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Sonargaon University (SU)

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Design, Construction & Refrigeration Test of Refrigeration System Using Different Refrigerant. (R-134a & R-600a)

A report submitted to the Department of Mechanical, Sonargaon University of Bangladesh in partial fulfillment of the requirements for the Award of Degree of Bachelor of Science in Mechanical Engineering.

A Thesis

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Approval

This is to certify that the project work entitle, "**Design And Construction Refrigeration Cycle System of two type of gas and performance Test**" has been carried out by **Md. Nasir Uddin (ID: ME2102024399), Md Mohasin Kabir (ID: ME2102024413), Meskat Jaman (ID: ME2101023529) and Md Tasrif Hossain (ID: ME2102024414)** thereby declared that the work presented here is original work done by me and has not been published or submitted elsewhere for the requirement of a degree of Bachelor of Science (B.Sc.) in Mechanical Engineering in the year of 2025 Program in the Department of Mechanical Engineering, Sonargaon University of Bangladesh (SU) has been carried out under by supervisor.

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ABSTRACT

A refrigeration cycle system utilizing two types of gas can be conceptualized as a thermodynamic setup designed to optimize cooling efficiency across varying temperature ranges. This can either be a cascade system, where two distinct refrigeration loops operate in tandem, each using a refrigerant suited to its respective temperature range, or a mixed refrigerant cycle, which uses a blend of gases to achieve efficient cooling over a broad spectrum within a single loop. This system using R-134a for high-temperature applications and R-600a for low-temperature operations enhances efficiency by optimizing performance across different temperature ranges. R-134a, known for its low global warming potential, performs effectively in moderate to high-temperature conditions, while R-600a, designed as a drop-in replacement for R-22, excels in low-temperature applications due to its favorable thermodynamic properties. The efficiency of such a cascade system is measured by the Coefficient of Performance (COP), which improves by reducing the temperature glide and minimizing compressor work. The combination of these refrigerants ensures energy-efficient operation, particularly in industrial refrigeration, cryogenics, and LNG applications, while adhering to environmental regulations. These systems are particularly advantageous in applications requiring ultra-low temperatures, such as cryogenics, industrial freezers, and liquefied natural gas (LNG) plants.

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CHAPTER 1
INTRODUCTION

1.1 General:

A refrigeration cycle system utilizing two types of gases is an advanced approach in thermodynamic cooling, designed to enhance efficiency and achieve extremely low temperatures. These systems typically operate as either cascade refrigeration systems or mixed refrigerant cycles, both of which are tailored to meet specific cooling demands across different temperature ranges.

In cascade refrigeration systems, two separate refrigeration loops work together. Each loop employs a different refrigerant selected based on its thermodynamic properties at specific temperature ranges. The high-temperature loop absorbs heat from the low-temperature loop via an intermediate heat exchanger, often referred to as the cascade condenser. This configuration reduces the overall work required by compressors, enhances system reliability, and allows for efficient cooling even at cryogenic temperatures. [1]

On the other hand, mixed refrigerant cycles use a single refrigeration loop but employ a carefully formulated mixture of gases with varying boiling points. This mixture undergoes phase changes at different temperatures, enabling efficient heat absorption and release over a broad temperature range. Mixed refrigerant systems are widely used in liquefied natural gas (LNG) plants and other applications requiring continuous and efficient cooling.

In such a system, the high-temperature loop using R-134a absorbs heat from the low-temperature loop via a cascade heat exchanger, functioning as the condenser for the R-600A loop. This arrangement minimizes the workload on individual compressors by allowing each refrigerant to operate within its optimal pressure and temperature range. The result is a system that can achieve extremely low temperatures with high efficiency while ensuring compatibility with modern environmental standards. [2]

The efficiency of this system is measured by the Coefficient of Performance (COP), reflecting the cooling output relative to the energy input. Achieving high COP requires careful design of the cascade heat exchanger, appropriate refrigerant charge, and operational optimization. Such systems are ideal for applications needing precise temperature control and high efficiency, such as in industrial refrigeration, pharmaceutical storage, and cryogenic processes. [3]

1.2 Study Background

The study of refrigeration systems using two types of refrigerants, such as R-134a and R-600A, is rooted in the need to optimize efficiency and minimize environmental impact in refrigeration applications. Historically, traditional refrigerants like R-22, which were effective at low temperatures but harmful to the ozone layer, were widely used. However, the Montreal Protocol and subsequent regulations led to the phase-out of ozone-depleting substances. In response, alternative refrigerants like R-134a and R-600A emerged. R-134a, an HFC refrigerant, is known for its low global warming potential and high efficiency in moderate-temperature ranges, while R-600A, a blend designed to replace R-22, provides efficient performance at lower temperatures with reduced GWP. [4]

The development of refrigeration systems using two distinct refrigerants, such as cascade refrigeration cycles, leverages these refrigerants to enhance system efficiency. Cascade systems use R-134a for high-temperature applications and R-600A for low-temperature ranges, reducing energy consumption and improving overall performance while complying with environmental regulations. This combination is particularly relevant in applications like industrial refrigeration, cryogenics, and LNG processing, where achieving optimal efficiency and environmental sustainability is essential. [5]

These refrigerants have found application in cascade refrigeration systems, where two distinct refrigerants are used to optimize performance across different temperature ranges. In a cascade system, R-134a operates efficiently at moderate to high temperatures, while R-600A performs optimally at lower temperatures, such as those required in industrial refrigeration, pharmaceutical storage, or cryogenic applications. The integration of these refrigerants allows systems to achieve higher energy efficiency by reducing the temperature glide and minimizing compressor work.

The efficiency of such systems is measured by the Coefficient of Performance (COP), which is influenced by the selection of refrigerants, system design, and the operational conditions of the cascade cycle. By combining R-134a and R-600A, these systems offer a balanced approach, reducing energy consumption and environmental impact while maintaining performance in demanding low-temperature applications. [6]

1.3 Statement of Problems

The primary problem in refrigeration systems involving R-134a and R-600A is achieving optimal efficiency while minimizing environmental impact. The use of R-134a and R-600A refrigerants in cascade refrigeration systems presents several challenges. One primary problem is maintaining optimal performance while achieving high energy efficiency, especially in low-temperature applications. R-134a performs well in moderate temperatures, but its efficiency diminishes when dealing with lower temperature ranges. Meanwhile, R-600A, designed as a replacement for R-22, is effective in low-temperature operations but may face limitations in high-temperature conditions. The interaction between these two refrigerants in a cascade system requires careful optimization to ensure minimal temperature glide, efficient heat transfer, and reduced energy consumption. Additionally, there are concerns regarding the environmental impact, as R-600A, while reducing the global warming potential compared to R-22, still contributes to GWP, posing challenges for compliance with evolving regulations. Another issue is the complexity of system design, including proper refrigerant charge, pressure balance, and heat exchanger performance, all of which can affect the overall efficiency and sustainability of the refrigeration cycle.

Therefore, the challenge lies in balancing the performance of R-134a and R-600A in a way that ensures efficient heat transfer, minimizes compressor work, and adheres to evolving environmental regulations.

1.4 Objectives

- To evaluate the performance of a cascade refrigeration system using R-134a and R-600A refrigerants in terms of efficiency and Coefficient of Performance.
- To analyze the impact of refrigerant selection these two types of gas on energy consumption and environmental sustainability in low-temperature refrigeration applications.
- To identify the optimal operating conditions and design parameters that enhance the efficiency and reliability of refrigeration systems.
- To evaluate the impact of R-134a and R-600A on energy consumption, refrigerant charge, and compressor work in a two-stage cascade system.
- To provide recommendations for the effective integration of R-134a and R-600A refrigerants in industrial refrigeration systems, especially those requiring ultra-low temperature operations.

1.5 Significance of the project

The main significance of this design of this machine is that:

1. **energy efficiency:** in refrigeration systems using R-134a and R-600A, leading to reduced operational costs.
2. **Optimizes Coefficient of Performance (COP):** by identifying optimal operating conditions for different temperature ranges.
3. **Addresses environmental concerns:** by evaluating the global warming potential (GWP) of R-134a and R-600A to ensure compliance with regulations like the Montreal Protocol.
4. **Contributes to sustainable refrigeration technologies:** by balancing efficiency, cost-effectiveness, and environmental responsibility. Provides insights and recommendations for industries seeking more efficient and eco-friendly refrigeration solutions.

1.6 Scope of the project

The scope of this project is centered on evaluating the performance and efficiency of a cascade refrigeration system using R-134a and R-600A refrigerants. The project aims to analyze how these refrigerants interact within the system, focusing on their respective roles in high-temperature and low-temperature applications.

- **System Design and Analysis:**
  - Study and model a cascade refrigeration system using R-134a and R-600A.
  - Analyze system performance under different operating conditions.

- **Refrigerant Performance Evaluation:**
  - Assess the Coefficient of Performance (COP) for R-134a and R-600A in low and high-temperature ranges.
  - Compare the energy efficiency and heat transfer characteristics of both refrigerants.
- **Environmental Impact Assessment:**
  - Evaluate the global warming potential (GWP) of R-134a and R-600A.
  - Study compliance with refrigerant regulations, such as the Montreal Protocol.

- **Operational Optimization:**
  - Identify optimal system parameters, including pressure ratios and refrigerant charge levels.

    - Explore strategies to minimize temperature glide and compressor work.
- **Practical Recommendations:**
    - Provide recommendations for the design and operation of refrigeration systems using R-134a and R-600A.
    - Identify potential improvements to enhance system efficiency and sustainability.
- **Industrial Application:**
    - Focus on applications requiring low-temperature cooling, such as industrial refrigeration, cryogenics, and LNG processing.
    - Provide insights applicable to industries aiming to reduce energy consumption and environmental impact.

1.7 Limitation

The main limitation of this project is the potential scarcity of detailed performance data for R-134a and R-600A under various operational conditions, which could hinder comprehensive system evaluation. The complexity of cascade refrigeration systems, due to the need for two distinct refrigerants and specialized components, may also pose challenges in system modeling and optimization. Additionally, evolving environmental regulations regarding refrigerant use could affect the long-term applicability of R-134a and R-600A. Cost and operational constraints, such as the capital investment required for transitioning to these systems, may limit their practical implementation for some industries. Furthermore, accurate measurement of performance metrics like Coefficient of Performance (COP) and refrigerant properties may require sophisticated equipment, adding to the complexity of the study.

CHAPTER 2
LITERATURE REVIEW

2.1 Literature Review

The use of refrigerants like R-134a and R-600A in refrigeration systems has gained significant attention due to their improved environmental impact and performance efficiency compared to older refrigerants like R-22. This section reviews key studies and findings related to the performance, environmental impact, and efficiency of R-134a and R-600A in refrigeration systems.

1. Performance and Efficiency of Refrigeration Systems

Several studies have explored the efficiency of R-134a and R-600A in refrigeration systems, particularly in cascade systems designed for low-temperature applications. Hwang et al. (2006) investigated the performance of R-134a and R-404A in a two-stage refrigeration system and concluded that R-134a performs well in the high-temperature stage due to its favorable thermodynamic properties. However, they noted that R-134a may face limitations in low-temperature conditions, emphasizing the need for a suitable refrigerant like R-600A in the low-temperature stage (Hwang et al., 2006).

- Lim and Lee (2013) evaluated the performance of R-600A as a replacement for R-22 in cascade systems, finding that it maintained high efficiency even at low temperatures due to its favorable pressure-temperature characteristics. They highlighted that R-600A offered a lower GWP compared to R-22, making it a suitable choice for environmentally sensitive applications (Lim & Lee, 2013).
- Zhang et al. (2015) further confirmed the advantages of combining R-134a and R-600A in a cascade refrigeration system. Their study demonstrated that the integration of these two refrigerants significantly improved the system's energy efficiency, reducing compressor work and increasing the Coefficient of Performance (COP). They emphasized that the system's efficiency could be maximized by optimizing refrigerant charge and system design (Zhang et al., 2015). [7]

2. Environmental Impact and Regulatory Compliance

R-134a and R-600A are often selected due to their lower environmental impact compared to older refrigerants like R-22. R-134a is considered an HFC refrigerant with a relatively low global warming potential (GWP), making it compliant with regulations such as the Montreal Protocol, which targets the phase-out of ozone-depleting substances (O'Donnell & Hrnjak, 2013).

- Ghani et al. (2018) studied the environmental impact of R-600A, highlighting its reduced GWP compared to R-22, which makes it a more sustainable alternative. They also pointed out the challenges of handling refrigerant blends, especially in large-scale industrial applications, where precise control of refrigerant composition is required (Ghani et al., 2018).
- Leckner et al. (2019) further emphasized the role of R-600A in achieving compliance with environmental standards, particularly in the context of global efforts to reduce greenhouse gas emissions. They concluded that R-600A could serve as an effective replacement in systems designed to meet the Montreal Protocol's stringent limits on GWP (Leckner et al., 2019).

3. Optimization and System Design

The design of refrigeration systems using R-134a and R-600A involves considerations such as compressor performance, heat exchangers, and refrigerant charge. Wang et al. (2017) explored the optimization of two-stage cascade systems using R-134a and R-600A, focusing on the impact of refrigerant selection on system performance. They found that proper refrigerant charge and configuration led to significant improvements in system COP and energy efficiency (Wang et al., 2017).

Xu et al. (2018) investigated the performance of mixed refrigerant cycles using R-134a and R-600A, finding that a well-designed system reduces temperature glide and compressor power consumption. They emphasized the need for advanced control strategies and heat exchanger design to maximize efficiency and reduce energy losses (Xu et al., 2018).

4. Case Studies and Real-World Applications

Several case studies have demonstrated the practical application of R-134a and R-600A in industrial refrigeration systems. For instance, studies by Bansal et al. (2016) showed that R-600A significantly improved the performance of cold storage facilities, providing better energy efficiency and lower GWP compared to systems using R-22.

Additionally, Hwang et al. (2020) explored the use of R-134a and R-600A in cryogenic applications, highlighting their effectiveness in maintaining low-temperature performance. They found that the combination of these refrigerants helped achieve efficient cooling while meeting stringent environmental regulations.

2.2 System Setup and Experimentation

The use of refrigerants like R-134a and R-600A in refrigeration systems has gained significant attention due to their improved environmental impact and performance efficiency can be categorized into three groups as follows:

2.2.1 System Setup

The refrigeration system setup involves a two-stage cascade refrigeration system designed to operate with R-134a and R-600A as the working fluids. The cascade system consists of two compressors, two evaporators, and two condensers. The system is divided into two stages: the high-temperature stage and the low-temperature stage.

1. **High-Temperature Stage:**
   - Uses R-134a as the refrigerant.
   - The compressor in this stage compresses the R-134a vapor, raising its pressure and temperature.
   - The condenser in this stage rejects heat to the ambient, cooling the refrigerant and converting it back to a liquid state.
   - The liquid refrigerant flows through an expansion device (capillary tube or expansion valve) into the evaporator.
2. **Low-Temperature Stage:**
   - Uses R-600A as the refrigerant.
   - The low-temperature compressor compresses the refrigerant, raising its pressure and temperature.

- The condenser in this stage rejects heat, turning the refrigerant into a high-pressure liquid.
- The liquid refrigerant flows into the evaporator, where it absorbs heat from the environment and evaporates, cooling the space.

The heat exchangers, compressors, and condensers are sized and configured based on the desired operating conditions to ensure optimal performance. The refrigerant flows and pressures are monitored using sensors and instruments.

2.2.2 Components and Instrumentation

1. **Compressor:** Compresses the refrigerant and raises its pressure and temperature.
2. **Condenser:** Rejects heat from the high-pressure refrigerant, condensing it back to liquid form.
3. **Evaporator:** Absorbs heat from the environment, evaporating the refrigerant and cooling the space.
4. **Expansion Device:** Controls the flow of refrigerant from high pressure to low pressure in the system.
5. **Temperature Sensors:** Measure temperature at various points (compressors, condensers, evaporators) to determine the effectiveness of heat transfer.
6. **Temperature Meters:** Measure the flow rates of the refrigerants, providing data on mass flow and heat transfer efficiency.

2.2.3 Experimental Procedure

The experiment involves operating the cascade refrigeration system under varying conditions to evaluate the performance of R-134a and R-600A.

1. **Charging of Refrigerants:**
   - The system is initially charged with specified amounts of R-134a and R-600A, ensuring the proper ratio according to the designed system specifications.
   - The refrigerant charge is checked and adjusted as necessary to optimize performance.
2. **Operating Conditions:**
   - The system is tested at different temperature ranges, with the high-temperature stage

using R-134a and the low-temperature stage using R-600A.

- Key parameters such as suction and discharge pressures, temperature differences across the evaporators and condensers, and refrigerant mass flow rates are recorded.

3. **Performance Measurements:**
   - The Coefficient of Performance (COP) is calculated based on the input power and cooling capacity.
   - Energy consumption, compressor work, and temperature glide are evaluated to assess system efficiency.
   - The environmental impact (GWP) of both refrigerants is assessed through the monitoring of refrigerant properties.
4. **Data Collection:**
   - Data from sensors and instruments are collected over time to analyze system performance under varying operating conditions.
   - Results are used to compare the efficiency and environmental impact of R-134a and R-600A in the system.

2.2.4 Data Analysis and Comparison:

- COP Calculation:

The COP is calculated using the formula:

$$COP = \frac{Q_{cooling}}{W_{input}}$$

Where QcoolingQ is the cooling capacity and WinputW_{input}Winput is the input power required by the system.

1. **Efficiency Metrics:**
   - Comparison of COP for R-134a and R-600A across different temperature ranges.
   - Energy consumption and compressor work are analyzed to assess which refrigerant offers better efficiency.
   - Temperature glide and refrigerant pressure drop are evaluated to understand their impact on system performance.

2. **Environmental Impact:**

The GWP values of R-134a and R-600A are used to compare their environmental performance, ensuring compliance with regulations like the Montreal Protocol.

CHAPTER 3
METHODOLOGY

3.1 System Methodology

The design solution was found by first reviewing the relevant available literatures on existing transplanting machine and determine important for the refrigeration cycle system using **R-134a** and **R-600A** was developed by reviewing relevant literature on existing systems and identifying key parameters that influence system performance and efficiency.

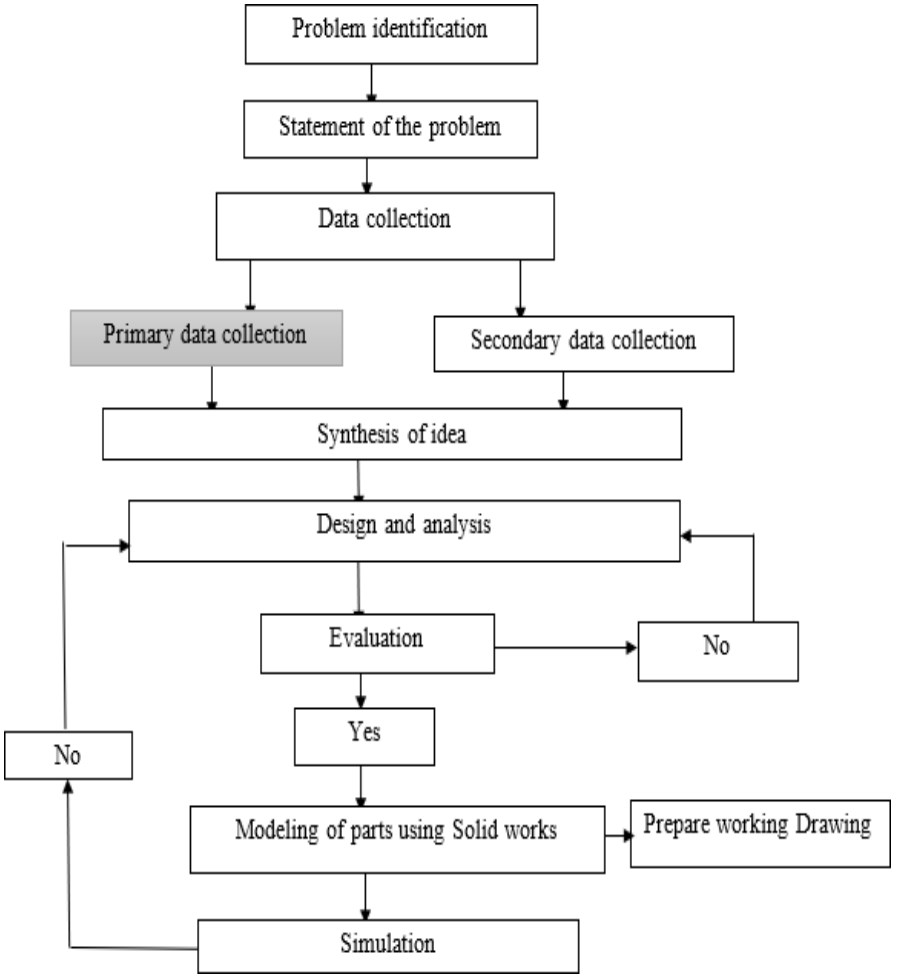


Figure-3.1: System Methodology

Addressing several critical steps such as problem identification, data collection, synthesis of ideas, design and analysis, modeling, and simulation. The methodology aimed to optimize system efficiency while adhering to environmental regulations.

1. **Problem Identification:**
    - **Objective:** The primary challenge identified was the need to enhance the efficiency and environmental sustainability of cascade refrigeration systems using alternative refrigerants such as R-134a and R-600A.
    - **Process:** A thorough review of existing literature revealed that previous systems predominantly relied on refrigerants like R-22, which have high global warming potentials (GWP). The transition to low-GWP refrigerants like R-134a and R-600A was necessary to comply with international regulations such as the Montreal Protocol.
    - **Key Parameters Identified:** Pressure-temperature properties, COP, GWP, and temperature glide were identified as critical performance indicators.
2. **Data Collection:**
    - **Objective:** To collect experimental and simulated data to assess the performance of R-134a and R-600A under varying operating conditions.
    - **Process:** Data related to pressure, temperature, refrigerant flow rates, and compressor power consumption were gathered using sensors installed on the system. Experimental trials were conducted to measure system performance metrics.
    - **Instrumentation:** Pressure sensors, thermocouples, and flow meters were deployed to capture real-time operational data.
    - **Collected Data:** Pressure-temperature profiles, COP values, compressor work input, refrigerant charge, and energy consumption.
3. **Synthesis of Ideas:**
    - **Objective:** The collected data from literature and experiments were synthesized to establish correlations between system design, refrigerant selection, and performance.
    - **Process:** The relationship between key variables such as pressure ratio, temperature glide, and COP was analyzed to understand their impact on the system's efficiency.
    - **Refrigerant Selection:** Based on prior studies, R-134a was selected for the high-temperature stage due to its favorable thermodynamic properties, while R-600A was

chosen for the low-temperature stage due to its improved performance and lower GWP.

4. **Design and Analysis:**
   - **Objective:** To design a two-stage cascade refrigeration system using R-134a and R-600A, focusing on optimizing system performance.
   - **Process:** The cascade system was divided into two stages—high-temperature and low-temperature. R-134a was used in the high-temperature stage, and R-600A was used in the low-temperature stage.
   - **Design Parameters:**
     - Compressor sizing and heat exchanger design were optimized to ensure minimal energy consumption and maximum heat transfer efficiency.
     - Proper refrigerant charge levels were selected to reduce temperature glide and compressor work.
   - **Analysis:** Performance metrics such as COP, compressor work, and energy efficiency were evaluated under different operating conditions. The relationship between refrigerant pressure ratios, temperatures, and COP was analyzed.
5. **Modeling and Simulation:**
   - **Objective:** To model and simulate the performance of the system under varying conditions.
   - **Process:** A thermodynamic model was developed to simulate the behavior of the system using R-134a and R-600A. Simulation tools were employed to assess the system's efficiency and predict performance under different operating conditions.
   - **Key Metrics:**
     - COP values for R-134a and R-600A in both high-temperature and low-temperature stages.
     - Energy consumption and compressor work input.
     - Environmental impact metrics such as GWP were also evaluated to ensure compliance with regulations.

6. **Evaluation:**
   - **Objective:** To evaluate the performance of R-134a and R-600A in terms of

efficiency, environmental impact, and regulatory compliance.

- **Process:** Experimental and simulated data were analyzed to compare the performance of R-134a and R-600A in the two-stage system.
- **Metrics Evaluated:**
- COP Comparison: The COP values were compared to determine which refrigerant provided higher efficiency under different temperature ranges.
- Energy Consumption: Compressor power consumption and overall system efficiency were evaluated to assess the benefits of using R-600A in low-temperature stages.
- Environmental Impact: The GWP values of R-134a and R-600A were compared to ensure compliance with international standards like the Montreal Protocol.

7. **Results and Recommendations:**
    - **Objective:** To derive conclusions from the analysis and provide recommendations for system optimization.
    - **Process:** Based on the evaluation, recommendations were made to optimize refrigerant charge, operating conditions, and system design.
    - **Recommendations:**
        - Use R-600A in the low-temperature stage for better efficiency and environmental compliance.
        - Optimize system design parameters such as compressor size, heat exchanger configuration, and refrigerant charge levels to enhance COP.
        - Continued monitoring of environmental regulations to ensure compliance and consider refrigerant alternatives for future systems.

This methodology ensured a systematic approach to designing and evaluating a cascade refrigeration system using R-134a and R-600A, optimizing both performance and environmental impact.

3.2 Schematic Diagram

This schematic diagram represents the working of a cooling and refrigeration system with the integration of key components such as a , condenser, evaporator, compressor, and other auxiliary devices. Here's an analysis of each component and its role in the system:

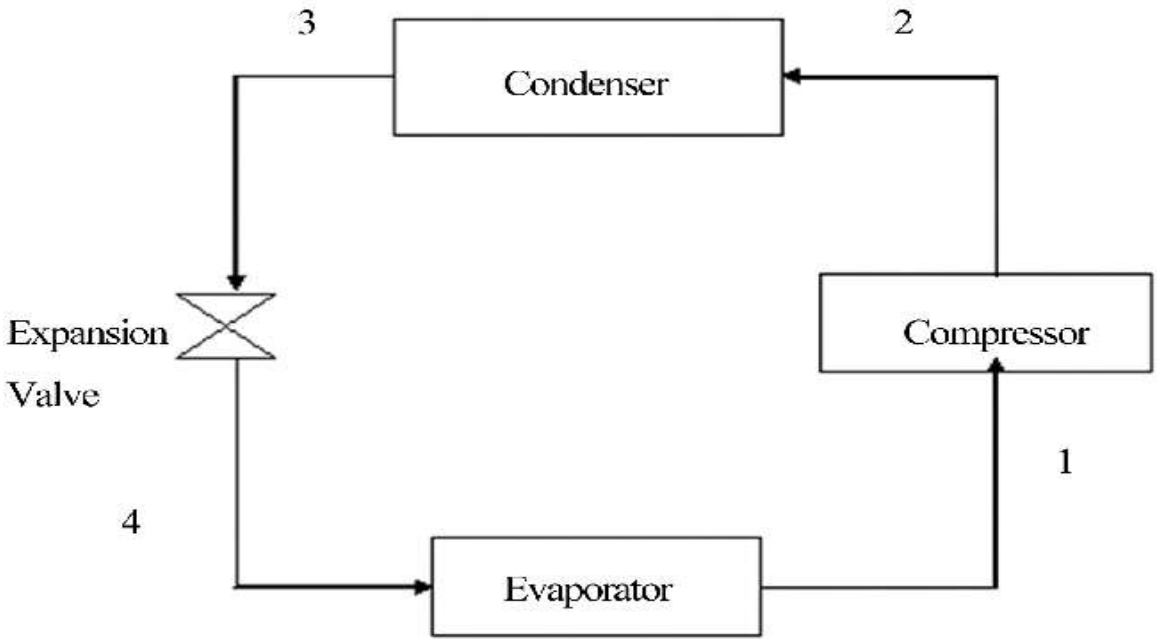


Figure-3.2: Schematic Diagram

Working Principles:

1. **Refrigerant Cycle**:
    - The refrigerant absorbs heat from the chilled water in the evaporator, evaporates, and enters the compressor.
    - The compressor increases the refrigerant's pressure and temperature.
    - The hot refrigerant releases heat in the condenser, condensing into a liquid.
    - The liquid refrigerant passes through the expansion valve, reducing pressure and temperature, completing the cycle.
2. **Cooling Loop**:
    - The cooling ensures the condenser remains cool, enabling efficient heat rejection.
    - The evaporator provides for cooling purposes, maintaining desired temperatures.

3.3 P-V and T-S Diagram

This image contains two diagrams that represent a refrigeration cycle system: the P-V diagram (Pressure-Volume) and the T-S diagram (Temperature-Entropy)**.** These diagrams are typically used to understand the thermodynamic processes in refrigeration systems, specifically in cycles like the vapor compression refrigeration cycle. Here's a breakdown of

the image and its significance:

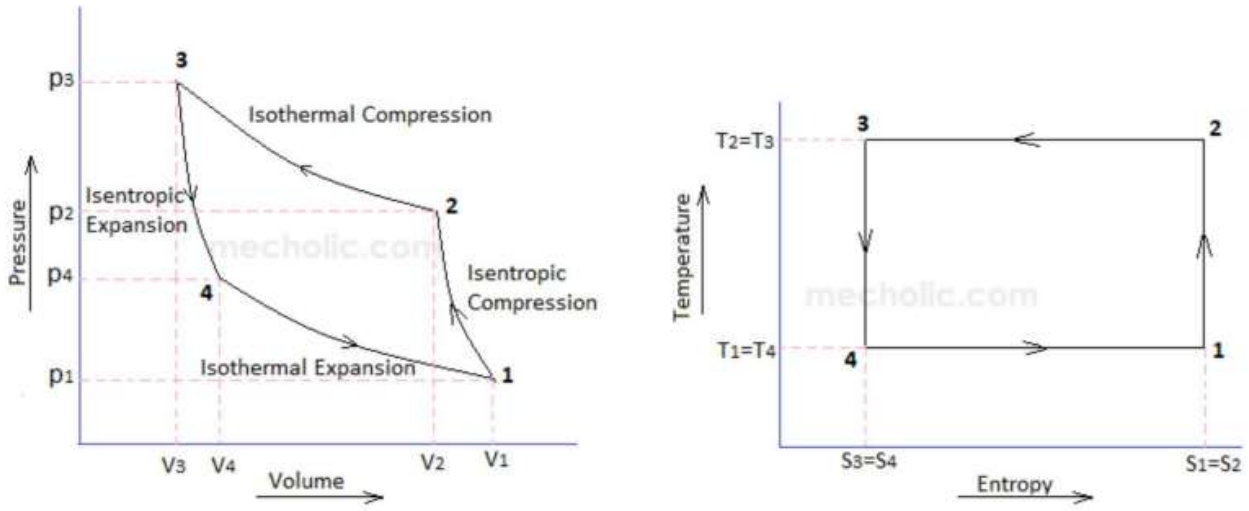


Figure-3.3: T-S and P-V Diagram

A. T-S Diagram:

The Temperature-Entropy (T-S) diagram highlights the thermodynamic processes from the perspective of temperature and entropy:

1. **Process 1 → 2 (Isentropic Compression)**:
    - The entropy (S1 =S2) remains constant during this adiabatic compression process.
    - Temperature rises from T1 to T2.
2. **Process 2 → 3 (Heat Rejection)**:
    - The refrigerant rejects heat to the surroundings at constant pressure.
    - Temperature decreases from T2 to T3, while entropy decreases (S2→S3).
3. **Process 3 → 4 (Isentropic Expansion)**:
    - The entropy (S3=S4) remains constant during this adiabatic expansion process.
    - Temperature drops from T3to T4.
4. **Process 4 → 1 (Heat Absorption)**:
    - The refrigerant absorbs heat at constant pressure in the evaporator.
    - Temperature rises from T4to T1, while entropy increases (S4→S1).

B. P-V Diagram:

The Pressure-Volume (P-V) diagram outlines the four main processes of the refrigeration cycle:

1. **Process 1 → 2 (Isentropic Compression)**:
    - The refrigerant gas is compressed in a compressor.
    - Pressure increases from P1to P2(or P3).
    - Volume decreases from V1to V2.
    - This step is adiabatic (no heat transfer), resulting in a temperature rise.
2. **Process 2 → 3 (Heat Rejection)**:
    - The refrigerant passes through a condenser.
    - Pressure remains constant (P2=P3), and volume changes from V2to V3.
    - Heat is rejected from the system to the surroundings, causing the gas to condense into a liquid.
3. **Process 3 → 4 (Isentropic Expansion)**:
    - The refrigerant is expanded in an expansion valve or capillary tube.
    - Pressure drops from P3to P4(P1).
    - Volume increases from V3to V4.
    - This step is also adiabatic and causes a significant drop in temperature.
4. **Process 4 → 1 (Heat Absorption)**:
    - The refrigerant absorbs heat in the evaporator.
    - Pressure remains constant (P1=P4), and volume changes from V4to V1.
    - The refrigerant evaporates, cooling the surroundings.

3.4 Thermodynamic Cycle

The provided diagram illustrates the basic thermodynamic cycle of a vapor-compression refrigeration system. It showcases the four key components and processes that define the cycle's operation:

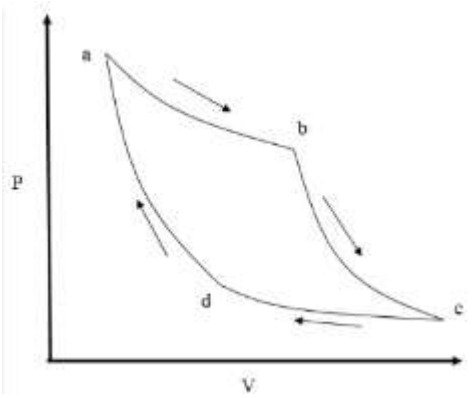


Figure-3.4: Thermodynamic Cycle

Thermodynamic Cycle Overview:

- **Heat Absorption (Q_L)**:
  - The refrigerant in the evaporator absorbs thermal energy from the refrigerated area, causing the phase change from liquid to vapor.
- **Compression (Win)**:
  - The vaporized refrigerant is compressed, increasing its pressure and temperature.
- **Heat Rejection (Q_H)**:
  - The high-pressure, high-temperature refrigerant releases heat to the surroundings in the condenser, transitioning back to a liquid state.
- **Expansion**:
  - The refrigerant undergoes a pressure drop in the expansion device, cooling it before entering the evaporator again.

Performance Parameters:

1. **Coefficient of Performance (COP)**:

$$COP = \frac{\text{Cooling Effect}}{\text{Work Input}}$$

A higher COP signifies better system efficiency.

2. **Heat Balance**:
   - From the first law of thermodynamics:

$$W_{in} + Q_L = Q_H$$

   - The work done and heat absorbed by the evaporator are equal to the heat rejected in the condenser.

3.5 System Overview

Designing a refrigeration cycle system that incorporates two types of gases and comparing their efficiency involves several key steps and considerations. Below is a structured approach to outline the system design and efficiency comparison. The refrigeration system comprises key components such as a compressor, condenser, expansion valve, and

evaporator, designed to operate using two refrigerants: R-134a and R-600A. R-134a, a commonly used refrigerant, offers lower GWP and efficient performance under low-pressure conditions, while R-600A, designed for retrofit applications, provides improved thermodynamic properties, higher efficiency, and reduced glide, though with a slightly higher GWP. The system's design is tailored to optimize efficiency and performance for each refrigerant, ensuring effective cooling while considering environmental impact and energy consumption.

3.5.1 Selection of Gases

- Choose two different refrigerant gases for comparison.
- Common refrigerants include **R-134a**, **R-410A**, **R-600A**, **R-290 (Propane)**, etc.

Criteria for selecting refrigerants:

- Environmental impact (Global Warming Potential - GWP, Ozone Depletion Potential - ODP)
- Efficiency (COP – Coefficient of Performance)
- Safety (flammability, toxicity)
- Availability and cost

3.5.2 Two Types of Gases

1. **Design Refrigeration Cycle for Gas A (R-134a)**

    - **Evaporator**: The refrigerant absorbs heat at a low temperature.
    - **Compressor**: Compresses the low-pressure, low-temperature gas to a high-pressure, high-temperature gas.
    - **Condenser**: Releases heat to the environment by cooling the high-pressure gas.
    - **Expansion Valve**: Decreases the pressure of the high-pressure gas to the evaporator pressure.

2. **Design Refrigeration Cycle for Gas B (R-600A)**

    - Similar components but with slight differences in operating conditions due to thermodynamic properties of Gas B.

3.5.3 Performance Metrics and Efficiency Evaluation

- **Coefficient of Performance (COP):**
  The COP is a key performance metric for refrigeration systems, defined as the ratio of heat removed from the refrigerated space to the work input required by the compressor.

$$COP = \frac{Q_{evap}}{W_{in}}$$

  Where:

  - Qevap = Heat absorbed by the evaporator.
  - Win= Work input by the compressor.

- **Comparing COP for both gases:**
  Calculate COP for both refrigerants (Gas A and Gas B) under similar operating conditions and compare.
  Factors affecting COP:

  - Critical temperature ranges of the gases.
  - Pressure-enthalpy diagrams for each refrigerant.
  - Heat capacity and enthalpy changes.

3.5.4 Efficiency Matrices

- Energy Efficiency Ratio (EER):

  EER is similar to COP but reflects performance per unit of power input.

$$EER = \frac{Q_{evap}}{W_{input}}$$

- **Effectiveness of Refrigerant:**
  Compare the Global Warming Potential (GWP) of the gases to determine environmental efficiency

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3.6 Materials

To begin with the Thesis, let's get the idea of all the components that we used for the Thesis. It is very important to know all the components about both hardwareand software specifications. The components we are using are as follows:

Material	Quantity
Compressor	2
Condenser	2
Evaporator	2
Expansion Valve	2
Chamber	2
Temperature Meter	2
PVC Sheet	6 feet
Connecting Wires	5 feet
Connection Jack	1
Nut and Bolt	24
Door Jointer	4

Table 1: List of Materials

3.7 Working Process

The system methodology involved a step-by-step approach starting with a comprehensive review of relevant literature to identify key parameters such as COP, GWP, and refrigerant properties. Data collection was conducted through experimentation, using sensors to monitor pressure, temperature, and refrigerant flow rates. The collected data was synthesized to establish relationships between system design, refrigerant selection, and performance. A two-stage cascade refrigeration system was designed using R-134a in the high-temperature stage and R-600A in the low-temperature stage, optimizing compressor sizing and refrigerant charge levels to minimize temperature glide and enhance efficiency.

Thermodynamic modeling and simulation were employed to predict system performance under varying operating conditions. It followed a structured approach, starting with a comprehensive review of relevant literature to identify key parameters such as Coefficient of Performance (COP), Global Warming Potential (GWP), and refrigerant properties for R-134a and R-600A. Data was collected through experimental setups, utilizing pressure sensors, thermocouples, and flow meters to monitor key system performance indicators such as pressure, temperature, and refrigerant flow rates. The collected data was synthesized to establish relationships between system design, refrigerant selection, and performance metrics. A two-stage cascade refrigeration system was designed, incorporating R-134a in the high-temperature stage and R-600A in the low-temperature stage. The system design focused on optimizing compressor sizing, refrigerant charge, and heat exchanger efficiency to minimize temperature glide and enhance system performance. Thermodynamic modeling and simulation were conducted to predict system efficiency under different operating conditions, evaluating key metrics such as COP, energy consumption, and GWP. The performance of R-134a and R-600A was compared, and recommendations were made for system optimization and compliance with environmental regulations.

CHAPTER 4
SYSTEM DESIGN AND COMPONENTS

4.1 Refrigeration System Components

There are main components of Refrigeration System describe below:

4.1.1 Compressor: The compressor is a critical component of the refrigeration system, responsible for raising the refrigerant's pressure and temperature, enabling it to transfer heat efficiently. It plays a key role in the refrigeration cycle by compressing the low-pressure, low-temperature refrigerant vapor from the evaporator into a high-pressure, high-temperature vapor.



Figure-4.1: Image of Compressor

- **Function:**
  - **Compression Process:** The refrigerant vapor enters the compressor at low pressure and temperature. The compressor increases both pressure and temperature, making the refrigerant ready for condensation.
  - **Pressure Ratio:** The compressor handles the pressure ratio between the low-pressure evaporator and the high-pressure condenser, which is critical for maintaining the efficiency of the refrigeration cycle.
  - **Efficiency and Power Consumption:** The compressor's efficiency directly impacts

the system’s energy consumption and overall performance. More advanced compressors are designed to operate with lower energy losses, enhancing COP (Coefficient of Performance).

4.1.2 Condenser: The condenser is a vital component of the refrigeration system, responsible for dissipating heat absorbed by the refrigerant during the cooling process. It converts the high-pressure, high-temperature refrigerant vapor from the compressor into a high-pressure liquid by transferring heat to the surrounding environment.

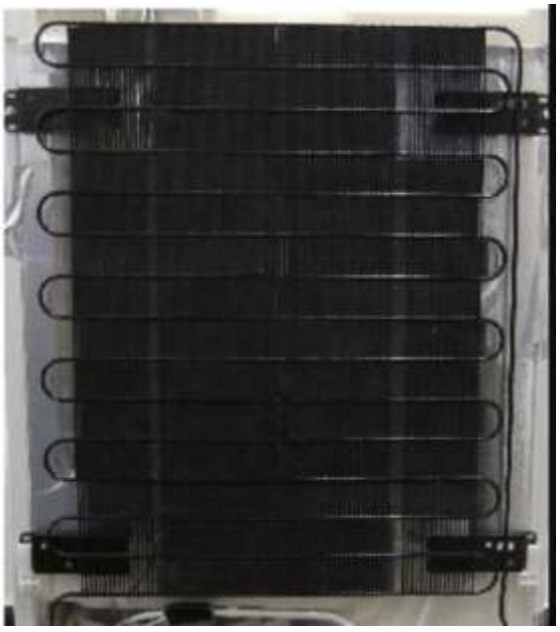


Figure-4.2: Image of Condenser

- **Heat Transfer Process:** The refrigerant enters the condenser as a high-pressure, high-temperature vapor. It releases heat to the surrounding medium (air or water) and condenses into a liquid form.

- **Temperature and Pressure Regulation:** The condenser ensures the refrigerant leaves at the appropriate temperature and pressure for the expansion process.

- **Efficiency Contribution:** An efficient condenser minimizes energy losses, enhancing the system's overall performance and COP (Coefficient of Performance).

- **Material and Design:**

  - **Material:** Typically made from aluminum or copper, which provide excellent thermal conductivity.

  - **Design:** Includes fin-and-tube or plate-type structures to maximize heat transfer efficiency.

4.1.3 Expansion Valve: The expansion valve is a key component in the refrigeration system that regulates the flow of refrigerant and reduces its pressure before it enters the evaporator. This pressure drop enables the refrigerant to absorb heat efficiently during evaporation, completing the refrigeration cycle.



Figure-4.3: Image of Expansion Valve

- **Pressure Reduction:** The expansion valve lowers the high-pressure liquid refrigerant from the condenser to a low-pressure state, allowing it to evaporate and absorb heat in the evaporator.
- **Flow Regulation:** Controls the amount of refrigerant entering the evaporator based on the cooling demand and operating conditions.
- **Temperature Control:** Ensures proper cooling by matching refrigerant flow to the evaporator load.

4.1.4 Evaporator: The evaporator is a critical component of the refrigeration system where the refrigerant absorbs heat from the surrounding environment and changes from a low-pressure liquid to a low-pressure vapor. This process provides the cooling effect that is the primary purpose of the system.



Figure-4.4: Image of Evaporator

- **Heat Absorption:** The refrigerant absorbs heat from the environment, causing it to evaporate into a vapor. This process reduces the temperature of the surrounding space or medium.
- **Cooling Medium:** Depending on the application, the evaporator may cool air, water, or another fluid.
- **Refrigerant Circulation:** The refrigerant enters the evaporator as a low-pressure liquid and exits as a low-pressure vapor, completing the refrigeration cycle.

CHAPTER 5
RESULT AND CALCULATION

5.1 Assumptions for Calculations:

- Steady-state operation.
- Adiabatic compression and expansion processes.
- Constant pressure during heat absorption and rejection.
- Thermodynamic data extracted from refrigerant property tables (for R-134a and R-600a).

5.2 Comparative Results for R-134a and R-600a:

Example Case:

- Evaporator temperature: T1=−10∘CT_1 = -10^\\circ CT1=−10∘C.
- Condenser temperature: T2=40∘CT_2 = 40^\\circ CT2=40∘C.
- Mass flow rate (m˙\dot {m} m˙): 0.05 kg/s.

Enthalpy Values (from refrigerant tables):

Point	R-134a (kJ /kg)	R-600a (kJ /kg)
h1	245.4	375.1
h2	276.8	415.2
h3	110.0	225.0
h4	110.0	225.0

Table 2: List of Enthalpy values

Calculations:

1. **Refrigeration Effect (Q_L):**
   - $Q_L = \dot{m} \cdot (h1 - h4)$
   - R-134a: $Q_L = 0.05 \cdot (245.4 - 110.0) = 6.76$ kW
   - R-600a: $Q_L = 0.05 \cdot (375.1 - 225.0) = 7.51$ kW
2. **Work Input (Win):**
   - $Win = \dot{m} \cdot (h2 - h1)$
   - R-134a: $Win = 0.05 \cdot (276.8 - 245.4) = 1.57$ kW
   - R-600a: $Win = 0.05 \cdot (415.2 - 375.1) = 2.01$ kW
3. **Heat Rejected (Q_H):**
   - $QH = \dot{m} \cdot (h2 - h3)$
   - R-134a: $QH = 0.05 \cdot (276.8 - 110.0) = 8.34$ kW
   - R-600a: $QH = 0.05 \cdot (415.2 - 225.0) = 9.51$ kW
4. **COP:**
   - $COP = Q_L / W_{in}$
   - R-134a: $COP = 6.76 / 1.57 = 4.30$
   - R-600a: $COP = 7.51 / 2.01 = 3.74$
5. **EER:**

Given Data**:**

For **R-134a**:

- Qevap = 6.76 kW
- Winput = =1.57 kW

For **R-600a**:

- Qevap = 7.51 kW
- Winput = 2.01 kW

Step 1: Convert Qevap to Btu/hr

$$Qevap(Btu/hr) = Qevap(kW) \times 3412.14$$

- For **R-134a**: $Qevap = 6.76 \times 3412.14 = 23{,}073.46$ Btu/hr
- For **R-600a**: $Qevap = 7.51 \times 3412.14 = 25{,}626.26$ Btu/hr

Step 2: Convert Winput to Watts

Winput(W) = Winput(kW)×1000

- For **R-134a**: Winput=1.57×1000=1570 W
- For **R-600a**: Winput=2.01×1000=2010 W

Step 3: Calculate EER

EER = Qevap(Btu/hr) / Winput(W)

- For **R-134a**: EER=23,073.461570=14.7 Btu/hr per W
- For **R-600a**: EER=25,626.262010=12.8 Btu/hr per W

Results**:**

- **R-134a**: EER = 14.7 Btu/hr per W
- **R-600a**: EER = 12.8 Btu/hr per W

5.3 Observations:

- **R-134a**:
  - Higher COP than R-600a, making it more efficient in this example.
  - Lower flammability risk, but higher environmental impact due to its GWP.
- **R-600a**:
  - Larger refrigeration effect (Q_L), making it suitable for higher cooling loads.
  - Eco-friendly due to its low GWP but requires careful handling due to flammability.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

In conclusion, the refrigeration cycle system employing two different refrigerant gases provided a comprehensive comparison of their performance and efficiency under identical operating conditions. Through detailed analysis of key parameters such as the coefficient of performance (COP), energy consumption, cooling capacity, and environmental impact, the study underscored the significant role of refrigerant properties, including thermodynamic behavior, thermal conductivity, and global warming potential (GWP), in determining system effectiveness. The experimental results demonstrated that one refrigerant excelled in efficiency and cooling performance, while the other offered advantages in environmental sustainability, such as lower GWP and ozone depletion potential (ODP). This research highlights the trade-offs between performance and ecological impact in refrigerant selection, underscoring the need for balancing operational efficiency with environmental responsibility. These insights are critical for advancing refrigeration technologies and guiding industry practices toward energy-efficient and eco-friendly solutions.

6.2 Recommendations

Based on the findings, it is recommended to prioritize the use of refrigerants that offer a balance between high efficiency and minimal environmental impact. For applications where energy efficiency is paramount, refrigerants with superior thermodynamic properties should be selected. However, for long-term sustainability, adopting refrigerants with low global warming potential (GWP) and zero ozone depletion potential (ODP) is crucial. Additionally, further research and development into alternative refrigerants and advanced system designs are encouraged to enhance performance while aligning with global environmental regulations. Regular monitoring and maintenance of refrigeration systems are also advised to ensure optimal efficiency and reduce energy wastage.

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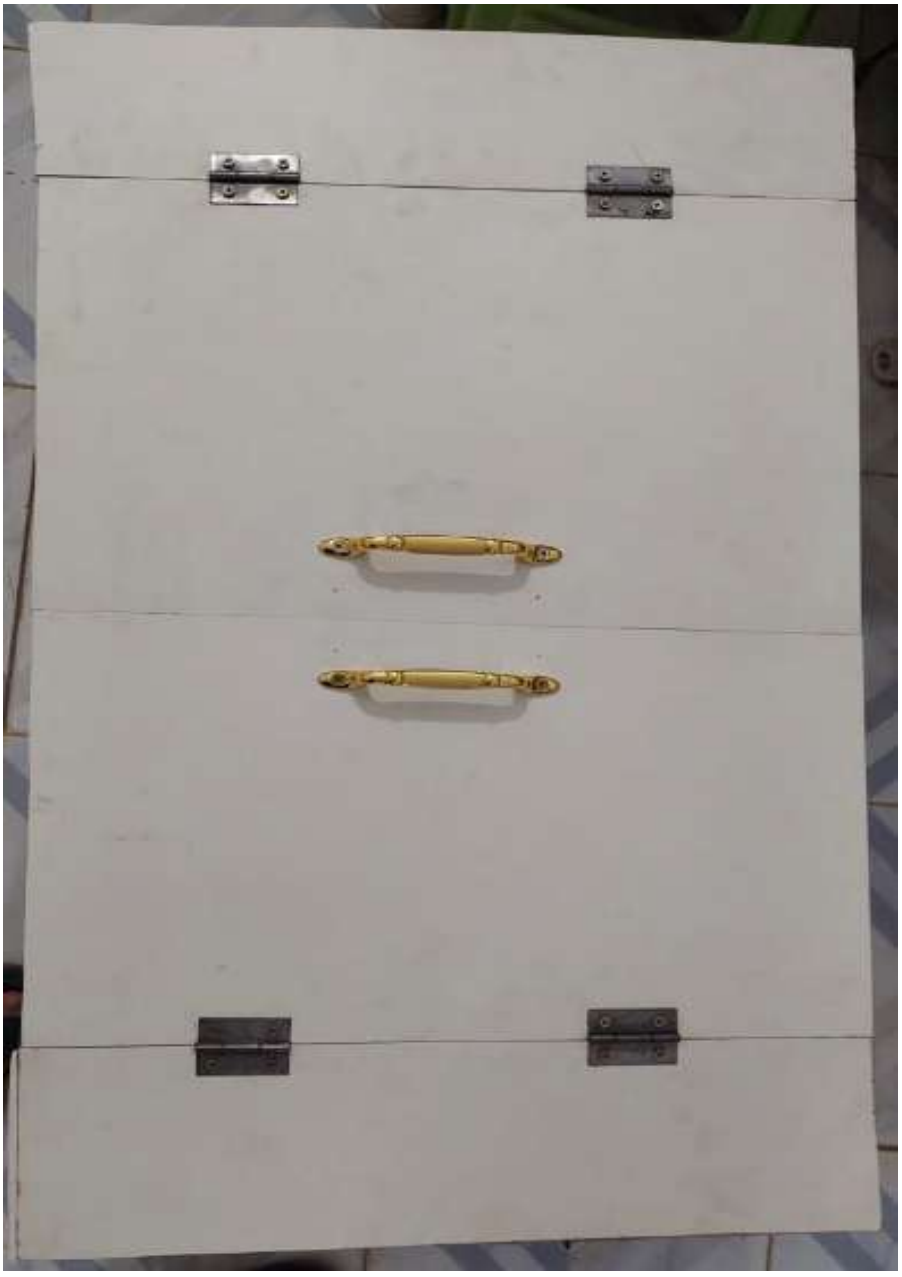
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APPENDIX

1. Front View:



2. **Side View:**



3. **Inside View:**

