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Experimental Investigation Of Water Chiller By Using Conical Coil And Helical Coil Evaporators In A Vapour Compression Refrigeration System

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The performance of helical and conical coil evaporators in a vapour compression refrigeration (VCR) system is compared in this study. The coefficient of performance (COP), temperature variation, condenser heat rejection, and refrigeration effect (RE) are among the key performance indicators that have been examined. According to the experimental results, the conical coil design greatly improves system performance by achieving higher theoretical and actual COP values, more stable temperature regulation, better heat rejection, and a larger refrigeration effect. These results lend support to the use of conical coil evaporators in refrigeration systems to increase efficiency and reduce energy consumption.

Keywords: Vapour Compression Refrigeration (VCR), Refrigeration Effect (RE), Conical Coil, Helical Coil.

1. Introduction

The rising demand for energy-efficient refrigeration systems has driven continuous innovation in component design, especially in the evaporator, the component responsible for absorbing heat during the refrigeration cycle. The geometry of the evaporator coil plays a vital role in determining the heat transfer characteristics and overall performance of a Vapour Compression Refrigeration (VCR) system.

Traditionally, helical coil evaporators have been widely used due to their simple construction and reliable performance. However, recent studies have shown that alternative geometries, such as conical coil configurations, may provide improved refrigerant flow dynamics, larger effective heat transfer surfaces, and enhanced turbulence. These factors can lead to improved heat absorption, better phase change performance of the refrigerant, and ultimately, a higher Coefficient of Performance (COP).

The study by Wang, Chang, and Hsieh (1999) explores the thermal and hydraulic performance of heat exchangers equipped with helical and conical coil configurations, which are innovative alternatives to conventional straight-tube designs [4]. The study by Thangamani, Manokar, and Suresh (2018) focuses on evaluating how the shape of evaporator coils influences the performance of vapour compression refrigeration (VCR) systems. Evaporator coils are critical because they facilitate heat absorption by evaporating the refrigerant, which in turn affects system efficiency and cooling capacity [5].

This study presents a comparative experimental investigation of conical coil and helical coil evaporators under identical operating conditions. Parameters such as theoretical and actual COP, temperature distribution, refrigeration effect (RE), and heat rejected by the condenser are recorded and analysed to evaluate the impact of coil geometry on system performance.

By examining the performance characteristics of both evaporator types, this research aims to provide practical insights for the development of more energy-efficient and thermally optimised refrigeration systems.

2. Experimental Setup and Design Parameters

The evaporator plays a crucial role in determining the overall efficiency of a vapour compression refrigeration (VCR) system. In this study, two different evaporator geometries—Conical Coil and Helical Coil—were designed and tested under identical environmental and operational conditions to evaluate their effect on the system's performance.

2.1 Material and Tube Specifications

Both evaporators were constructed using copper tubing due to its high thermal conductivity of 386 W/m·K, which ensures rapid heat transfer. The tube dimensions were identical for both designs to isolate the impact of coil geometry.

A. **Inner Diameter of Tube**: 6 mm

B. **Outer Diameter of Tube**: 8 mm

C. **Total Coil Length (L)**: 508.68 cm (≈5.08 m or 16.68 feet)

2.2 Geometrical Differences

While the base materials and tube dimensions remained the same, the overall coil geometry varied significantly:

Parameter	**Conical Coil**	**Helical Coil**
Outer Diameter of Coil	22.5 cm	27 cm
Inner Diameter of Coil	8 cm	N/A

Parameter	Conical Coil	Helical Coil
Number of Coils	12	6
Height of Coil	30 cm	30 cm
Distance Between Two Coils	2.5 cm	5 cm

2.3 Impact of Geometry on Performance

The conical coil features more turns (12 vs. 6) and a smaller pitch (2.5 cm vs. 5 cm), which results in:

- **Greater surface area for heat exchange**
- **Higher turbulence inside the tubes**, improving refrigerant heat absorption
- **Compact design** that optimises space and heat distribution

These characteristics collectively contribute to the superior performance observed in the conical coil evaporator, as evidenced by the higher average actual COP (2.1736) compared to the helical coil (2.0509).

Design Parameter for Evaporator in tabular form:-

Figure 1: Conical coil evaporator

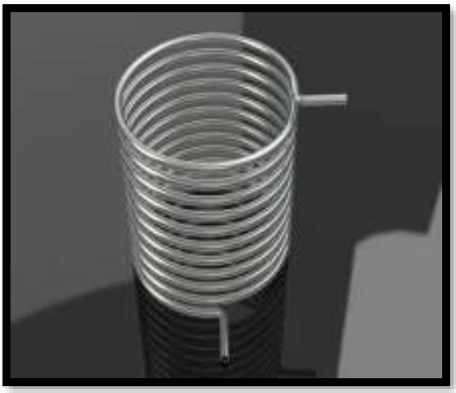

Figure 2: Helical coil evaporator

Figure 3: Experimental setup

3. Results

3.1 Experimental Observations

The experiment was conducted on a vapour compression refrigeration (VCR) test rig to evaluate the performance of two types of evaporator coils:

- Conically coiled evaporator
- Helically coiled evaporator

The key performance metric under consideration was the Coefficient of Performance (COP), assessed under both theoretical and actual operating conditions. The observed data sets were compiled, and the average COP values for each configuration were calculated as follows:

3.2 Data Interpretation

The data reveals a consistent trend where the conical coil evaporator outperforms the helical coil in both theoretical and actual COP:

Evaporator Type	Average Theoretical COP	Average Actual COP
Conical Coil	2.8155	2.1736
Helical Coil	2.7642	2.0509

- The theoretical COP of the conical coil is 2.8155, slightly higher than the 2.7642 obtained for the helical coil.
- The actual COP, which reflects real-world efficiency, shows a more noticeable difference: 2.1736 for the conical coil and 2.0509 for the helical coil.

This demonstrates that the conical coil provides an increase of approximately 1.86% in theoretical COP and about 5.98% in actual COP, highlighting its superior thermal performance.

3.3 Performance Enhancement Justification

The improved performance of the conical coil design can be attributed to:

- **Improved refrigerant flow distribution** due to conical geometry
- **Larger effective heat transfer area**
- **Higher turbulence**, which enhances heat exchange
- **Reduced pressure drop losses**, aiding in better refrigerant phase change efficiency

These factors collectively reduce compressor load and improve thermal exchange, thereby boosting the overall system performance.

3.4 Implications

The study indicates that using a conical coil evaporator leads to a measurable improvement in refrigeration efficiency. This insight is particularly valuable for low-cost VCR systems where even modest improvements in COP translate to significant energy savings over operational life.

Table: Actual and theoretical cop

Readings for the Conically coiled design of the evaporator		Readings for Helically coiled design of evaporator	
COP_{Th}	COP_{Act}	COP_{Th}	COP_{Act}
2.734	2.05	2.677	1.9
2.734	2.05	2.677	2.05

2.734	2	2.677	1.8
2.794	2.1	2.734	2.1
2.794	2.1	2.734	2
2.871	2.15	2.871	2.15
2.871	2.16	2.750	2.16
2.855	2.25	2.824	2
2.887	2.3	2.887	2.3
2.825	2.35	2.766	1.7
2.871	2.4	2.810	2.4
Avg=2.8155	**Avg=2.1736**	**Avg=2.7642**	**Avg=2.0509**

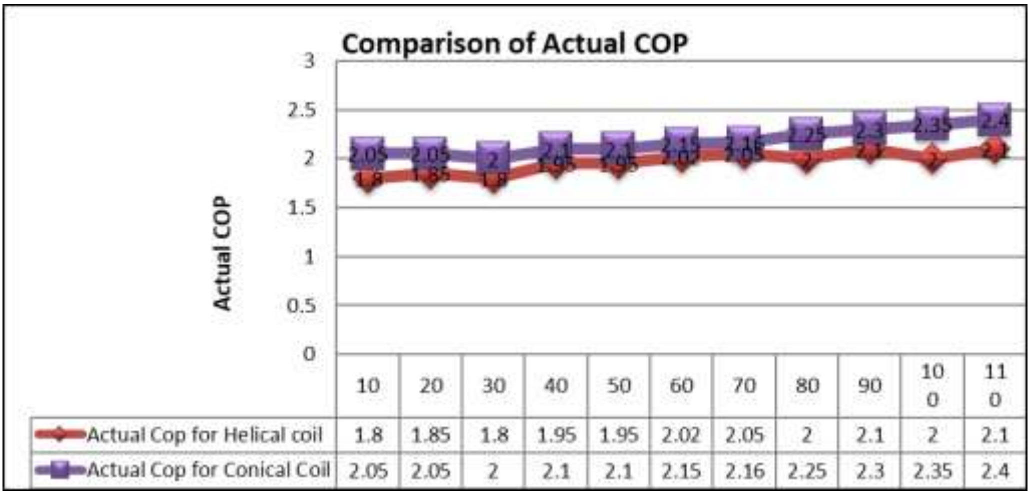

Figure 4: Comparison of actual cop

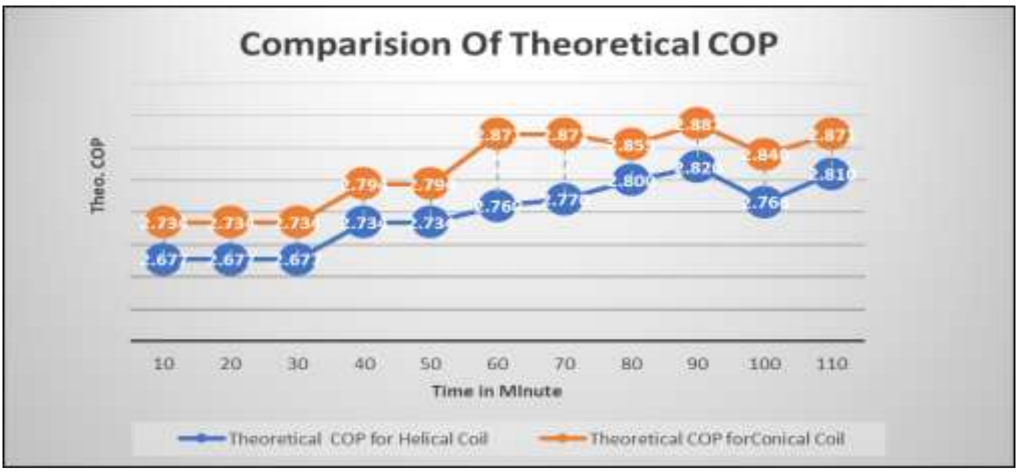

Figure 5: Comparison of Theoretical co

3.5 Refrigeration Effect (RE) Analysis:

Observed Trends in Refrigeration Effect:

The chart titled "Comparison of Refrigeration Effect" illustrates the variation in refrigeration effect (in kJ/kg) over a time span of 10 to 110 minutes for both conical and helical coil evaporator configurations.

Time (min)	RE in KJ/kg (Conical Coil)	RE in KJ/kg (Helical Coil)
10 – 30	175	174
40 – 50	176	175
60 – 70	178	176
80	178.5	176.5
90	179	178
100 – 110	178	177

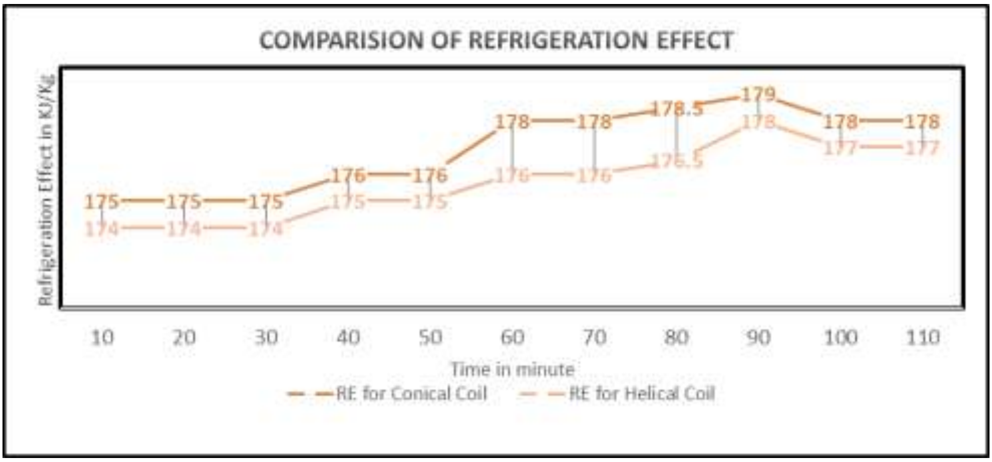

Figure 6: Refrigeration effect comparison

3.6 Interpretation and Performance Insights

- The conical coil consistently demonstrates a higher refrigeration effect than the helical coil across all time intervals.

- The peak RE for the conical coil is 179 kJ/kg, compared to 178 kJ/kg for the helical coil.
- At all time points, the difference in RE ranges from 1 to 2.5 kJ/kg, indicating the improved efficiency of the conical geometry.

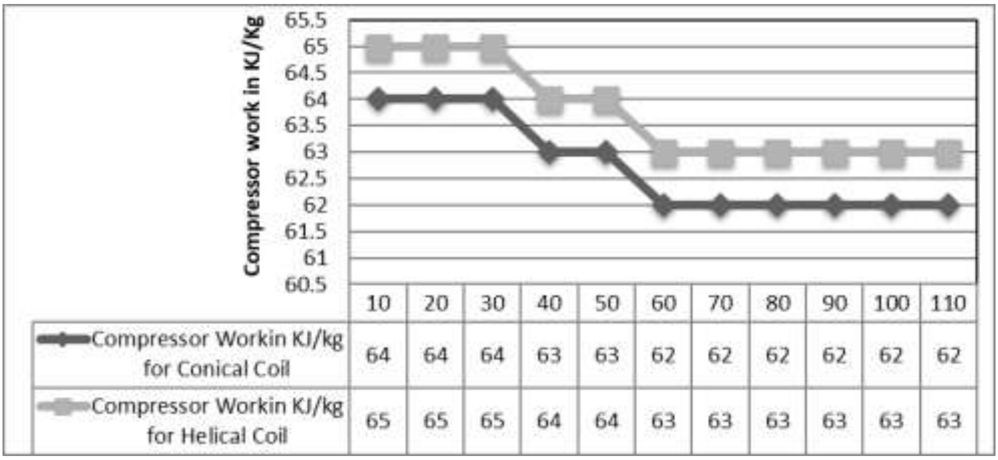

Figure 7: Work consumed by the compressor

3.7 Heat Rejection Analysis:

The bar chart titled "Comparison of Heat Rejected by Condenser" presents the heat rejection values in kJ/kg for conical and helical coil evaporators over a range of load or operating conditions (from 10 to 110, denoting time in minutes).

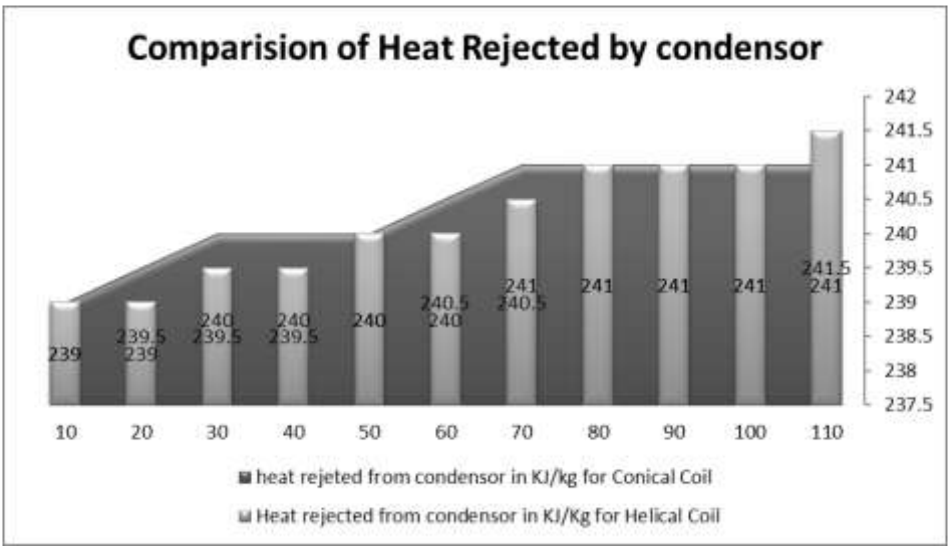

Figure 8: Heat rejection by bar chart

Table: Observed Heat Rejection Trends

Time in Minutes	Heat Rejected (kJ/kg) – Conical	Heat Rejected (kJ/kg) – Helical
10	239	239.5
20	239.5	239
30	240	239.5
40	240	239.5
50	240	240
60	240.5	240
70	241	240.5
80	241	241
90	241	241
100	241	241
110	241	241.5

3.7.1 Interpretation of Results

- For most operating conditions, the conical coil configuration shows slightly higher or equivalent heat rejection than the helical coil.
- Maximum heat rejection for the conical coil remains stable at 241 kJ/kg over several points (70 to 110), indicating consistent condenser performance under higher loads.
- The helical coil peaks at 241.5 kJ/kg at the final condition (110), but otherwise slightly lags or matches the conical design in earlier intervals.

3.7.2 Discussion and Performance Insight

- The conical coil evaporator, due to its geometry, promotes better refrigerant vaporisation, leading to more efficient heat transfer downstream at the condenser.
- Stable heat rejection in the 241 kJ/kg range for the conical coil reflects a uniform and efficient condensation process, a sign of good system balance.

- While both coil types perform similarly at high loads, the conical coil demonstrates a more consistent and slightly more efficient rejection trend, which correlates with its higher actual COP seen in earlier results.

3.7.3 Implications for System Design

- Efficient and stable heat rejection improves the overall energy efficiency and reliability of the refrigeration system.
- The slight edge shown by the conical coil suggests that adopting such a geometry in evaporator design can lead to enhanced system-level thermal management, particularly in medium to high load applications.

3.8 Temperature Analysis with COP – Conical Coil

3.8.1 Observed Temperature Trends

The graph illustrates the temperature variations at key locations in the vapour compression refrigeration (VCR) system—compressor outlet (T2), condenser (T3), and evaporator (T4)—concerning the Coefficient of Performance (COP) for the conical coil evaporator.

- Compressor Outlet Temperature (T2):
  - Starts at 52°C for lower COP values (~2.734) and gradually decreases to 46°C as the COP increases to ~2.87.
  - This indicates a reduction in compression work or improved heat rejection efficiency.
- Condenser Temperature (T3):
  - Decreases from 30°C to 25°C as COP increases.
  - Suggests improved condensation or better heat transfer performance at higher efficiencies.
- Evaporator Temperature (T4):
  - Falls from 4°C to 1°C across the COP range.
  - Indicates better refrigerant evaporation and absorption of heat from the evaporator environment.

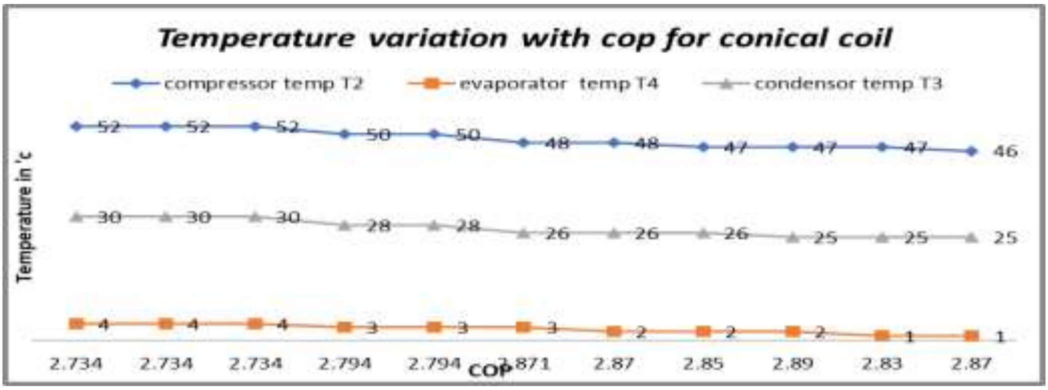

Figure 9: Temperature variation with COP for Conical coil

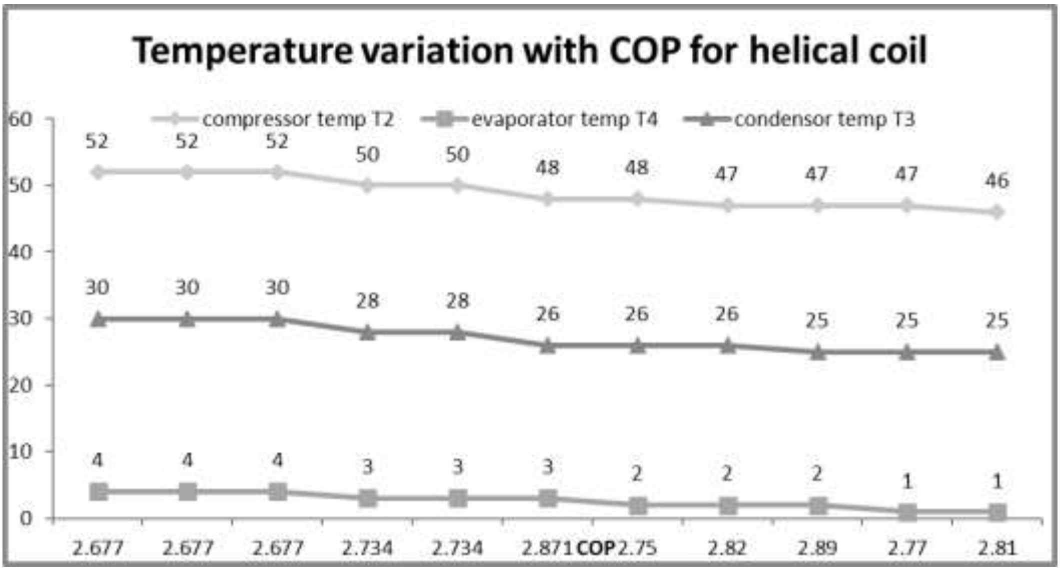

Figure 10: Temperature variation with COP for helical coil

3.8.2 Interpretation and Discussion

The data reflect that higher COP values are associated with lower operating temperatures in all three stages (compressor, condenser, evaporator). This behaviour can be attributed to:

- Efficient refrigerant flow and phase change inside the conical coil, due to better geometry and heat transfer characteristics.
- Lower evaporator temperature enhances refrigerant evaporation, improving the cooling effect, which directly increases COP.

- The reduction in compressor temperature implies reduced compressor load or more effective suction conditions, resulting in less energy input per unit of refrigeration effect.

3.8.3 Performance Implications

The temperature drop across the system with increasing COP confirms that the conical coil design contributes to more effective heat transfer. This leads to:

- Reduced thermal resistance, allowing the refrigerant to absorb and reject heat more efficiently.
- Optimised operating pressures and temperatures, thereby enhancing system performance without needing extra power input.

This analysis further supports the earlier COP data findings, which show that the conical coil evaporator outperformed the helical coil configuration. Lower temperatures at key system points result in improved energy efficiency and system reliability.

4. Discussion

The experimental analysis was carried out to evaluate and compare the performance of a Vapour Compression Refrigeration (VCR) system equipped with conically coiled and helically coiled evaporators. The primary performance parameter assessed was the Coefficient of Performance (COP), calculated under both theoretical and actual operating conditions.

4.1 Performance Comparison

The summarised COP values are as follows:

Evaporator Type	Average Theoretical COP	Average Actual COP
Conical Coil	2.8155	2.1736
Helical Coil	2.7642	2.0509

From the data, it is observed that the conical coiled evaporator exhibited a higher COP than the helical design under both theoretical and actual conditions. Specifically:

- The theoretical COP for the conical coil was 2.8155, compared to 2.7642 for the helical coil, marking a 1.86% improvement.
- The actual COP for the conical coil was 2.1736, whereas the helical coil showed 2.0509, indicating a 5.98% enhancement.

4.2 Interpretation of Results

The improved performance of the conical coiled evaporator can be attributed to its enhanced geometry, which promotes better refrigerant distribution, increased surface area for heat exchange, and improved flow characteristics. These factors collectively contribute to more efficient heat absorption and transfer, reducing thermal losses and compressor work. The difference between theoretical and actual COP values in both configurations can be attributed to real-world inefficiencies, including frictional losses, minor leakages, imperfect insulation, and non-ideal compressor behaviour.

4.3 Summary of Findings

- The conical coil consistently outperforms the helical coil in terms of both theoretical and actual COP.
- The percentage increase in actual performance is more significant, emphasising the real-world benefit of using conical coil geometry in evaporator design.
- These findings support the adoption of conical coil configurations in refrigeration systems where energy efficiency is a key objective.

4.4Discussion

The higher refrigeration effect observed with the conical coil evaporator can be attributed to several key design and operational advantages:

- Increased heat transfer surface area due to its tighter coil spacing and more turns.
- Improved refrigerant distribution and turbulence, enhancing latent heat absorption in the evaporator.
- Faster and more uniform heat pickup, resulting in a better cooling effect per kilogram of refrigerant.

The helical coil, though performing well, shows slightly lower and less consistent RE values, indicating relatively reduced evaporator effectiveness under identical test conditions.

4.5 Implications

- A higher refrigeration effect directly contributes to improved system COP and cooling capacity.
- The conical coil design is validated as a more effective evaporator geometry for VCR systems aimed at achieving higher performance and energy efficiency.

  This performance gain is particularly valuable in applications that require steady-state or long-duration cooling operations.

8. Conclusion

This research investigated the impact of evaporator geometry—conical coil versus helical coil—on the performance of a Vapour Compression Refrigeration (VCR) system. A detailed experimental analysis was conducted by comparing key performance metrics, including the Coefficient of Performance (COP), temperature distribution, heat rejected by the condenser, and refrigeration effect (RE).

The key findings can be summarised as follows:

- The conical coil evaporator consistently achieved higher average theoretical and actual COP values compared to the helical coil, with an improvement of approximately 1.86% in theoretical COP and 5.98% in actual COP.
- Temperature variations indicated better thermal regulation in the conical coil configuration, with lower evaporator and condenser temperatures observed at higher COPs, confirming improved heat exchange and system efficiency.
- Heat rejection analysis showed that the conical coil maintained a more stable and efficient condenser heat rejection profile over time, with values consistently around 241 kJ/kg, which is slightly higher or equivalent to the helical coil.
- The refrigeration effect of the conical coil evaporator remained superior throughout the test duration, peaking at 179 kJ/kg compared to 178 kJ/kg for the helical coil, demonstrating enhanced cooling performance.

Overall, the study confirms that conical coil evaporator designs offer measurable improvements in system efficiency, thermal performance, and refrigerant utilisation. These advantages make the conical configuration a viable and energy-efficient alternative to traditional helical coil designs in modern refrigeration systems.

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