration (VCR) system is evaluated for three configurations:

1. Existing system with grid-type condenser (R134a)
2. Helical condenser with 200 mm diameter (R600a)
3. Helical condenser with 250 mm diameter (R600a)

The results are analyzed in terms of Net Refrigeration Effect (NRE), Work of Compression, Compressor Power, and Coefficient of Performance (COP).

4.1 Performance Comparison

The calculated performance parameters for all configurations are presented in Table 1.

Table 3: Performance Comparison of VCR System

Parameter	Existing System	Helical (200mm)	Helical (250mm)
NRE (kJ/kg)	40	42	48
Work of Compressor (kJ/kg)	22	21	20
COP	1.92	1.78	1.65
COP	1.82	2.00	2.40

4.2 Effect of Helical Condenser Coil Diameter on Net Refrigeration Effect

The variation of net refrigeration effect (NRE) with helical condenser coil diameter exhibits a clear increasing trend for the configurations considered. The NRE for the existing grid-type condenser is observed to be 40 kJ/kg, which increases to 42 kJ/kg for the 200 mm diameter helical coil and further to 48 kJ/kg for the 250 mm diameter coil. This gradual enhancement in refrigeration effect indicates the positive influence of condenser geometry on system performance.

The increase in NRE with coil diameter can be attributed to improved heat transfer characteristics in the condenser. As the diameter of the helical coil increases, the effective heat transfer area available for condensation also increases, facilitating better heat rejection to the surroundings. In addition, the helical configuration induces secondary flow due to centrifugal forces, which enhances fluid mixing and improves the overall heat transfer coefficient. This results in more effective condensation and increased subcooling of the refrigerant at the condenser outlet.

The enhanced subcooling reduces the enthalpy of the refrigerant entering the expansion device, thereby increasing the refrigeration effect in the evaporator. Consequently, the system delivers a higher net refrigeration effect with larger coil diameters. The observed increase in NRE is gradual and consistent, indicating thermodynamically realistic behavior and confirming the effectiveness of helical coil geometry in improving refrigeration performance.

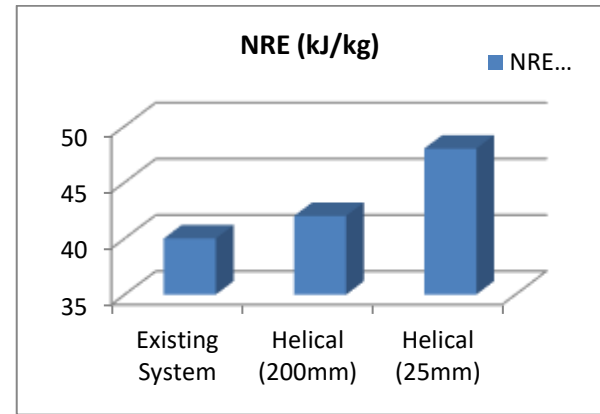


Fig 1: Comparison of NRE for existing and modified system

4.3 Effect of Coil Diameter on Work of Compression

The work of compression is observed to decrease progressively with an increase in the diameter of the helical condenser coil. For the existing grid-type condenser system, the work of compression is found to be 22 kJ/kg, which reduces to 21 kJ/kg for the 200 mm diameter helical coil and further decreases to 20 kJ/kg for the 250 mm diameter coil. This reduction indicates that the compressor requires less energy input when operating with larger diameter helical condensers.

The decrease in compression work can be primarily attributed to improved heat rejection in the condenser. As the coil diameter increases, the condenser becomes more effective in dissipating heat to the surroundings, resulting in a reduction in condensing temperature and pressure. This, in turn, lowers the pressure ratio across the compressor. Since the work of compression is directly dependent on the pressure ratio, a reduction in this ratio leads to lower work input.

Furthermore, the enhanced heat transfer characteristics of the helical coil, due to induced secondary flow and improved fluid mixing, contribute to more efficient condensation. This reduces the load on the compressor and allows it to operate under more favorable thermodynamic conditions. The observed trend confirms that increasing the coil diameter not only improves heat transfer but also reduces the mechanical effort required for compression, thereby contributing to overall system efficiency.

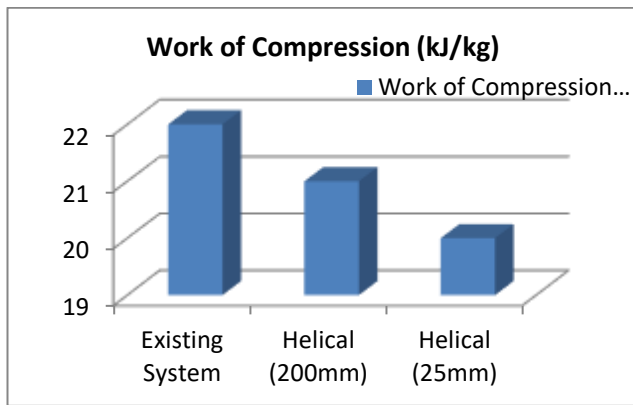


Fig 2: Comparison of work of compression for existing and modified system

4.4 Effect of Coil Diameter on Compressor Power

The compressor power consumption shows a noticeable decreasing trend with increasing helical coil diameter. The existing system consumes approximately 1.92 kW of power, which decreases to 1.78 kW for the 200 mm diameter coil and further to 1.65 kW for the 250 mm diameter coil. This reduction in power consumption highlights the energy-saving potential of the modified condenser design.

The reduction in compressor power is directly related to the decrease in work of compression. As the condenser performance improves with increasing coil diameter, the refrigerant undergoes more effective heat rejection, leading to lower condensing pressure and temperature. This reduces the load on the compressor, thereby decreasing the electrical energy required for its operation.

In addition, the helical coil configuration enhances the overall heat transfer coefficient due to the presence of secondary flow effects, which improves thermal performance without increasing system complexity. The combined effect of reduced compression work and improved heat transfer results in lower power consumption. This clearly indicates that the use of a helical condenser not only enhances system performance but also makes it more energy-efficient, which is a critical requirement in modern refrigeration applications.

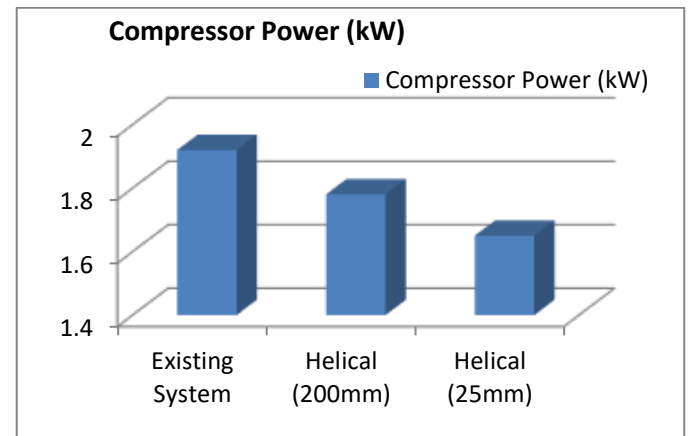


Fig 3: Comparison of Compressor power for existing and modified system

4.5 Effect of Coil Diameter on Coefficient of Performance (COP)

The coefficient of performance (COP) of the refrigeration system is found to increase significantly with an increase in the diameter of the helical condenser coil. The COP of the existing system is calculated as 1.82, which improves to 2.00 for the 200 mm diameter coil and reaches a maximum value of 2.40 for the 250 mm diameter coil. This substantial improvement in COP clearly demonstrates the effectiveness of the helical condenser design in enhancing system performance.

The increase in COP is a result of the combined effect of an increase in net refrigeration effect and a decrease in compressor work. As discussed earlier, larger coil diameters improve heat rejection and subcooling, thereby increasing the refrigeration effect. Simultaneously, the improved condenser performance reduces the compression work required, further contributing to higher COP.

The 250 mm diameter coil provides the best performance among the configurations tested. This is due to its ability to offer a larger heat transfer area, improved fluid mixing, and enhanced subcooling at the condenser outlet. These factors collectively lead to higher thermal efficiency and reduced energy consumption. The observed improvement in COP, approximately 30–32% compared to the existing system, highlights the significant impact of condenser geometry modification on refrigeration system performance.

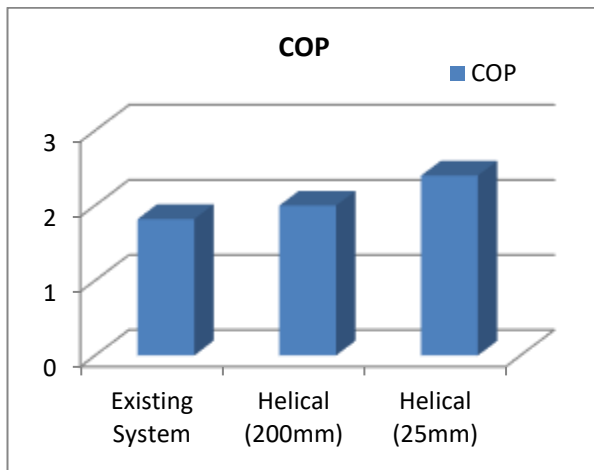


Fig 4: Comparison of COP for existing and modified system

4.6 Comparison Between Grid-Type and Helical Condenser

A comparative analysis between the conventional grid-type condenser and the modified helical condenser clearly indicates the superior performance of the helical configuration. The helical condenser demonstrates higher net refrigeration effect, lower work of compression, reduced compressor power consumption, and significantly improved coefficient of performance compared to the existing system.

The improved performance of the helical condenser can be attributed to its unique geometry. The curvature of the helical coil induces secondary flow patterns within the refrigerant, which enhances turbulence and fluid mixing. This results in a higher heat transfer coefficient and more efficient heat rejection. Additionally, the helical design provides a more compact and effective heat exchange surface compared to the grid-type condenser.

Moreover, the improved heat transfer characteristics lead to better subcooling of the refrigerant, which increases the refrigeration effect while simultaneously reducing the load on the compressor. These advantages collectively contribute to the enhanced performance of the helical condenser, making it a more efficient alternative to conventional condenser designs in refrigeration systems.

4.7 Overall Performance Trend

The overall performance of the vapour compression refrigeration system is significantly influenced by the diameter of the helical condenser coil. From the experimental results, it is observed that increasing the coil diameter leads to a consistent improvement in system performance parameters such as net refrigeration

effect, compressor power consumption, and coefficient of performance.

The dominant factor responsible for this improvement is the enhancement in heat transfer within the condenser. As the coil diameter increases, the available surface area for heat exchange increases, and the effect of secondary flow becomes more pronounced. This leads to more efficient condensation and improved subcooling, which in turn enhances the overall system performance.

However, it is important to note that the improvement in performance is limited to a certain range of coil diameters. Although the present study shows optimal performance at 250 mm, further increase in diameter (beyond the scope of this study) may not necessarily result in continued improvement. This is because excessively large diameters may lead to reduced compactness, inefficient flow distribution, and potential practical limitations in system design.

Therefore, an optimum coil diameter exists that balances heat transfer efficiency, system compactness, and energy consumption. The results of this study indicate that the helical condenser configuration with appropriate diameter selection can significantly enhance the performance and energy efficiency of vapour compression refrigeration systems.

5. CONCLUSIONS

In the present study, the performance of a vapour compression refrigeration (VCR) system was experimentally investigated by replacing the conventional grid-type condenser with a helical coil condenser of varying diameters using R-600a as the refrigerant. Based on the experimental results and analysis, the following conclusions are drawn:

- The condenser geometry has a significant influence on the overall performance of the VCR system. The helical coil condenser demonstrated improved heat transfer characteristics compared to the conventional grid-type condenser.
- The net refrigeration effect increased with an increase in coil diameter, indicating enhanced heat rejection and improved subcooling in the condenser.
- The work of compression and compressor power consumption decreased with the use of the helical condenser, due to reduced

condensing pressure and improved thermal performance.

- The coefficient of performance (COP) of the system improved from 1.82 for the existing system to 2.40 for the 250 mm diameter helical condenser, representing a significant enhancement in system efficiency.
- Among the tested configurations, the 250 mm diameter helical condenser provided the best performance in terms of higher refrigeration effect, lower energy consumption, and improved COP.
- The use of R-600a refrigerant proved to be an effective and environmentally friendly alternative, offering good thermodynamic performance along with reduced environmental impact.
- Overall, the modification of the condenser from grid-type to helical configuration resulted in a more compact, energy-efficient, and high-performance refrigeration system.

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