A Project report on

EXPERIMENTAL INVESTIGATION OF THE EFFECT OF CAPILLARY TUBE LENGTH ON THERMODYNAMIC PERFORMANCE AND CO_2 EMISSION ANALYSIS OF REFRIGERATOR OPERATING WITH R134A ALTERNATIVE

Submitted in partial fulfillment of the requirements

for the award of the degree of

BACHELOR OF TECHNOLOGY

in

Mechanical Engineering

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(AUTONOMOUS)

Rotarypuram Village, B K Samudram Mandal, Ananthapuramu – 515701

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MECHANICAL ENGINEERING

Certificate

This is to certify that the project report entitled Experimental Investigation of The effect of Capillary Tube length on Thermodynamic Performance and CO_2 emission Analysis of refrigerator operating with R134a Alternative is the bonafide work carried out by **N.ROSHAN VALI, K.JAYAVANTH KUMAR, P.JAGADEESH, G.KARTHEEK, C.AKHIL KUMAR REEDY** bearing Roll Number **224G5A0328, 224G5A0314, 214G1A0310, 214G1A0311, 224G5A0302** in partial fulfilment of the requirements for the award of the degree of **Bachelor of Technology** in **Mechanical Engineering** during the academic year 2024-2025.

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Date:

Place: Anantapur

External Examiner

DECLARATION CERTIFICATE

We are students of **Mechanical Engineering**, **SRINIVASA RAMANUJAN INSTITUTE OF TECHNOLOGY(AUTONOMOUS)**, Rotarypuram, hereby declare that the dissertation entitled **“EXPERIMENTAL INVESTIGATION OF THE EFFECT OF CAPILLARY TUBE LENGTH ON THERMODYNAMIC PERFORMANCE AND CO_2 EMISSION ANALYSIS OF REFRIGERATOR OPERATING WITH R134A ALTERNATIVE”** embodies the report of our project work carried out by us during IV year under the guidance of Dr. Mr. Shaik Sharmas Vali, MTech, Ph.D., Associate Professor, Department of Mechanical Engineering, Srinivasa Ramanujan Institute of Technology, and this work has been submitted for the partial fulfillment of the requirements for the award of degree of Bachelor of Technology.

The results embodied in this project report have not been submitted to any other University or Institute for the award of any Degree or Diploma.

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Project Associates

ABSTRACT

The Capillary tube is a critical component in Vapour compression refrigeration (VCR) system, Serving as an expansion device to regulate refrigerant flow. This study investigates the effect of capillary tube length on the performance of a VCR system, Focusing on cooling capacity, Coefficient of performance (COP). By varying the capillary tube length, experimental and computational analysis were conducted to evaluate system behavior under different operating conditions and two different Refrigerants such as R134a, R600a & R290 mixture. The results indicate that capillary tube length significantly influences refrigerant flow rate, pressure drop, and system efficiency by comparing two refrigerants. An optimal length ensures stable operation, enhances COP, While excessively short or long tubes lead to inefficiencies such as overfeeding or underfeeding of refrigerants.

Additionally, A computation-based CO_2 emission analysis was performed to assess the environment impact of the system under varying capillary tube lengths, Comparing effects of two refrigerants.

Keywords: Capillary tube, Vapour Compression System (VCR), Refrigerant Flow, R134a and R600a & R290 mixture Refrigerants, Coefficient Of Performance (COP), CO_2 Emission.

CONTENT

LIST OF FIGURES

LIST OF ABBREVIATIONS

VCR	Vapour Compression Refrigeration
COP	Coefficient Of Performance
CO_2	Carbon dioxide

CHAPTER – 1

INTRODUCTION

1.1 VCR System

A Vapour Compression Refrigeration System (VCRS) is the most widely used refrigeration system, found in applications such as refrigerators, air conditioners, and industrial cooling systems. It operates by compressing and expanding a refrigerant to absorb and release heat, thereby cooling a space or substance.

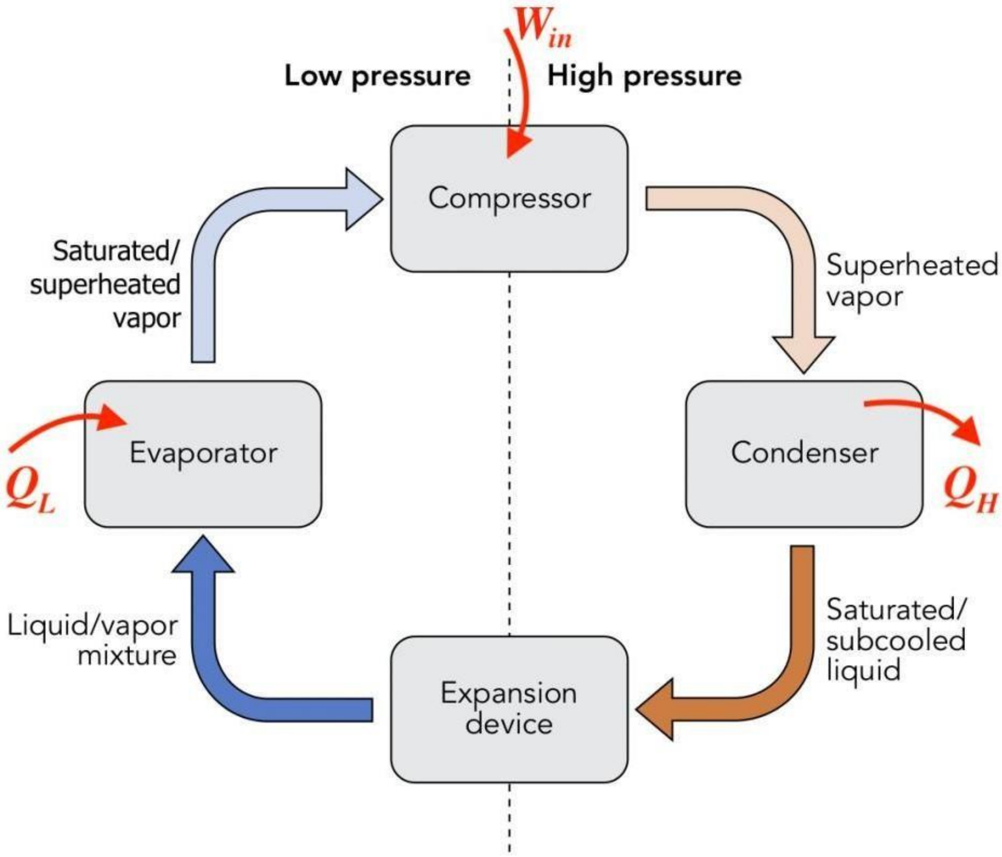

Figure 1. simple vapour compression refrigeration cycle

Main Components of VCRs

1. Compressor – Increases the pressure and temperature of the refrigerant gas.

2. Condenser – Releases heat from the refrigerant and condenses it into a high-pressure liquid.

3. Expansion Valve (or Throttle Valve) – Lowers the pressure and temperature of the refrigerant.

4. Evaporator – Absorbs heat from the surroundings, cooling the desired space.

Working Principle (Cycle Stages)

• Process 1: Isentropic compression in compressor.

• Process 2: Constant pressure heat rejection in condenser.

• Process 3: Isenthalpic expansion in expansion device.

• Process 4: Constant pressure heat absorption in evaporator.

1.2 Applications

Domestic and commercial refrigeration.

Air conditioning systems.

Industrial cooling and process refrigeration.

Automotive air conditioning.

1.2 Objective of project

To study and investigate the effect of capillary tube length on the performance of the VCR system (COP) and the comparison of CO_2 emissions released by two different refrigerant R134a andR600a.

Increasing the Coefficient of Performance (COP) of a refrigerator is essential for improving energy efficiency, reducing costs, and minimizing environmental impact. A higher COP means the refrigerator requires less electricity to remove the same amount of heat, leading to lower energy consumption and reduced electricity bills. This also helps decrease greenhouse gas emissions, making refrigeration systems more environmentally friendly.

CHAPTER – 2

LITERATURE SURVEY

2.1 Review of previous research

- Chandrasekhar Yadav et al. (2002) studied the effect of capillary tube length On vcr system and this Research suggests that capillary tube length significantly influences parameters such as the coefficient of performance (COP), refrigeration effect, compressor power, and mass flow rate of the refrigerant. Experimental studies indicate that as the length of the capillary tube increases, the mass flow rate and compressor pressure decrease, leading to reduced compressor power consumption. However, an optimal length exists where system performance is maximized. Previous studies have shown that for a 30-liter refrigeration unit using R-134a, an optimal capillary tube length of 4.5 feet efficiency. The test results confirm that increasing the capillary length beyond this point may reduce mass flow rate but improve net refrigeration effect.

- D. M. Madyira et al. (2019) investigate performance of refrigerator by using R600a his Experimental studies have shown that R600a offers higher coefficient of performance (COP) compared to R134a. Research findings indicate that refrigerators using R600a exhibit lower power consumption, with optimized capillary tube length further enhancing efficiency. Specifically, a capillary tube length of 1.30 meters has been identified as the optimal length for minimizing power consumption in systems using R600a. Additionally, increasing the capillary tube length has been observed to improve the cooling capacity of

R600a-based systems. The feasibility of retrofitting refrigerators originally designed for R134a with R600a has been widely investigated. Studies confirm that performance improvements can be achieved through capillary tube modifications, making R600a a viable and energy-efficient substitute.

- K. Neelakanta et al. (2017) done investigations on a 30-liter refrigeration unit using R-134a as the refrigerant have identified an optimal capillary tube length of 1.37 meters (54 inches). At this length, the refrigeration system demonstrated improved efficiency across multiple aspects, including higher COP, enhanced cooling performance, lower compressor power usage, and a balanced mass flow rate. It was observed that increasing the capillary tube length beyond this point resulted in a decrease in refrigerant flow rate and compressor pressure, leading to reduced power consumption but an increased net refrigeration effect.

2.2 Problem Identification

Using of R134a leads to Global Warming due its high global warming potential.

Global Warming

Global warming refers to the long-term increase in Earth's average surface temperature due to human activities, primarily the emission of greenhouse gases like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These gases trap heat in the atmosphere, leading to climate changes such as rising sea levels, extreme weather, and ecosystem disruptions.

Optimizing capillary tube length is crucial for improving refrigeration efficiency, as it directly affects refrigerant flow, cooling performance, and energy consumption. Studies focus primarily on optimizing capillary tube length to improve system efficiency but often overlook the combined impact of capillary tube length and CO_2 emissions. While adjusting capillary length (typically 1.3 to 1.5 meters) enhances cooling performance and reduces energy consumption, the environmental benefits could be greater if considered alongside refrigerant selection. Using low-GWP refrigerants like R-600a with optimized capillary tubes can further reduce greenhouse gas emissions, improving both energy efficiency and environmental sustainability.

CHAPTER – 3

SELECTION OF REFRIGERANT

3.1 Selection of Refrigerant

When selecting a refrigerant, it is essential to evaluate a range of factors to ensure optimal system performance and compliance with environmental and safety standards. First, consider the thermodynamic properties: the refrigerant should provide high cooling efficiency (as measured by the Coefficient of Performance), operate effectively within the system's pressure range, and offer an appropriate latent heat of vaporization and boiling point for the intended temperature range. Environmental impact is equally crucial, with low ozone depletion potential (ODP) and global warming potential (GWP) being key requirements under current regulations.

3.1.1 R134a (Tetrafluoro ethane)

R-134a is a non-flammable, non-toxic HFC refrigerant with zero ozone depletion potential but a high global warming potential (GWP 1,430). It is widely used in automotive air conditioning, refrigerators, and HVAC systems. Due to environmental concerns, it is being phased out in favor of low-GWP alternatives like R-12.

3.1.2 Properties of R134a

Molecular formula	-	$C_2H_2F_4$
Molecular Weight	-	102.03 g/mol
Boiling point	-	-26.3 ^{0}C
Critical temperature	-	101.1 ^{0}C

Ozone Depletion Potential - 0

Global warming potential - 1430

Flammability - non – flammable

Toxicity - Low

3.1.3 R600a (Isobutane)

R-600a (Isobutane) is a hydrocarbon (HC) refrigerant with zero ozone depletion potential (ODP) and very low global warming potential (GWP ~3). It is highly efficient and widely used in domestic refrigerators, freezers, and small commercial cooling units. However, it is flammable, requiring careful handling. Due to its environmental benefits and energy efficiency, R-600a is a preferred replacement for high-GWP refrigerants like R-134a in household refrigeration.

3.1.4 Properties of R600a

Molecular Formula - C_4H_{10}

Molecular Weight - 58.12 g/mol

Boiling point - -11.7 ^{0}C

Critical temperature - 134.7 ^{0}C

Ozone Depletion Potential - 0

Global warming potential - -3

Flammability - Highly flammable

Toxicity - Low

3.1.5 R290 (Propane)

R-290, also known as propane refrigerant, is a natural hydrocarbon widely used in cooling and air conditioning systems. It is an environmentally friendly alternative to traditional refrigerants, with a Global Warming Potential (GWP) of only 3 and an Ozone Depletion Potential (ODP) of 0. Due to its excellent thermodynamic properties, R-290 offers high energy efficiency and superior cooling performance while consuming less power. However, its primary drawback is its high flammability, which requires strict safety precautions, including proper ventilation, leak detection, and adherence to regulatory guidelines. Despite these challenges, R-290 is commonly used in domestic and commercial refrigeration, small air conditioners, and industrial cooling applications. Its increasing adoption is driven by stringent environmental regulations and the global shift toward sustainable refrigeration solutions.

3.1.6 Properties of R290

Molecular Formula - C_3H_8

Molecular Weight - 44.1 g/mol

Boiling point - -42.1 ^{0}C

Critical temperature - 96.7 ^{0}C

Ozone Depletion Potential - 0

Global warming potential - 3

Flammability - Highly flammable

Toxicity - Low

3.1.7 Performance parameters

The objective of this project is to calculate the COP of vapour compression refrigeration system and to compute the CO_2 emissions analysis of R134a, R600a and R290 in order to calculate the we need know some performance parameters those are:

- Mass flow rate : $m=Qc/RE$
- Refrigeration effect : $RE=(h1-h4)$
- Compressor work : $Wc=(h2-h1\ )$
- Coefficient of performance : $COP=RE/Wc$
- Discharge temperature
- Pressure ratio : PK/PE
- Volumetric refrigerator capacity : Q × RE
- Power per ton of refrigerator : QC/COP

Superheating: Superheating is the process in which the excess amount of heat is provided to the coolant. This increases the rate of cooling, which is a good indicator for COP. But also, we should understand that if superheating occurs in a refrigerator, the external energy should be greater to keep the cycle moving.

Sub-cooling: Sub cooling is the process of cooling the liquid refrigerant below the condensing temperature for a given pressure. Degree of sub-cooling: The difference between the saturation temperature and the temperature of sub cooled liquid at that pressure is called the degree of sub-cooling.

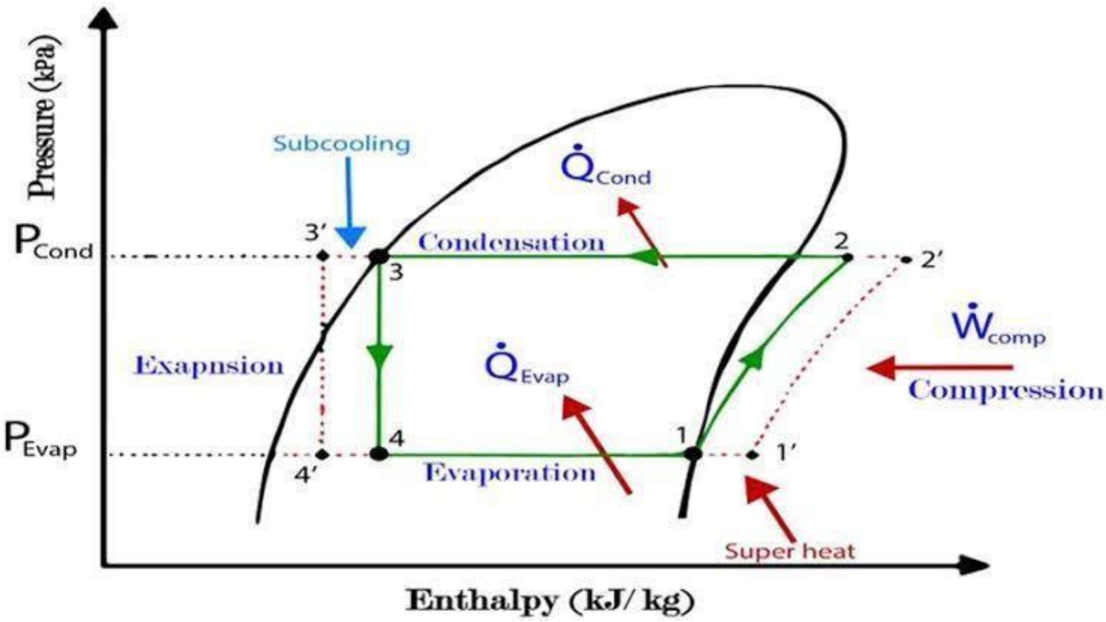

Figure 2. effect of superheating and subcooling

3.1.8 Theoretical operating conditions

Observations	**R134a**	**R600a**
Compressor temperature (^{0}C)	55	55
Evaporator temperature (^{0}C)	-25	-25
Degree of Subcooling (^{0}C)	10	10
Degree of Superheating (^{0}C)	10	10

By taking the values from the pressure enthalpy chart we may get the values as follows:

For R134a-

h_1 = 397.5 kj/kg h_2 = 459 kj/kg Discharge temperature 85 ^{0}C

$h_3 = h_4$ = 250 kj/kg

where,

h_1 is enthalpy at compressor inlet

h_2 is enthalpy at compressor outlet

h_4 is enthalpy at evaporator outlet

we know that,

Refrigeration effect, RE = h_1-h_4 = 397.5 - 250 = 147.5 kj/kg

Compressor work, WC = $h_2 - h_1$ = 459 - 397.5 = 61.5 kj/kg

Coefficient of performance, COP = RE/WC

$= \frac{147.5}{61.5} = 2.398$

Pressure ratio = PK/PE

$= \frac{1.50}{0.1086} = 13.812$

QC = 1TR   1TR=3.5167 kw

Now, mass flow rate = $\frac{3.5167}{147.5} = 0.0238$ kg/sec

Power per ton of refrigeration = COP/3.1567

$= \frac{3.5167}{2.398} = 0.681$ kw/TR

Volumetric refrigeration capacity = Q × RE

$= 5.142 \times 147.5 = 758.57$ kj/m^3

For R600a-

$h_1 = 537.5$ kj/kg $h_2 = 625$ kj/kg   discharge temperature= 65^{0}C

$h3 = h_4 = 310$ kj/kg

then RE= 537.5 – 310 = 227.5 kj/kg

WC = 625 – 537.5 = 87.5 kj/kg

COP = $\frac{227.5}{87.5} = 2.6$

Pressure ratio = $\frac{0.75}{0.06} = 12.5$ QC = 1 TR

Mass flow rate = $\frac{3.5167}{227.5} = 0.0154$ kg/sec

Power per ton of refrigerant = $\frac{2.6}{3.5167} = 0.7393$ kw/TR

Volumetric refrigeration capacity = 1.7 × 227.5 = 386.75 kj/m^3

3.1.9 Theoretical calculations

Refrigerant	R134a	R600a
Refrigeration effect (kj/kg)	147.5	227.5
Compressor work (kj/kg)	61.5	87.5
COP	2.398	2.6
Pressure ratio	13.812	12.5
Discharge temperature (^{0}C)	85	65
Mass flow rate (kg/sec)	0.0238	0.0154
Power per ton of refrigerant (kw/TR)	1.465	1.3527
Volumetric refrigeration capacity (kj/m^3)	758.57	386.75

CHAPTER – 4

EXPERIMENTAL SETUP

4.1 Experimental setup

This setup appears to be a modified or experimental refrigeration system, possibly designed for testing multiple cooling circuits or optimizing refrigerant flow.

Figure 2. experimental setup

At the bottom, the black cylindrical component is the compressor, which pressurizes and circulates the refrigerant through the system. On the left side, a manifold with multiple red-knobbed valves is used to control the distribution of refrigerant to different circuits. Above it, several capillary tubes and coiled copper tubing function as expansion devices, regulating the refrigerant's pressure and flow rate. On the right side, a black wire-grid condenser coil helps dissipate heat as the refrigerant transitions from gas to liquid. Pressure gauges mounted near the condenser monitor system performance, ensuring it operates within safe limits. The presence of electrical wiring and control devices suggests automated monitoring of pressure, temperature, or refrigerant flow. This setup may be an experimental multi-evaporator system, a custom-built refrigeration unit, or a test rig for studying cooling efficiency under different conditions.

4.2 Equipment

4.2.1 VCR system

The vcr system have the following equipment :

Compressor

Condenser coil

Capillary tube

Evaporator

Compressor

The compressor is the heart of a Vapor Compression Refrigeration (VCR) system, responsible for circulating the refrigerant and maintaining the cooling cycle. It plays a crucial role in increasing the refrigerant pressure and temperature, allowing effective heat transfer in the condenser and evaporator. The compressor functions by compressing low-pressure, low-temperature refrigerant vapor from the evaporator into a high-pressure, high-temperature gas before it enters the condenser. This pressure increase enables efficient heat rejection in the condenser and ensures continuous refrigeration. Its primary function is to compress the low-pressure refrigerant vapor coming from the evaporator, increasing its pressure and temperature before sending it to the condenser. This compression process is crucial because it raises the refrigerant's energy level, allowing it to release heat more effectively in the condenser. As the refrigerant condenses into a high-pressure liquid, it can efficiently absorb heat again when it enters the evaporator. The compressor also maintains the necessary pressure difference between the high-pressure side (condenser) and the low-pressure side (evaporator), ensuring continuous refrigerant flow. Different types of compressors, such as reciprocating, rotary, scroll, and screw compressors, are used based on the application and cooling requirements. An efficiently functioning compressor enhances the overall performance, cooling efficiency, and energy consumption of the VCR system.

Specifications :

Capacity : 165-190 litres

Refrigerant : R134a

Operate at 220V and 50 Hz

Cooling capacity – 112 watts

Energy efficiency ratio – 381 Btu/h

Coefficient of performance – 1.2

Height – 172mm

Fig 3. compressor

Condenser coil

A condenser coil is a crucial component of a Vapor Compression Refrigeration (VCR) system. It is responsible for releasing heat absorbed by the refrigerant from the evaporator, allowing the refrigerant to condense from a high-pressure gas into a high-pressure liquid. This process helps maintain the refrigeration cycle and ensures efficient cooling. The condenser coil is made of different materials like copper, aluminium, steel. When the high-pressure, high-temperature refrigerant gas leaves the compressor, it enters the condenser coil, where it starts losing heat to the surrounding environment. Depending on the type of condenser, this heat is dissipated using air (air-cooled), water (water-cooled), or a combination of both (evaporative condenser). As the refrigerant moves through the coil, it gradually cools down, changing from a superheated gas to a high-pressure liquid in a process called condensation.

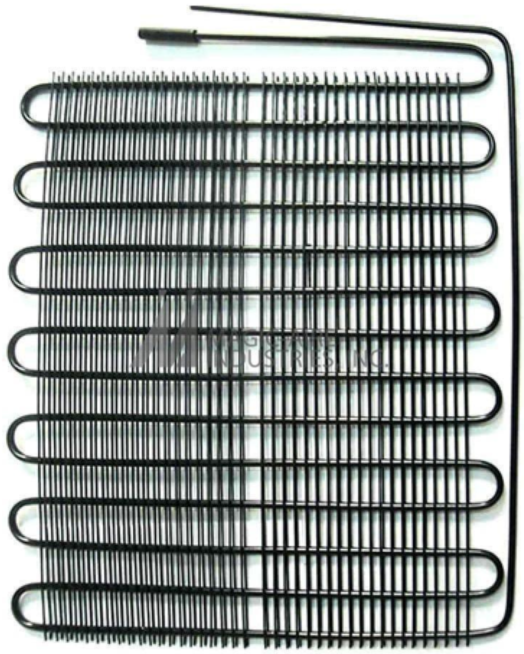

Figure 4. condenser coil

This phase change occurs at a constant pressure, releasing latent heat into the environment. To improve system efficiency, the refrigerant is further subcooled to ensure it remains in liquid form before reaching the expansion device, such as a capillary tube or an expansion valve. The efficiency of a condenser coil depends on factors such as airflow, ambient temperature, coil cleanliness, and the refrigerant type.

Capillary tube

A capillary tube is a simple, fixed-orifice expansion device used in refrigeration and air conditioning systems to regulate the flow of refrigerant from the condenser to the evaporator. It plays a crucial role in maintaining the pressure difference necessary for the refrigeration cycle to function effectively. Although it has some limitations, it remains widely used due to its simplicity, reliability, and cost-effectiveness.

For optimal system performance, the capillary tube length must be carefully selected based on factors such as refrigerant type, evaporator load, condenser pressure, and ambient conditions. A well-designed capillary tube ensures proper refrigerant flow, efficient cooling, and reduced compressor workload, ultimately enhancing the overall energy efficiency and reliability of the VCR system. A longer capillary tube increases the resistance to refrigerant flow, leading to a greater pressure drop. This results in lower refrigerant flow rates, which can be beneficial in low-load conditions but may reduce overall cooling capacity and lead to insufficient refrigerant supply in the evaporator. If the capillary tube is too long, it may cause excessive pressure drop, leading to refrigerant starvation in the evaporator and reduced cooling efficiency. On the other hand, a shorter capillary tube offers less resistance, allowing a higher flow rate of refrigerant. While this can improve cooling capacity, an excessively short capillary tube may lead to higher pressure in the evaporator, inefficient heat transfer, and potential compressor overload.

We take 5 different length of capillary tubes measures 2m, 2.2m, 2.4m, 2.6m, 2.8m.

Figure 5. capillary tube

Evaporator

In a refrigerator, the evaporator is a vital component of the cooling cycle. It absorbs heat from the refrigerator’s interior, keeping food and beverages at a low temperature. Located inside the freezer or cooling compartment, the evaporator consists of metal coils that contain low-pressure liquid refrigerant. As the refrigerant evaporates into gas, it absorbs heat from the surrounding air, reducing the internal temperature. A fan circulates the cooled air throughout the refrigerator, ensuring even cooling. The warmed refrigerant then moves to the compressor, where it is pressurized and sent to the condenser to release heat before repeating the cycle.

Figure 6. evaporator

A well-functioning evaporator ensures efficient cooling, while issues like frost buildup, clogged coils, or leaks can reduce performance, leading to improper cooling or spoiled food. Regular maintenance, such as cleaning the evaporator coils and checking airflow, helps keep the refrigerator running efficiently and extends its lifespan.

4.2.2 Refrigerant (R134a, R600a and R290)

R134a:

R-134a (chemical formula: $C_2H_2F_4$) is a hydrofluorocarbon (HFC) refrigerant widely used in refrigeration and air conditioning systems. It is a non-ozone-depleting alternative to older refrigerants like R-12 (CFC-12) and is commonly used in domestic, commercial, and automotive applications.

Properties of R-134a

Molecular formula - C2H2F4

Boiling point - -26.3o C

Critical temperature- 101.1oC

Ozone Depletion Potential- 0

Global warming potential – 1430

Flammability – non – flammable

Toxicity – low

R600a:

R-600a (chemical formula: C_4H_{10}) is a hydrocarbon (HC) refrigerant commonly used in domestic and commercial refrigeration systems. It is a natural refrigerant and an eco-friendly alternative to synthetic refrigerants like R-134a due to its low Global Warming Potential (GWP) and zero Ozone Depletion Potential (ODP).

Properties of R-600a

Chemical formula - C_4H_{10}

Boiling point - -11.7oC

Critical temperature – 134.7oC

Ozone depletion potential – 0

Global warming potential – 3

Toxicity – low

R290:

R-290, also known as propane refrigerant, is a natural hydrocarbon widely used in cooling and air conditioning systems. It is an environmentally friendly alternative to traditional refrigerants, with a Global Warming Potential (GWP) of only 3 and an Ozone Depletion Potential (ODP) of 0. Due to its excellent thermodynamic properties, R-290 offers high energy efficiency and superior cooling performance while consuming less power.

Properties of R290

Molecular Formula	-	C_3H_8
Molecular Weight	-	44.1 g/mol
Boiling point	-	-42.1 ^{0}C
Critical temperature	-	96.7 ^{0}C

Ozone Depletion Potential	-	0
Global warming potential	-	3
Flammability	-	Highly flammable
Toxicity	-	Low

R134a is non-flammable and commonly used in automotive air conditioning and commercial refrigeration, but has a high GWP, making it less environmentally friendly.

R600a and R290 is a natural refrigerants with low GWP and excellent energy efficiency, making it ideal for domestic refrigerators, but its flammability requires strict safety measures. Due to environmental regulations, many manufacturers are shifting from R134a to R600a R290 in domestic applications to promote sustainability.

Overall, the choice between R134a and R600a depends on safety requirements, application type, and environmental considerations.

Figure 7. refrigerants R134a and R600a

Figure 8 . refrigerants R290

4.2.3 Flow control valves

Flow control valves regulate the flow rate of fluids (liquids or gases) in a system. They are used to control speed, pressure, and volume of flow to ensure efficient operation in various applications, including hydraulics, pneumatics, water systems, and process industries. A flow control valve works by regulating the flow of fluid through a system, ensuring that the desired flow rate is maintained regardless of pressure changes. When fluid enters the valve, it encounters a control mechanism, such as a needle, spool, or diaphragm, which adjusts the opening size to either restrict or allow more flow. In manual valves, this adjustment is made by turning a knob or lever, while in automated valves, electronic or hydraulic actuators control the movement. As the valve restricts flow, it creates a pressure drop that determines the final flow rate exiting the valve. Some advanced flow control valves, like pressure-compensated ones, automatically adjust to maintain a steady flow despite fluctuations in pressure. This process ensures precise control in applications like hydraulic machinery, pneumatic systems, water distribution, and industrial automation.

Figure 9. flow control valve

4.2.4 Pressure gauges

A pressure gauge is an instrument used to measure the pressure of gases or liquids in a system. It helps monitor and maintain optimal pressure levels in various applications, including industrial processes, hydraulics, pneumatics, and HVAC systems. Pressure gauges are categorized based on the pressure range they measure. High-pressure gauges are designed for extreme pressure applications, while low-pressure gauges are used for measuring small pressure variations.

1. High-Pressure Gauges

These gauges are used for measuring high pressures, typically above 1,000 psi (70 bar) and can go up to 50,000 psi (3,500 bar) or more.

Working Principle

Usually based on the Bourdon tube mechanism, where the tube expands slightly under high pressure, moving the needle on the dial.

Made from strong materials like stainless steel or brass to withstand high pressures.

Often filled with glycerin or silicone oil to absorb vibrations and protect the gauge from pressure spikes.

Applications

✓ Hydraulic Systems – Measures pressure in hydraulic circuits.

✓ Gas and Oil Industry – Used in pipelines, compressors, and drilling equipment.

✓ Industrial Machinery – Monitors pressure in heavy-duty manufacturing.

✓ High-Pressure Testing – Used in laboratories and pressure chambers.

2. Low pressure gauges:

These gauges are used to measure pressures below 15 psi (1 bar) and are sensitive to small pressure changes.

Working Principle

Often use a diaphragm or capsule mechanism, where the diaphragm deforms under pressure and moves a needle or sends an electronic signal.

Designed for precision in low-pressure environments.

Figure 10. pressure gauges

Applications

✓ HVAC Systems – Measures air pressure in ducts and filters.

✓ Medical Devices – Used in oxygen tanks, anesthesia machines, and ventilators.

✓ Gas Flow Measurement – Used in propane and natural gas systems.

✓ Laboratory Equipment – Used for scientific experiments requiring low-pressure monitoring.

Advantages :

1. High thermal performance
2. Reduce carbon emissions
3. Improved pressure drop control
4. Better refrigerant flow regulation
5. Better cooling performance in small scale applications

Applications :

1. Domestic refrigerator
2. Air conditioner
3. Cold storages
4. Laboratories

4.2.5 Digital Thermocouples

A thermocouple is a temperature-sensing device that measures temperature based on the Seabeck effect, which states that when two different metals are joined at two junctions, a voltage is generated that corresponds to the temperature difference between them. Thermocouples are widely used in industrial, scientific, and domestic applications due to their simplicity, durability, and wide temperature range capabilities Thermocouples consist of two dissimilar metal wires joined at one end, forming a junction called the hot junction. The other ends of the wires remain separate and are connected to a measuring instrument, forming the cold junction. When the hot junction is exposed to a different temperature than the cold junction, a voltage (thermoelectric EMF) is generated due to the temperature difference. This voltage is proportional to the temperature and can be measured to determine the exact temperature at the hot junction.

Thermocouples are highly versatile temperature sensors used in various industries due to their ruggedness, fast response, and wide temperature range. Despite their limitations in accuracy, they remain a preferred choice for high-temperature and industrial applications.

Advantages of Digital Thermocouples:

✓ More Accurate – Built-in compensation and processing improve accuracy.

✓ Easier Integration – No need for separate ADC and CJC components.

✓ Noise Resistance – Digital signals are less affected by electrical noise compared to low-voltage analog signals.

✓ Remote Monitoring – Data can be transmitted over longer distances without significant signal loss.

Figure 11. thermocouple

4.2.6 Energy meter

An energy meter is an electrical device used to measure the amount of electrical energy consumed by a residence, business, or electrical device. It plays a crucial role in monitoring electricity usage and billing consumers based on their consumption. Energy meters are commonly used by utility companies to track electricity consumption and generate accurate electricity bills.

This will measure the amount of electricity used by the refrigerator under operating condition.

An energy meter operates based on the formula:

Electrical Energy (kWh) = Power (kW) *Time (hours)

It continuously measures the voltage (V) and current (I) in the circuit, calculates the power consumption, and integrates it over time to determine total energy usage.

Current and Voltage Measurement

The meter has current coils and voltage coils that detect the amount of current flowing and the supply voltage.

2. Power Calculation

The meter multiplies voltage and current to determine instantaneous power (Watts).

If the load is inductive (e.g., motors), the meter also considers power factor for accurate readings.

3. Energy Accumulation

The power readings are accumulated over time to calculate total energy consumption in kilowatt-hours (kWh).

4. Display and Data Storage

The total energy used is displayed on a mechanical dial (analog meter) or digital screen (electronic meter).

Figure 12. energy meter

4.2.7 T bends

In pipe fitting, T-bends (or tee bends) are essential for changing the direction of fluid flow while allowing branching into another pipeline.

Figure 13. t bend

Proper installation of T-bends improves fluid dynamics, reduces pressure loss, and enhances overall system efficiency. They play a crucial role in water supply networks, oil refineries, and gas pipelines, ensuring smooth and reliable fluid transport.

4.2.8 Welding equipment

Gas welding is a process that uses a high-temperature flame to melt and join metal pieces. The most common type is oxy-acetylene welding, where acetylene and oxygen produce a flame reaching up to 3,500°C. It is widely used for welding thin metals, pipes, and automobile repairs. Essential equipment includes gas cylinders, regulators, hoses, a torch, flame adjusters, filler rods, and flux. The process is cost-effective, portable, and suitable for small-scale welding, brazing, and cutting. Safety precautions, such as wearing protective gear and controlling the flame properly, are crucial to prevent burns, gas leaks, and fire hazards.

4.2.9 Refrigerant charging unit

In a Vapor Compression Refrigeration (VCR) system, gas charging equipment is essential for filling or refilling refrigerant to maintain efficient cooling. Proper charging ensures optimal pressure, preventing issues like insufficient cooling or compressor failure. The key equipment includes a vacuum pump to remove air and moisture, a manifold gauge set to monitor pressure, and a refrigerant cylinder containing gases like R-134a or R-410A. A charging hose connects the cylinder to the system, while a weighing scale ensures the correct refrigerant amount. Additionally, a leak detector checks for leaks after charging. Proper gas charging improves system efficiency, prevents energy wastage, and extends the refrigeration unit’s lifespan while ensuring environmental safety.

CHAPTER – 5

EXPERIMENTALANALYSIS

5.1 Performance parameters (experimental)

We calculate the following performance parameters by the values obtained by the conducting experiments with R134a and mixture of R600a and R290 under the study conditions.

- Mass flow rate : $m=Qc/RE$
- Refrigeration effect : $RE=(h1-h4)$
- Compressor work : $Wc=(h2-h1\ )$
- Coefficient of performance : $COP=RE/Wc$
- Pressure ratio : PK/PE
- Volumetric refrigerator capacity : Q × RE
- Power per ton of refrigerator : QC/COP
- Carbon emissions released by respective refrigerant

5.2 Experimental Calculations

R134a:

For 2 meter capillary tube length

h_1 =390, h_2 = 460, h_3 = h_4 = 245

Mass flow rate = 0.7724 kg/s

Refrigeration effect = 390 – 245 =145 kj/kg

Compressor work = 460 – 390 = 70 kj/kg

Coefficient of performance = $\frac{145}{70} = 2.02$

Pressure ratio = $\frac{205}{4} = 18.68$

Power per ton of refrigeration = $\frac{2.02}{3.5167} = 0.5744$

The values of remaining lengths are follows:

Performance Parameters Of Refrigerant R134a:

Length of capillary tube	2 meter	2.2 meter	2.4 meter	2.6 meter	2.8 meter
Mass flow rate (kg/s)	0.7724	0.7724	0.7466	3.2	0.8
Refrigeration effect (kj/kg)	145	145	150	35.0	140
Compressor work (kj/kg)	70	70	70	80	66
Coefficient of performance	2.07	2.07	2.14	0.43	2.12
Pressure ratio	18.68	21.11	18.50	21.66	20.0
Volumetric refrigeration capacity (kj/m^3)	464	464	510	112	462
Power per ton of refrigerator	0.5744	0.5890	0.6093	0.1244	0.6031

Mixture of R290 and R600a :

For 2 meter length capillary tube

h_1 = 540 kj/kg, h_2 = 628 kj/kg, $h_3 = h_4$ = 320 kj/kg

Mass flow rate = 0.5090 (kg/s)

Refrigeration effect = 540 – 320 =220 kj/kg

Compressor work = 628 – 540 = 88 kj/kg

Coefficient of performance = $\frac{220}{88} = 2.5$

Pressure ratio = $\frac{12.93}{1.17} = 11.05$

Power per ton of refrigeration = $\frac{2.5}{3.5167} = 0.7108$

The values of various lengths and Performance parameters of R600a & R290 :

Length of Capillary tube	2 meter	2.2 meter	2.4 meter	2.6 meter	2.8 meter
Mass flow rate (kg/s)	0.5090	0.5490	0.5558	0.6037	0.5947
Refrigeration effect (kj/kg)	220	204	201.5	185.5	188.3
Compressor work (kj/kg)	88	87	87.5	92.5	91.6
Coefficient of performance	2.5	2.3	2.3	2.0	2.05
Pressure ratio	11.05	10.25	10	11.2	10.87
Volumetric refrigerator capacity (kj/m^3)	814	856.8	785.85	723.45	847.35
Power per ton of refrigeration	0.7108	0.66	0.65	0.57	0.58

5.3 Effect of capillary tube length

The table presents the performance characteristics of a refrigeration system based on different capillary tube lengths ranging from 2.0 meters to 2.8 meters. As the capillary length increases, there is a noticeable impact on various parameters. The refrigeration effect decreases from 220 units at 2.0 meters to a minimum of 185.5 at 2.6 meters, before slightly increasing again at 2.8 meters. Similarly, compressor work fluctuates, with the lowest value (87) at 2.2 meters and peaking at 92.5 for 2.6 meters. The coefficient of performance (COP) is highest at 2.0 meters (2.5) and declines with increased length, reaching 2.0 at 2.6 meters, then slightly recovering to 2.05 at 2.8 meters. The pressure ratio follows a similar trend, with a high of 11.2 at 2.6 meters. Power consumption per ton of refrigeration improves (i.e., decreases) with increased capillary length, starting from 0.7108 at 2.0 meters and reducing to 0.57 at 2.6 meters, indicating better energy efficiency, though it rises slightly at 2.8 meters. Overall, while shorter lengths provide higher cooling capacity and COP, longer capillaries tend to enhance energy efficiency. The choice of optimal capillary length involves balancing these performance parameters depending on system priorities.

5.4 Refrigeration effect and CO_2 Emissions

The refrigeration effect varies noticeably with changes in the capillary tube length, as shown in the table. At a length of 2.0 meters, the system exhibits the highest refrigeration effect of 220 units, indicating maximum cooling performance. As the capillary length increases to 2.2 meters and 2.4 meters, the refrigeration effect gradually decreases to 204 and 201.5 units respectively, suggesting a slight decline in cooling capacity. A significant drop is observed at 2.6 meters, where the refrigeration effect falls to 185.5 units, the lowest in the dataset. This decrease can be attributed to increased resistance in the longer capillary, which restricts refrigerant flow and reduces the system's ability to absorb heat. Interestingly, at 2.8 meters, the refrigeration effect rises slightly to 188.3 units, indicating a minor recovery. Overall, the data suggests that shorter capillary lengths favor higher refrigeration effects, while longer lengths may hinder cooling efficiency due to flow limitations

CO_2 Emissions is calculated in terms of Total Equivalent Warming Impact (TEWI)

For different capillary tube length we calculate different CO_2 emission valves thy are as follows:

TEWI Calculations:

Length (meters)	TEWI for R600a/R290	TEWI for R134a
2	7502	165.68
2.2	7330	162.62
2.4	7707	163.55
2.6	7707	171.63
2.8	7491	171.80

5.5 Result and Discussion

The refrigeration effect is highest at 2.0 meters (220 units) and gradually decreases with length, reaching a low at 2.6 meters (185.5 units). The coefficient of performance (COP) also follows this trend, dropping from 2.5 at 2.0 meters to 2.0 at 2.6 meters, indicating reduced efficiency.

The power per ton of refrigeration improves as the length increases, with the lowest value at 2.6 meters (0.57), showing better energy efficiency. However, when analyzing the TEWI (Total Equivalent Warming Impact) values, the lowest emission is recorded at 2.2 meters (7330), despite a moderate performance level. The highest TEWI values of 7707 at 2.4 and 2.6 meters suggest increased carbon emissions due to lower efficiency. At 2.8 meters, TEWI drops again to 7491, likely due to improved power consumption.

In summary, 2.2 meters provides the best balance between efficiency and lowest carbon emissions, making it the most suitable length from a performance and environmental standpoint.

CONCLUSION

This study examined the effect of varying capillary tube lengths on the performance and environmental impact of a refrigeration system. Based on the analysis, it was observed that a shorter capillary tube length of 2.0 meters delivers the highest refrigeration effect and COP, indicating superior cooling performance. However, as the length increases, both cooling capacity and efficiency decrease, while energy consumption improves slightly.

From an environmental perspective, the Total Equivalent Warming Impact (TEWI) calculations reveal that a capillary length of 2.2 meters results in the lowest CO_2 emissions, making it the most environmentally favorable option. Although 2.4 and 2.6 meters offer lower power per ton, they are associated with the highest TEWI values due to reduced overall performance.

Therefore, it can be concluded that a capillary tube length of 2.2 meters offers the best compromise between system efficiency, power consumption, and environmental sustainability, and is recommended as the optimal configuration for practical applications in refrigeration systems.

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