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EXPERIMENTAL PERFORMANCE ON CAPILLARY TUBE LENGTH WITH VARIOUS REFRIGERANTS MIXTURE TO INCREASE THE COEFFICIENT OF PERFORMANCE (COP) OF REFRIGERATION SYSTEM

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ABSTRACT:

Capillary tubes are commonly used expansion devices in refrigeration systems. Their primary function is to reduce the higher pressure of the working fluid from the condenser pressure to the evaporator pressure. This project investigates the experimental performance of capillary tubes of various lengths with different refrigerants to enhance the coefficient of performance (COP) of refrigeration systems.

The study utilizes environmentally friendly refrigerants, R134a (Tetrafluoroethane), and R600a (Isobutane), known for their zero ozone depletion potential (ODP) and low global warming potential (GWP). The thermodynamic performance of the system is experimentally analyzed by simultaneously varying the refrigerants and the length of the capillary tube (L). The experiments are conducted with capillary tubes of different lengths, specifically 6 feet and 9 feet, while keeping the diameter of each test section constant.

The impact of varying capillary tube lengths on the overall performance of the system is evaluated. Results indicate that refrigerant R134a exhibits higher refrigeration effect, coefficient of performance, and lower power consumption compared to refrigerant R600a. The refrigeration effect of the system is determined and analyzed.

Key words: Helical capillary tube, Refrigerants.

1. INTRODUCTION:

A capillary tube is a long, narrow tube used in refrigeration systems, known for its absence of moving parts. This feature offers several advantages, including minimal wear and tear and the maintenance of equilibrium pressure in the system when it stops, reducing the load on the engine.

Recent advancements in capillary tube projects involve the use of larger diameter and longer tubes, which are less susceptible to blockages from dirt, ice, and wax. These larger diameter capillaries are commonly employed in air conditioning systems.

Advantages and disadvantages of capillary tubes:

Some advantages of capillary tubes include their low cost, lack of moving parts requiring maintenance, and provision of an open connection between the condenser and evaporator. This allows pressure equalization during off-cycle periods, reducing the starting torque requirement of the motor and enabling the use of motors with low starting torque.

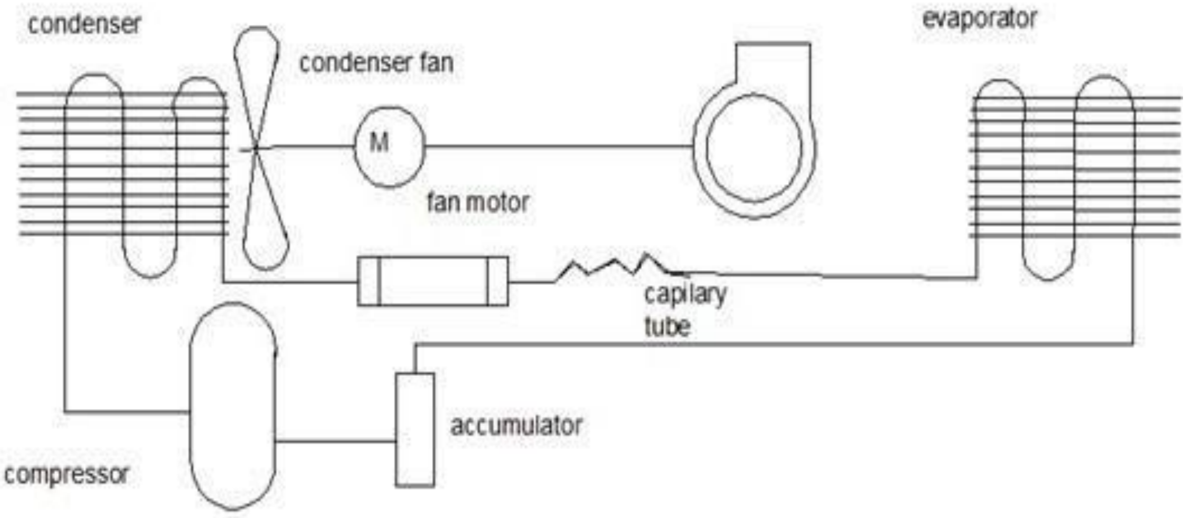


Fig 1: schematic layout of components

Working Principle of Capillary Tube:

When the refrigerant leaves the condenser and enters the capillary tube, its pressure experiences a sudden drop due to the very small diameter of the capillary. This pressure reduction occurs not due to an orifice, but rather due to the small opening of the capillary tube.

Literature Review:

Paliwal and Kant (2006) developed a flow model to design and study the performance of helical coiled capillary tubes. They considered homogeneous flow of two-phase fluid through the adiabatic capillary tube, including various parameters like condenser and evaporator pressures, refrigerant flow rate, degree of subcooling, tube diameter, internal roughness, pitch, and length of the capillary tube.

Akintunde (2007) investigated the effect of different geometries of capillary tubes and studied the impact of pitches of both helical and serpentine coiled capillary tubes on the performance of vapor compression refrigeration systems. They developed correlations to describe relationships between straight and coiled capillary tubes, and between helical coiled and serpentine coiled capillary tubes.

Park et al. (2008) simulated the effects of a non-adiabatic capillary tube on refrigeration cycles, focusing on capillary tube-suction line heat exchangers (CT-SLHX). Their simulation, based on fundamental conservation equations of mass and energy, showed that both the location and length of the heat exchange section influence the coefficient of performance (COP) of the system.

Santhosh Kumar Dubba et al. conducted experimental investigations on straight and helically coiled capillary tubes with different inlet subcooling degrees and varying pressures. They discussed the effects of capillary tube diameter, subcooling degree, and inlet pressure on mass flow rate, finding that the mass flow rate in straight capillary tubes was higher compared to coiled capillary tubes.

Pravin Jadhav et al. conducted numerical studies on straight and spiral capillary tubes using CO2 and R22 refrigerants. They found that for similar operating conditions, the mass flow rate and length of the tube were significantly larger in the case of CO2 refrigerant compared to R22 refrigerant.

Sudharash Bhargava and Jagdev Singh experimentally investigated the effects of pitch and length of serpentine coiled adiabatic capillary tubes on the flow of an eco-friendly gas. They used an azeotropic blend as a refrigerant and measured mass flow rates for different capillary tubes with different lengths and pitches, also examining straight capillary tubes.

PROBLEM DESCRIPTION:

Previous studies have primarily focused on variations in refrigerants and geometric parameters (compressor, condenser, and evaporator). However, there is a gap in understanding the thermodynamic properties of refrigerants and materials. This study addresses this gap by investigating the performance of a mixture of refrigerants, such as R134a and R600, in a vapor compression refrigeration system. The aim is to control temperature and pressure using different lengths of capillary tubes while prioritizing eco-friendliness, specifically targeting refrigerants with zero ozone depletion potential (ODP) and low global warming potential (GWP). The goal is to enhance the coefficient of performance (COP) and reduce power consumption.

OBJECTIVE:

1. Enhance the coefficient of performance of the refrigeration system.
2. Decrease the power consumption of the system.

METHODOLOGY:

The refrigeration process performance is evaluated based on the following phases:

- Saturated vapor refrigerant phase before entering the compressor.
- Superheated refrigerant phase after the compressor.

- Saturated liquid phase before entering the capillary tube.
- Mixture refrigerant phase after entering the capillary tube.

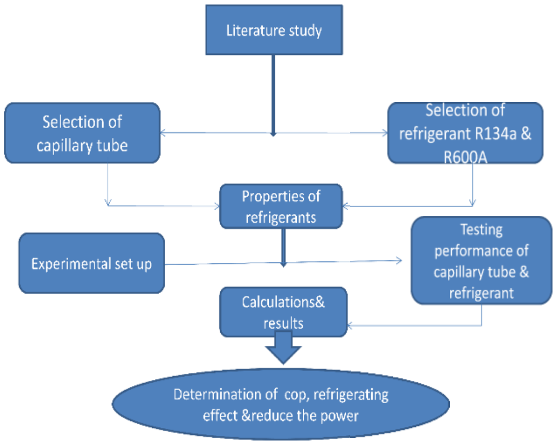
The study compares the refrigeration performance of capillary tubes with different diameters under various load conditions. Instead of an orifice, a capillary tube with a small diameter is used for fluid expansion. The inside diameter of the capillary tube typically ranges from 0.5 mm to 2.30 mm, with longer tubes or smaller diameters resulting in greater pressure drops and flow rate control.

Experimental Setup:

The vapor compression refrigeration system comprises several components:

- Compressor
- Condenser
- Expansion device
- Evaporator

Flowchart



The performance of the refrigeration process involves several phases:

1. **Saturated Vapor Refrigerant Phase before Entering Compressor:** At this stage, the refrigerant is in a saturated vapor state before it enters the compressor. It has absorbed heat from the surroundings and evaporated, transitioning from a liquid to a vapor. This saturated vapor refrigerant phase is crucial for efficient compression in the compressor.
2. **Superheated Refrigerant Phase after Compressor:** After the refrigerant is compressed in the compressor, it enters a superheated phase. Superheating refers to the process of further increasing the temperature of the refrigerant vapor beyond its saturation point. This phase occurs after the compression process and is necessary for maximizing the refrigeration effect.
3. **Saturated Liquid Phase before Entering Capillary Tube:** Before entering the capillary tube, the refrigerant undergoes a phase change from superheated vapor to saturated liquid. This phase transition occurs as the high-pressure, high-temperature refrigerant passes through a condenser, where it loses heat and condenses into a saturated liquid state.

4. **Mixture Refrigerant Phase after Entering Capillary Tube:** Upon entering the capillary tube, the refrigerant undergoes expansion, leading to a decrease in pressure and temperature. This expansion causes a phase change from saturated liquid to a mixture of liquid and vapor. The refrigerant exits the capillary tube as a mixture phase, ready to absorb heat in the evaporator and repeat the refrigeration cycle.

Each phase of the refrigeration process plays a critical role in the overall efficiency and performance of the system, ensuring effective heat transfer and temperature control throughout the refrigeration cycle.

5. Experimental Setup: Vapor Compression Refrigeration System

The experimental setup comprises the following components arranged to create a vapor compression refrigeration system:

1. **Compressor:** The compressor is responsible for compressing the refrigerant vapor, increasing its pressure and temperature. This high-pressure, high-temperature vapor is then condensed in the condenser.
2. **Condenser:** The condenser is where the high-pressure, high-temperature refrigerant vapor releases heat to the surroundings, causing it to condense into a saturated liquid state. Heat transfer occurs as the refrigerant exchanges heat with a cooling medium (e.g., air or water) flowing over the condenser coils.
3. **Expansion Device:** The expansion device, often a capillary tube or thermal expansion valve, is located between the condenser and the evaporator. Its role is to regulate the flow of refrigerant into the evaporator, causing a pressure drop and enabling the refrigerant to expand and cool.
4. **Evaporator:** The evaporator is where the low-pressure, low-temperature liquid refrigerant absorbs heat from the surroundings (e.g., air or water) and evaporates into a low-pressure vapor. This process results in cooling, making the evaporator coil cold to facilitate heat exchange.

The vapor compression refrigeration system operates on the principle of cyclic refrigeration, where the refrigerant undergoes successive compression, condensation, expansion, and evaporation phases to achieve cooling. Heat transfer occurs at the condenser and evaporator, enabling the removal of heat from the refrigerated space.

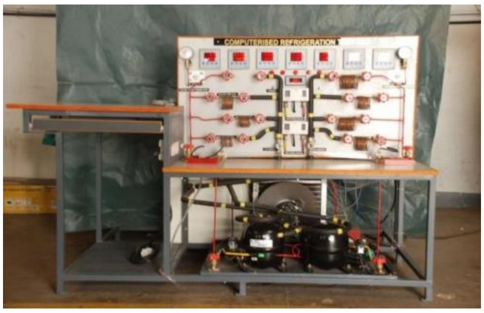


Fig: Schematic Diagram of Refrigeration System

This setup facilitates the investigation of different capillary tube lengths and diameters, allowing for the assessment of their impact on system performance.

Here is the table detailing the physical properties of HCF-134a refrigerant:

Physical Properties	**HCF-134a**
Boiling Point at 1atm	-15.34 °F (-26.3 °C)
Freezing Point	-153.9 °F (-103.3 °C)
Critical Temperature	213.9 °F (101.1 °C)
Critical Pressure	4060 kPa (588.9 lb./in^2)
Critical Volume	1.94 × 10^-3 m^3/kg
Critical Density	515.3 kg/m^3 (32.17 lb./ft^3)
Density (Liquid) at 25 °C (77 °F)	1206 kg/m^3 (75.28 lb./ft^3)
Density (Saturated Vapor) at boiling point	5.25 kg/m^3 (0.328 lb./ft^3)
Heat Capacity (Liquid) at 25 °C (77 °F)	0.339 kcal/kg·K or Btu/(lb.) (°F)

These properties provide essential information about the behavior and characteristics of HCF-134a refrigerant, which is crucial for designing and analyzing vapor compression refrigeration systems.

In which compressor, condenser, expansion valve and evaporator. Main component in refrigeration system is compressor, condenser, evaporator and throttling device.

REFRIGERANT R134a

Fig.R-134a Refrigerant

Refrigerant R134a (Tetrafluoroethene - CF_3CH_2F):

- Commonly known as Tetrafluoroethene, R134a belongs to the family of HFC (Hydrofluorocarbon) refrigerants.
- It has been widely used as a replacement for CFCs (Chlorofluorocarbons) and HCFCs (Hydrochlorofluorocarbons) due to the damaging effect of these compounds on the ozone layer.
- R134a is valued for its lower impact on the ozone layer and reduced contribution to global warming compared to older refrigerants.

Refrigerant R600a (Isobutane - $HC(CH_3)_3$):

- Also known as isobutane or 2-methylpropane, R600a is a chemical compound with the molecular formula HC(CH3)3.
- It is considered a possible replacement for other refrigerants, particularly in domestic refrigeration systems, due to its lower environmental impact.
- R600a is favored for its relatively low global warming potential (GWP) and zero ozone depletion potential (ODP), making it an environmentally friendly choice for refrigeration applications.

Both R134a and R600a are part of the effort to transition away from ozone-depleting substances and reduce the environmental impact of refrigeration systems.

Fig.R-600a Refrigerant

Table 3.2: Properties of R600a

Physical Properties	R600a
Boiling Point	-11.7°C (10.9°F)
Melting Point	-159.42°C (-254.96°F)
Critical Temperature	135°C
Critical Pressure	3.65 MPa
Vapour Pressure	204.8 kPa
Specific Heat of Liquid	2.38 kJ/kg°C
Density	2.51 kg/m³
Latent Heat of Evaporation	362.6 kJ/kg

Experimental Procedure of R-134a Performance Analysis:

1. Initially, ensure that all valves are in the closed position.
2. Install the capillary tube with the desired diameter (e.g., 1.1mm) and suitable length (e.g., 8 feet).
3. Evacuate the refrigeration circuit using a vacuum pump to remove any moisture content and other gas particles.
4. Charge the refrigerant R-134a into the circuit and check the refrigerant charge.
5. Switch on the apparatus and open the valve of the capillary tube.
6. Set the thermostat valve to its maximum condition.

7. Choose the desired evaporator temperature and start the timer.
8. Record the readings displayed on the digital indicator and note the time taken for every one-degree drop in temperature.
9. Repeat the process

Fig Refrigerant charging

Fig. Cutting of capillary tube at variable length

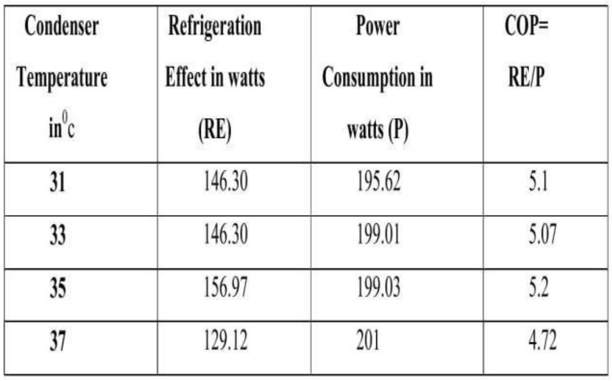
Fig. Shaping and brazing of capillary tube

Experimental Results

Tables:

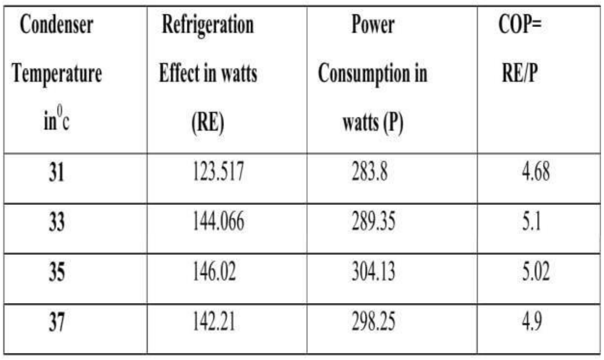
1. **Power Consumption and Refrigeration Effect at Different Condenser Temperatures and Capillary Tube Lengths for R134a**:
    - Present detailed data on power consumed and refrigeration effect for various combinations of condenser temperatures and capillary tube lengths using R134a refrigerant.

6.1 R134a Capillary length of 6-feet



Condenser Temperature in^{0}c	Refrigeration Effect in watts (RE)	Power Consumption in watts (P)	COP= RE/P
31	146.30	195.62	5.1
33	146.30	199.01	5.07
35	156.97	199.03	5.2
37	129.12	201	4.72

6.2 R600a Capillary length of 6-feet



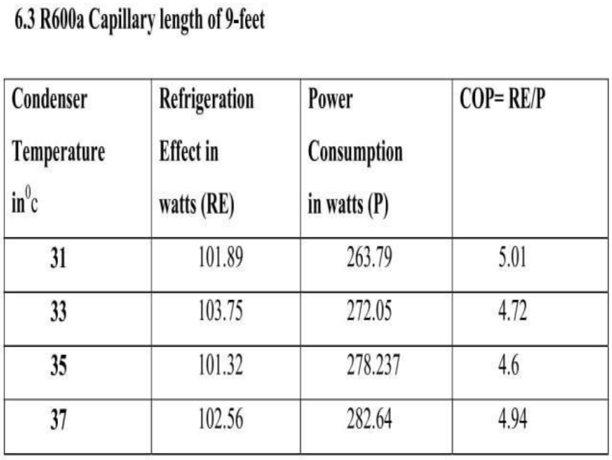
Condenser Temperature in^{0}c	Refrigeration Effect in watts (RE)	Power Consumption in watts (P)	COP= RE/P
31	123.517	283.8	4.68
33	144.066	289.35	5.1
35	146.02	304.13	5.02
37	142.21	298.25	4.9

Graphs:

1. **Comparison of Capillary Tube Lengths on System Performance**:
    - Graphically compare the performance of the system with different capillary tube lengths using R134a refrigerant. Plot the refrigeration effect and coefficient of performance (COP) against capillary tube length for easy visualization.
2. **Effect of Capillary Tube Length on Refrigeration System Performance**:

- Show how changing the length of the capillary tube affects the refrigeration system's performance. Graphically illustrate the relationship between capillary tube length and key performance parameters such as COP and refrigeration effect.

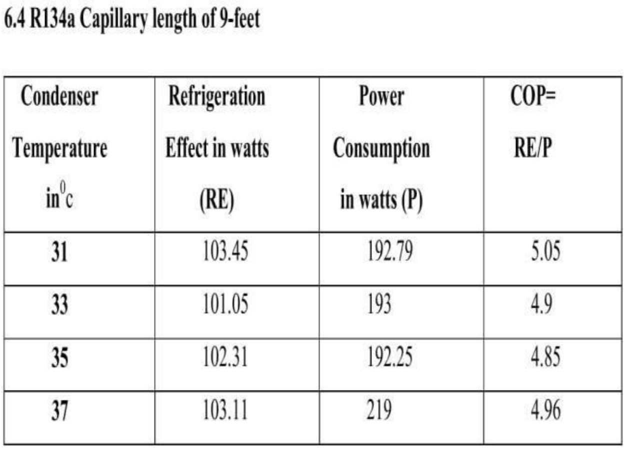
R600a Capillary length of 9-feet



6.3 R600a Capillary length of 9-feet

Condenser Temperature in^{0}c	Refrigeration Effect in watts (RE)	Power Consumption in watts (P)	COP= RE/P
31	101.89	263.79	5.01
33	103.75	272.05	4.72
35	101.32	278.237	4.6
37	102.56	282.64	4.94

R134a Capillary length of 9-feet



6.4 R134a Capillary length of 9-feet

Condenser Temperature in^{0}c	Refrigeration Effect in watts (RE)	Power Consumption in watts (P)	COP= RE/P
31	103.45	192.79	5.05
33	101.05	193	4.9
35	102.31	192.25	4.85
37	103.11	219	4.96

Analysis:

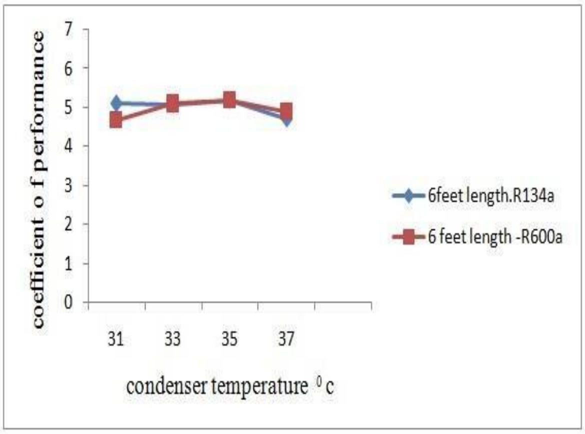
1. **Impact of Capillary Tube Length on System Performance**:
   - Analyze the data presented in the tables and graphs to determine the impact of capillary tube length on the power consumption and refrigeration effect of the system. Discuss any trends or patterns observed.
2. **Comparison of R134a and R600a Performance**:

- Compare the performance of the system using R134a refrigerant to that using R600a refrigerant. Discuss any significant differences in power consumption, refrigeration effect, or COP between the two refrigerants under various conditions.

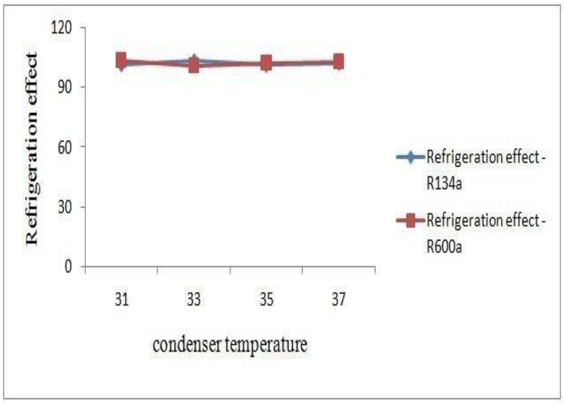
By structuring your experimental results section in this manner, you can effectively present and analyze the data collected during your research study on refrigeration systems using R134a refrigerant.

Capillary Tube 6-Feet Length

1. **Coefficient of Performance vs. Condenser Temperature:**
    - Graph compares the coefficient of performance (COP) of R134a and R600a refrigerants at different condenser temperatures (310°C, 330°C, 350°C, and 370°C). R134a exhibits higher refrigeration performance compared to R600a.

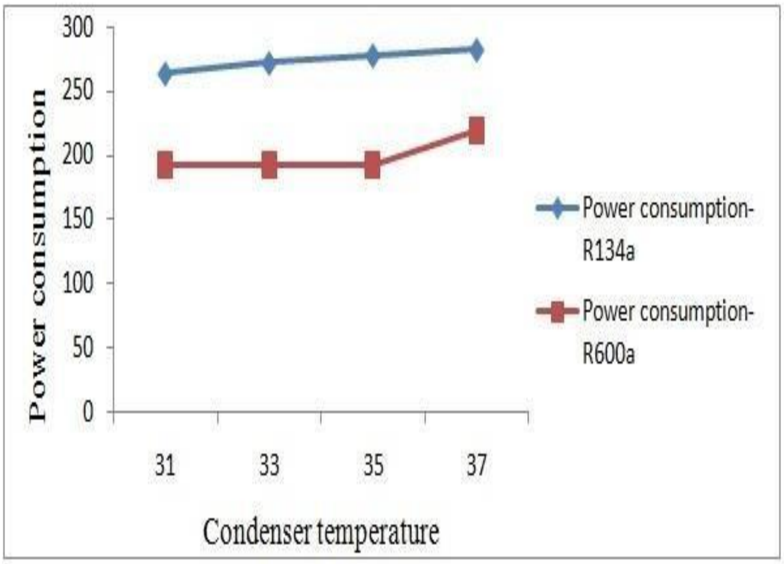


2. **Refrigeration Effect vs. Condenser Temperature:**
    - Graph compares the refrigeration effect of R134a and R600a refrigerants at various condenser temperatures. R134a demonstrates a higher refrigeration effect than R600a.
3. **Power Consumption vs. Condenser Temperatures:**
    - Graph illustrates the power consumption rates of R134a and R600a refrigerants at different condenser temperatures. R134a shows a higher power consumption rate compared to R600a.

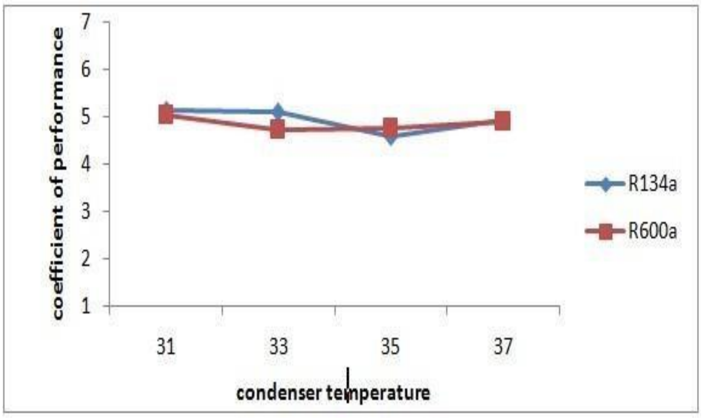


Capillary Tube 9-Feet Length

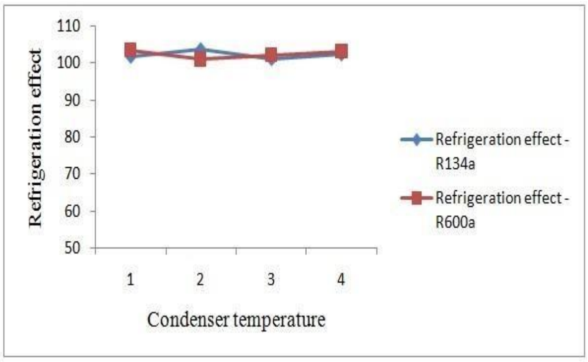
1. **Coefficient of Performance vs. Condenser Temperature:**
    - Graph compares the coefficient of performance (COP) of R134a and R600a refrigerants at different condenser temperatures. R134a performs better in refrigeration compared to R600a.



2. **Refrigeration Effect vs. Condenser Temperature:**
    - Graph shows the refrigeration effect of R134a and R600a refrigerants at various condenser temperatures. R600a exhibits a higher refrigeration effect than R134a.

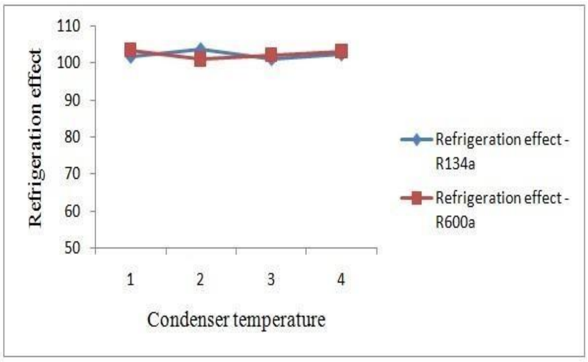


3. **Power Consumption vs. Condenser Temperature:**
    - Graph illustrates the power consumption rates of R134a and R600a refrigerants at different condenser temperatures. R134a shows a higher power consumption rate compared to R600a.



Comparison of 6-Feet and 9-Feet Lengths

1. **Coefficient of Performance vs. Condenser Temperature:**
   - Graph compares the coefficient of performance (COP) of R134a and R600a refrigerants with different capillary tube lengths at various condenser temperatures. R134a demonstrates better refrigeration performance than R600a.



2. **Refrigeration Effect vs. Condenser Temperature:**
   - Graph illustrates the refrigeration effect of R134a and R600a refrigerants with different capillary tube lengths at various condenser temperatures. R134a shows better refrigeration performance than R600a.
3. **Power Consumption vs. Condenser Temperature:**
   - Graph compares the power consumption rates of R134a and R600a refrigerants with different capillary tube lengths at various condenser temperatures. R134a exhibits a higher power consumption rate compared to R600a.

By presenting your experimental results in this organized manner, readers can easily understand the comparative performance of the refrigeration system using different refrigerants and capillary tube lengths.

6. Conclusion

In this study, the performance of R600a, an environmentally friendly refrigerant with zero ozone depletion potential (ODP) and low global warming potential (GWP), was experimentally investigated in a vapor compression refrigeration system. The performance of R600a was compared with that of R134a refrigerant in the same system using different capillary tube lengths and refrigerant charges.

The study analyzed various parameters such as capillary tube diameter, length, and refrigerant performance. At a capillary tube length of 6 feet, R134a demonstrated a higher coefficient of performance compared to R600a.

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