CLL251 Project – Peer Evaluation Form

Please evaluate your team members based on their contribution to the group.
5 = This team member made unique and irreplaceable contributions to the group
4 = This team member made important contributions to the group.
3 = This team member made a satisfactory contribution to the group.
2 = This team member made a sub-par contribution to the group
1 = This team member was frequently absent and contributed very little to the group.
0 = This team member was completely absent or disruptive to the group.

SNo.	Team member Name	Entry No	Ranking
1	Priyanshu	2022CH11465	5
2	Manish Meena	2022CH11035	5
3	Rounak Parsai	2022CH11445	5
4	Suyash Pankaj Gupta	2022CH11433	5
5			
6			

Study of Air Conditioning Unit Of Electrical Vehicles

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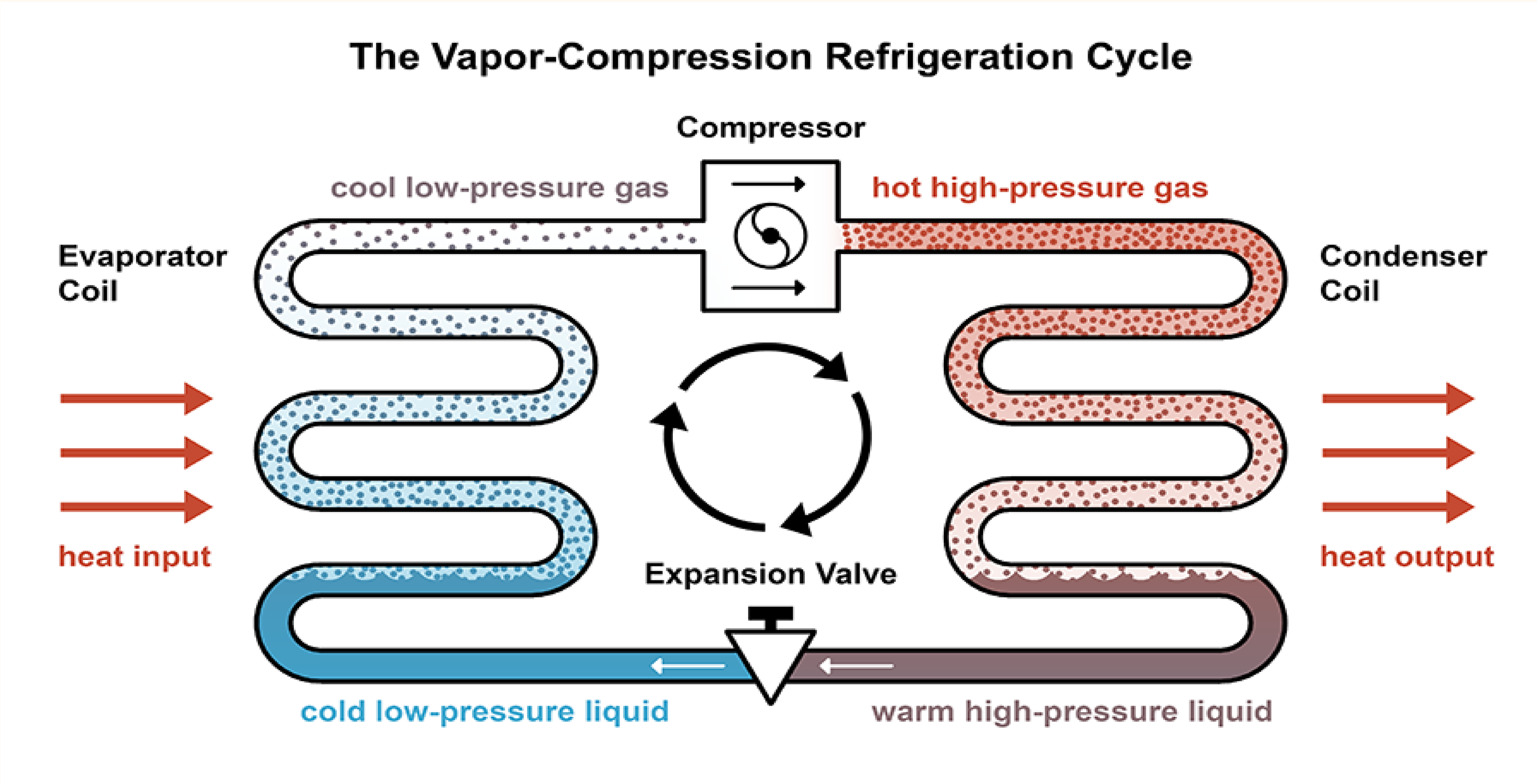


[The Vapor-Compression Refrigeration Cycle | daniel overbey // blog]

Methods and Materials

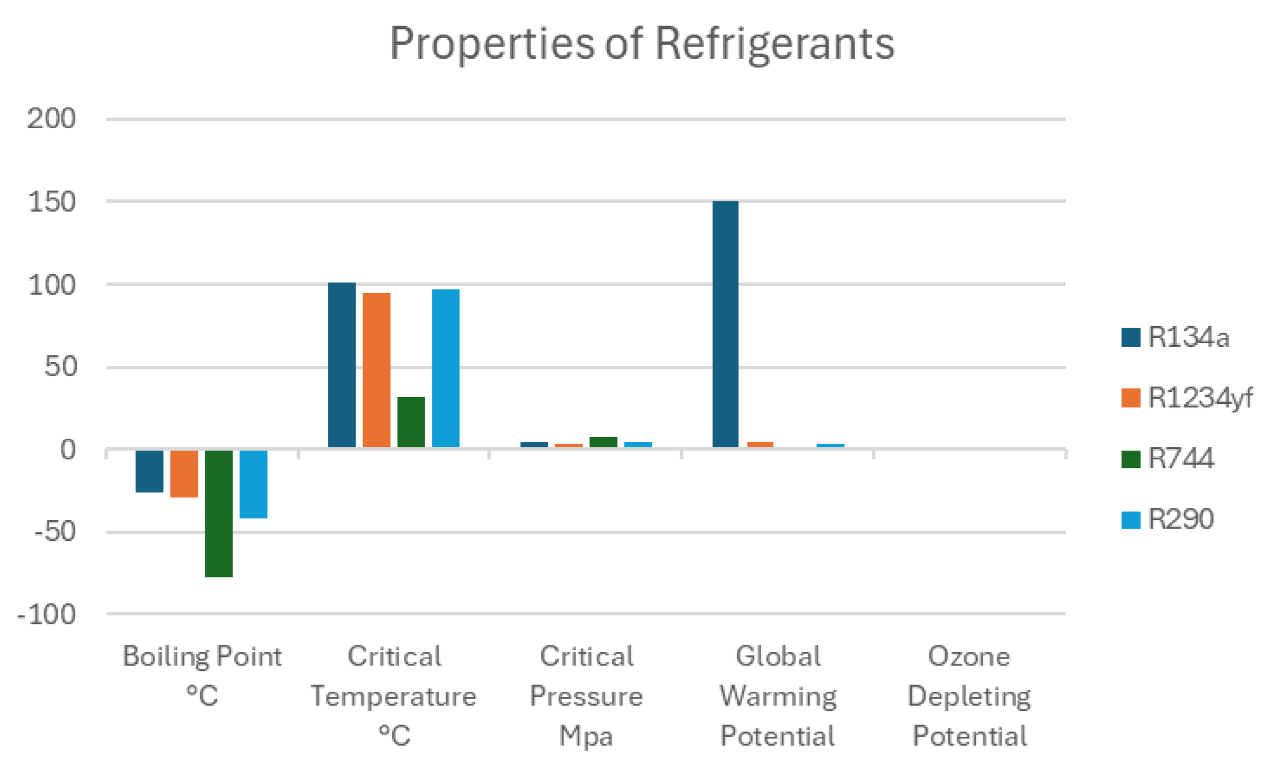
- The main components of air conditioning unit are compressor, condenser, expansion valve, evaporator and refrigerant.
- The compressor creates the flow of refrigerant in the vapor compression cycle. The low temperature and low pressure refrigerant is compressed to high temperature and high pressure vapor which then forced to condenser from this compressor.
- The condenser is a heat exchanger located at the front of the vehicle's cabin which condenses vapor to liquid at high pressure.
- The high-pressure liquid refrigerant flows through the expansion valve, where it undergoes a sudden decrease in pressure. The cabin's evaporator enables the transfer of heat between the refrigerant and the warmer air inside the cabin.
- The blower fan subsequently circulates the cooled air over the evaporator coils, resulting in a decrease in cabin temperature and a reduction in humidity levels due to the condensation of moisture on the surface of the evaporator.
- The viable EV batteries used in AC systems are chemical batteries and ultracapacitors or supercapacitors.

Table 1. Comparison of thermophysical properties of refrigerants

	R134a	R1234yf	R744	R290
Chemical formula	CF3CH2F	CF3CF=CH2	CO2	C3H8
Boiling Point (◦C)	-26	-29	-78	-42
Critical Temperature (◦C)	101	94.7	31.4	96.7
Critical Pressure (MPa)	4.1	3.4	7.4	4.2
GWP (Global Warming Potential)	1300	<4	1	3.3
ODP (Ozone Depleting Potential)	0	0	0	0

Results

- Improving the insulation of the vehicle cabin can help maintain a stable temperature, reducing the load on the AC system and thereby conserving energy.
- During the expansion step, the turboexpander can be used instead of a throttle valve to achieve higher efficiency. However, the turboexpander's large size makes it impractical for use in car air conditioning systems.
- For cooling a wide range of temperatures and pressures we can use cascade compression cycles in which two separate cycles are used , this allows the high-temperature cycle to reject heat at a higher temperature level than it would achieve alone, increasing overall system efficiency.
- Systems that recover waste heat from other vehicle components (such as the electric motor or power electronics) and use it to supplement the AC system can improve overall energy efficiency.
- R290 (C3H8) has its ODP is 0 and GWP is low which makes it suitable refrigerant.



Discussion

- R134A, R1234YF, R410A and other refrigerants in common use have no destructive effect on the ozone layer, but their GWP values are relatively high.
- The type of refrigerant used in the cycle affects efficiency and environmental impact. EV manufacturers are exploring low global warming potential (GWP) refrigerants to minimize environmental harm.
- The electronic expansion valve is not only the main component to control the superheat of the system, but also the important component to regulate the air supply and flow of the system.
- The performance of the R290 as a refrigerant is theoretically calculated in the report using the concepts of thermodynamics and heat transfer.
- According to the principle of air enthalpy difference method, a laboratory for measuring the heat and cooling capacity of air conditioning systems is built.

Conclusions

- The AC system plays a role in managing the battery temperature in addition to cooling the cabin. Proper battery thermal management is critical for battery longevity and performance.
- Research into more efficient and environmentally friendly refrigerants can enhance the performance of AC systems while minimizing environmental impact.
- Solar panels on the roof of an EV could power a ventilation system to keep the cabin cool while the vehicle is parked, reducing the need for intensive cooling when the vehicle is started.
- R290 refrigerant has a lower molar mass than R134a, reducing flow requirements in heat pump systems and reducing costs compared to R134a, despite having lesser specific heat.
- The air conditioning (AC) system can significantly increase the energy consumption of an EV, especially in hot climates. The system uses energy from the battery to function, which can reduce the vehicle's range.
- There is still room for further research and development in areas such as thermoelectric cooling, energy harvesting, and high-efficiency components. These innovations could lead to more sustainable and efficient AC systems.

Figure 1. Compressor

Figure 2. Thermostatic expansion valve

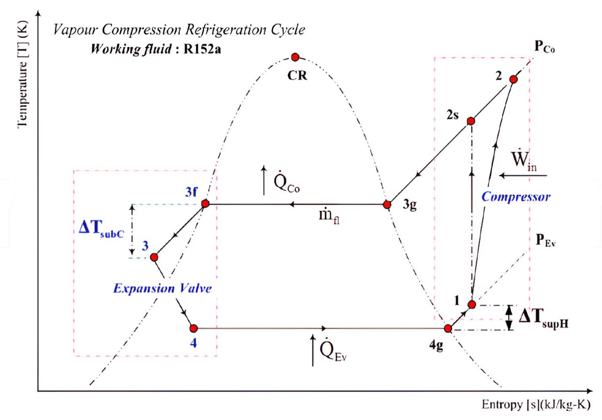


Figure 3. Vapor Compression Cycle

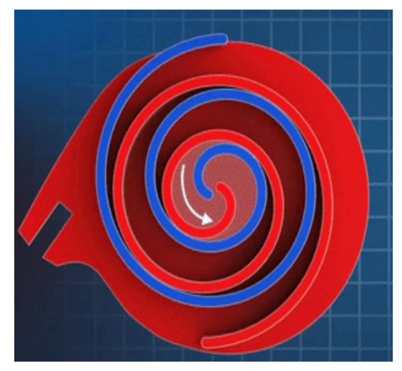


Figure 4. Spiral Compressor

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CLL251: HEAT TRANSFER FOR CHEMICAL ENGINEERING

Prof. MKS Verma

Topic: Study of Air Conditioning Unit of Electric Vehicles

Group Members :

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Suyash Pankaj Gupta 2022CH11433

Priyanshu 2022CH11465

Submission date : 08-05-2024

CLL251: HEAT TRANSFER FOR CHEMICAL ENGINEERING

REPORT

Topic: Study of Air Conditioning Unit of Electric Vehicles

ABSTRACT:

As time goes on, discharge standards have become stricter. This has made problems with environmental toxins even more important. People also want cars that are better for the earth and don't use dangerous fuels. Standard EVs (Electrical Vehicles) meet this need. Almost all cars, even electric vehicles, have air conditioning to keep people cool, especially in places that are very hot or dry. A gas-powered car's air conditioning system can increase fuel consumption by up to 20%. R290 was chosen as the best new refrigerant for the electric car heat pump air conditioning system. Setting up a performance test platform proves that the electric car heat pump air-conditioning system with water loop based on R290 refrigerant is both possible and better.

INTRODUCTION:

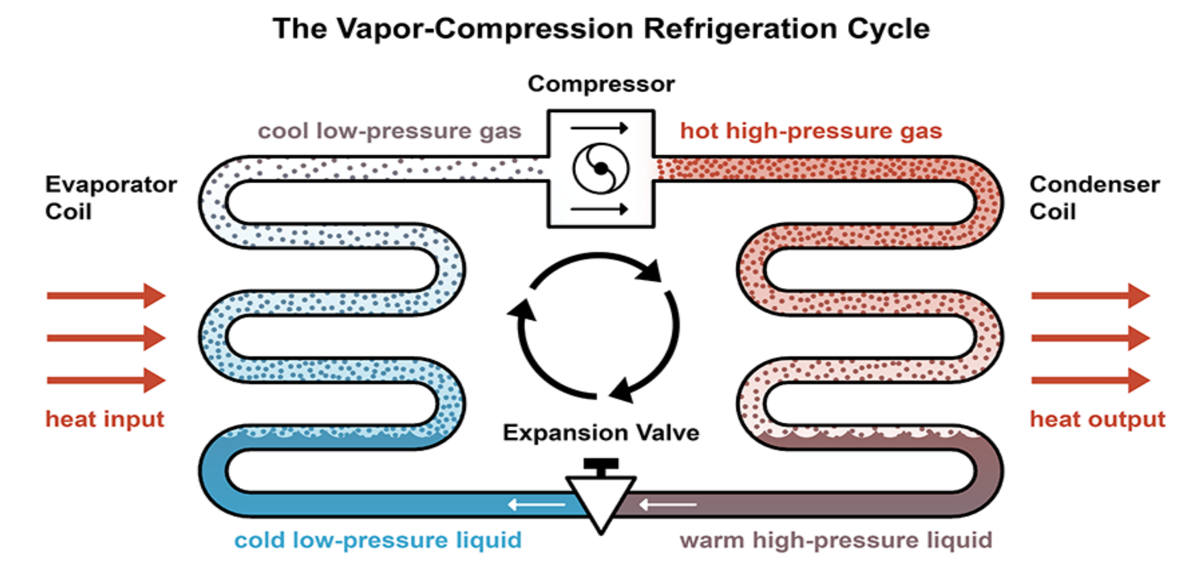
In recent years, the automobile sector has seen substantial changes due to the emergence of electric cars (EVs). Despite the widespread focus on developments in battery technology, electric drivetrains, and autonomous capabilities, the air conditioning system is sometimes disregarded as a crucial area of research. The use of air conditioning in electric cars has distinct obstacles and opportunities in contrast to conventional internal combustion engine vehicles. With the growing popularity and market dominance of electric vehicles, the effectiveness and functionality of their air conditioning systems are becoming more crucial. Air conditioning not only plays a vital role in guaranteeing passenger comfort, but it also directly affects the entire range and energy consumption of electric vehicles.

The AC system in electric vehicles (EVs) is responsible for providing cooling, heating, and ventilation to the cabin. Its main purpose is to regulate the interior thermal conditions, including temperature, relative humidity, and air velocity, to provide safety and visibility by preventing fogging and ice formation. In addition, the batteries of electric vehicles operate within a specific temperature range. Efficient thermal control of the battery pack is essential to avoid early deterioration and consequent reduction in capacity. On average, AC systems in electric vehicles (EVs) reduce driving range by around 30-40%. The extent of the drop depends on the size of the AC system and the driving cycle.

To increase the usage of electric vehicles (EVs), it is necessary to enhance the driving range by minimizing battery power consumption. This may be achieved via the creation of a very efficient AC system. Therefore, the AC system plays a vital role in the advancement of electric vehicles. The AC system is the sole heat sink/source that enables effective cooling/heating at elevated/reduced ambient temperatures. The integration of the thermal management system, which combines the interior climate and battery pack, poses a significant problem for the AC system. Hence, it is imperative to discover a groundbreaking air conditioning solution for electric vehicles. This research seeks to examine the topic of air conditioning systems in electric cars, including their design, difficulties, and advancements. This report aims to emphasize the significance of improving air conditioning systems in electric cars to enhance their overall success and global acceptance by comprehending the complexities involved. Through our research, we will delve deep into the working of air conditioning systems of an electric vehicles, we will look at the different types of refrigerants used, their pros and cons, also we will look at the drawbacks of the AC systems involved.

METHODS:

VAPOUR COMPRESSION CYCLE:



The main components of an air-conditioned system are the compressor, the condenser, the expansion valve, and the evaporator.

- **COMPRESSOR :**
  The vapour compression cycle starts with the compressor that creates the flow of refrigerant through the air conditioning system. The compressor is usually driven by the engine using a drive belt with a magnetic clutch being used to engage and disengage the drive to the compressor. For electric and hybrid vehicles, the compressors are driven by electric motors.

Fig.2. Compressor

- **CONDENSOR :**

Fig.3. Condenser

In an electric vehicle, the condenser controls the heat that is made by parts like the motor and battery, making sure that the vehicle works well and lasts a long time. It transfers heat and keeps the engine away from getting too hot when being charged quickly or driven at high speeds for a long time i.e. acts as a heat exchanger.

- **EXPANSION VALVE :**

Fig.4. Expansion valve

Expansion valves remove pressure from liquid refrigerant, allowing it to change state from liquid to vapor in the evaporator. This process takes heat away from the tubes it expands in, which are in contact with the air you want to cool. Many expansion valves are thermostatically controlled. A sensing bulb attached to the valve monitors the temperature or pressure of the refrigerant leaving the evaporator.

- **EVAPORATOR :**
  The evaporator is an essential component in the air conditioning system of an automobile, responsible for chilling the air within the vehicle. The device extracts thermal energy from the air that flows across its coils, leading to the evaporation of the refrigerant and subsequently reducing the temperature. The cooled air is subsequently sent into the cabin, ensuring the occupants' comfort.

PROCESS :

We will look at the vapor compression cycle for AC. It is electric motors that power the compressor in hybrid and electric cars. The superheated refrigerant from the evaporator is sucked into the compressor, which gets its heat from the passenger area. The gas is then squished together, adding more heat. The hot, pressurized gas is then pushed from the compressor output port to the condenser, which has four parts: gaseous heat removal, compression, gas-to-liquid separation (modulator), and subcooling. The high-pressure refrigerant flows through these sections, with the heat from the high-temperature refrigerant gas exiting through the fins, allowing the gas to condense in the condensing area.

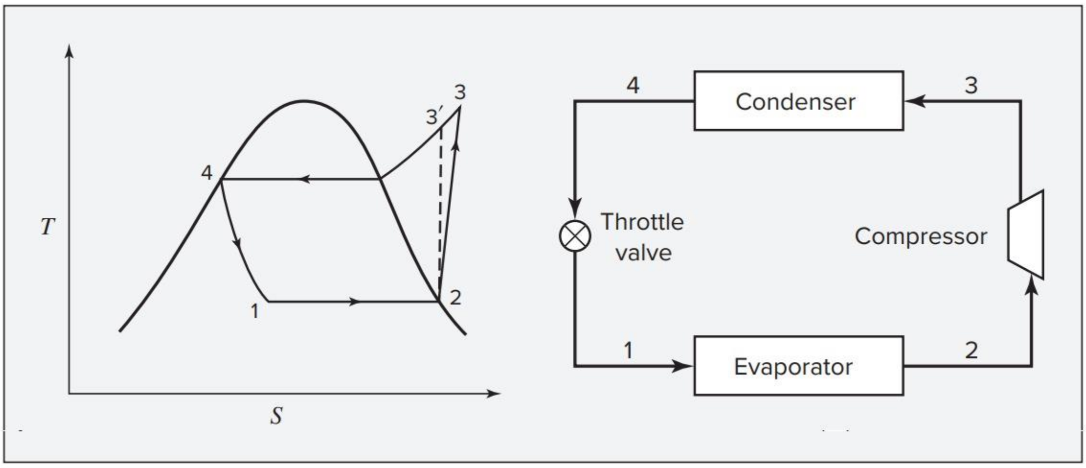


Fig.5. Vapour compression cycle

Forcing the liquid refrigerant into the gas-liquid separator separates the remaining gas from the liquid and releases heat. The subcooling segment chills the liquid refrigerant even further by releasing heat energy into the surrounding air via the condenser fins. This lowers the temperature even further and enhances cooling efficiency generally. The refrigerant is now forced through a tiny hole or orifice by the high pressure of the refrigerant, which results in the refrigerant entering the aperture as a mist that may then expand, as the chilled liquid refrigerant flows to the expansion valve. The refrigerant once again changes state from a heated, high-pressure liquid to a cooler low-pressure mist that can more readily absorb heat as it goes through the evaporator as a result of the expansion allowing the pressure to drop, which also lowers the temperature.

The low-pressure mist refrigerant enters the evaporator, the final component of the air conditioning system. Airflow through the evaporator's tank, tubes, and fins absorbs heat from the passenger compartment, causing the coolant to evaporate and return to a gas. This process is called the refrigerant cycle. The pressure monitor is a crucial safety element in some Air Conditioners, located between the compressor and expansion valve. If the coolant pressure is incorrect, which could damage system components, the compressor can be shut off.

- **RESULTS & DISCUSSION:**

A) SUITABLE REFRIGERANT :

Refrigerant	R134a	R1234yf	R410a	R744	R290
Chemical formula	CF3CH2F	CF3CF=CH2	R32+R125 (CH2F2+CHF2CF3)	CO2	C3H8
Boiling Point (◦C)	-26	-29	-51	-78	-42
Critical Temperature (◦C)	101	94.7	72	31.4	96.7
Critical Pressure (MPa)	4.1	3.4	5	7.4	4.2
GWP (Global Warming Potential)	1300	< 4	2090	1	3.3
ODP (Ozone Depleting Potential)	0	0	0	0	0
Flammability	A1	A2L	A1	A1	A3

Table.1. comparison of various refrigerant's thermophysical properties

A1: Non- Flammable   A2L : Middle Flammable   A3 : Highly Flammable   R: Refrigerant

In recent years, R134A, R1234YF, R410A, and other refrigerants in common use have no destructive effect on the ozone layer, but their GWP values are relatively high. R290 is a hydrocarbon refrigerant that can be obtained directly from liquefied gas. Its ODP is 0 and its GWP is low, so it is an ideal alternative refrigerant. R290 refrigerant not only has good thermophysical properties and environmental protection properties but also cannot corrode metal materials. It is compatible with general lubricating oils and mechanical structures and does not need to be synthesized. In addition, the operating pressure of the R290 heat pump system is almost the same as that of the R134a, so it can borrow the parts of R134a heat pump system directly. Therefore, this system selects R290 refrigerant as the best alternative refrigerant currently available.
R290 is considered a better alternative to R1234yf as it has better performance, lower generation temperature, and doesn't corrode metals. R290 is also more efficient, with a 30% improvement in volumetric efficiency and 15% improvement in compressor efficiency

compared to R1234yf. R290 has a better coefficient of performance (COP) for environment temperatures between 10°C and 35°C.

In India, R290 refrigerant gas costs between ₹295 and ₹1,200 per kilogram, depending on the type. While R1234yf refrigerant gas costs around ₹11,500–₹17,000 per kilogram.

B) MATHEMATICS INVOLVED:

The following results can be utilized to calculate theoretical thermal performance of R290.

h_{a1} = Air inlet enthalpy of vehicle heat exchanger

h_{a2} = Exhaust air enthalpy of vehicle heat exchanger

Q = Refrigerating / heating capacity of heat pump system

W = Consumption of compressor power

q = Air quantity at measuring point of heat exchanger in vehicle

v_n = Specific volume of moist air in front of nozzle

w_n = Moisture content of air in front of nozzle

Q_r = The refrigerating/heating capacity of refrigerant side in refrigerant loop

m_r = The refrigerant flow of system

h_{r1} = The inlet refrigerant enthalpy value of plate heat exchanger

h_{r2} = The outlet refrigerant enthalpy value of plate heat exchanger

Q_w = The cooling/heating capacity of water side in the water loop

m_{wc} = The water flow of system

t_{w1} = The inlet water temperature of heat exchanger in vehicle

t_{w2} = The outlet water temperature of heat exchanger in vehicle

m_r = The refrigerant flow of system

Refrigerating/heating capacity of heat pump system:

$$\boxed{Q = (q * |h_{a1} - h_{a2}| / 3.6 * v_n * (1 + w_n))}$$

Refrigerating/heating performance factor of heat pump system:

$$\boxed{\text{COP (Coefficient of performance)} = Q / W}$$

Refrigerant side refrigerating/heating capacity in refrigerant loop:

$$Q_r = m_r \ |h_{r1} - h_{r2}| \ / \ 3.6$$

The water loop is the water side cooling/heating capacity:

$$Q_w = m_{wc} \ |t_{w1} - t_{w2}| \ / \ 3.6$$

Heat exchanger Log mean temperature difference :

$$\Delta T_m = (\Delta T_1 - \Delta T_2) \ / \ \ln (\Delta T_1 - \Delta T_2)$$

Which simplifies to,

$$\Delta Tm = (\Delta T1 + \Delta T2) \ / \ 2 \quad \text{if} \quad (\ \Delta T1 \ \Delta T2 > 1.7\ )$$

For,

$$\text{Counter current:} \ \ \Delta T_1 = T_2 - t_1$$

$$\text{Downstream:} \ \ \Delta T_1 = T_2 - t_2$$

REFRIGERANT	Ambient Temperature (◦C)	Working condition	Heat/Cooling Capacity	COP
R290	-20	HEATING	6217	2
R290	38	COOLING	7501	1.3

Table.2. Theoretical thermal performance of R290

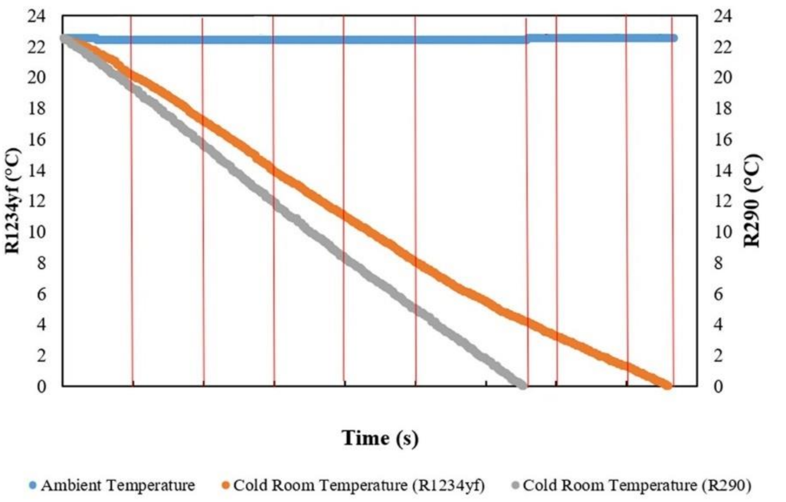


Fig.6. Temperature time distribution for various refrigerants

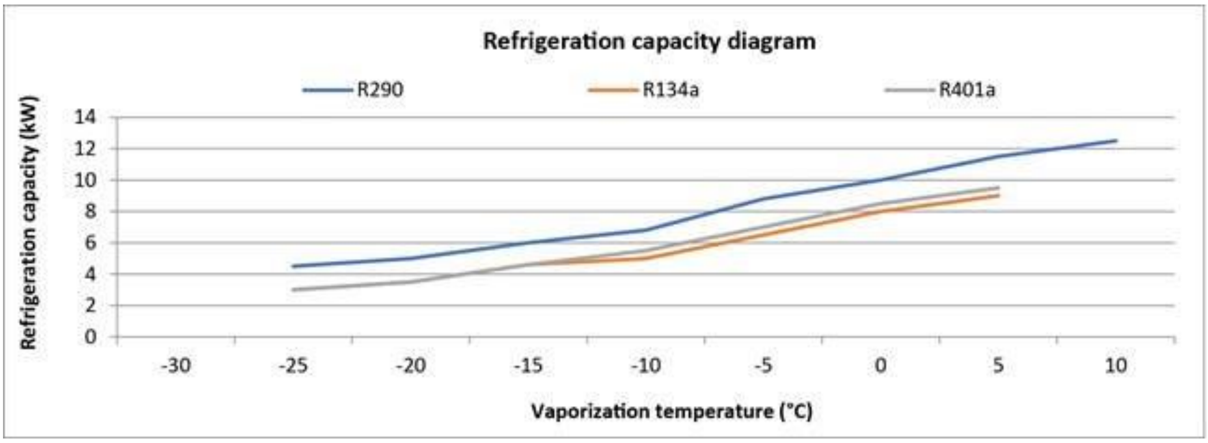


Fig.7. Refrigeration capacity diagram

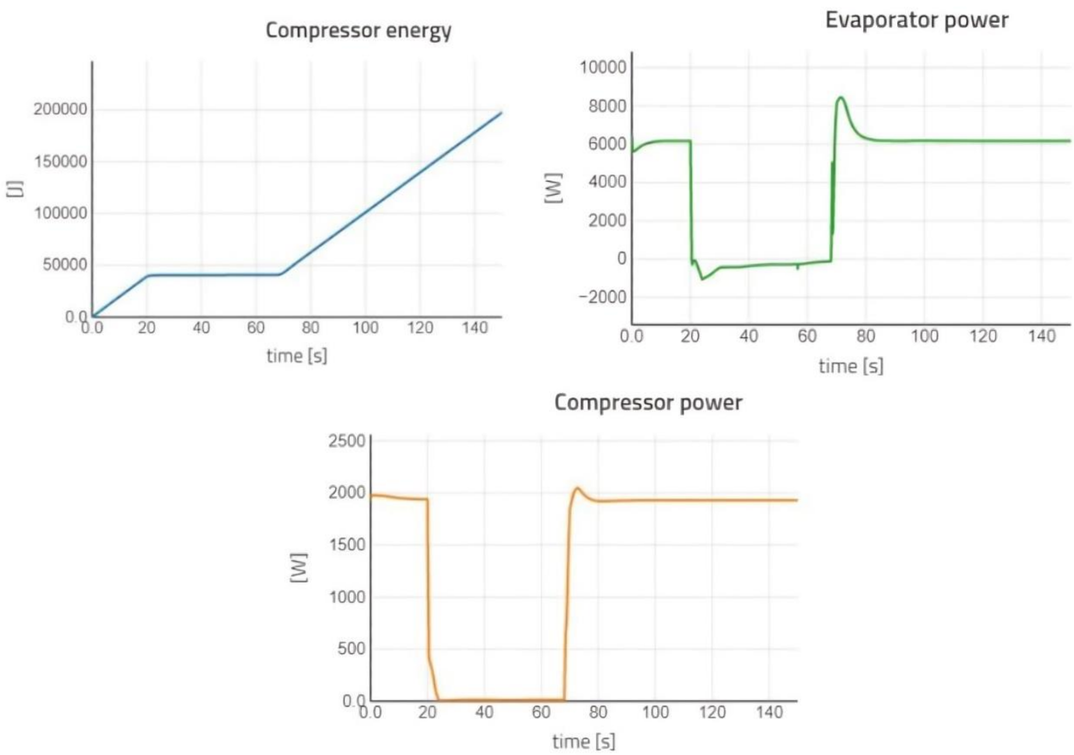
Refrigeration Capacity

Refrigeration capacity refers to the amount of heat energy that a refrigeration system can remove or transfer from a space (such as a room, refrigerator, or air conditioning unit) within a given time. It is a crucial parameter in designing and evaluating cooling systems.

R290 (Propane): Excellent performance at higher temperatures, making it suitable for applications with elevated cooling demands.

R134a: Lower capacity overall, possibly less efficient or less suitable for extreme temperature variations.

R401a: Balanced performance, offering moderate capacity across the temperature spectrum.

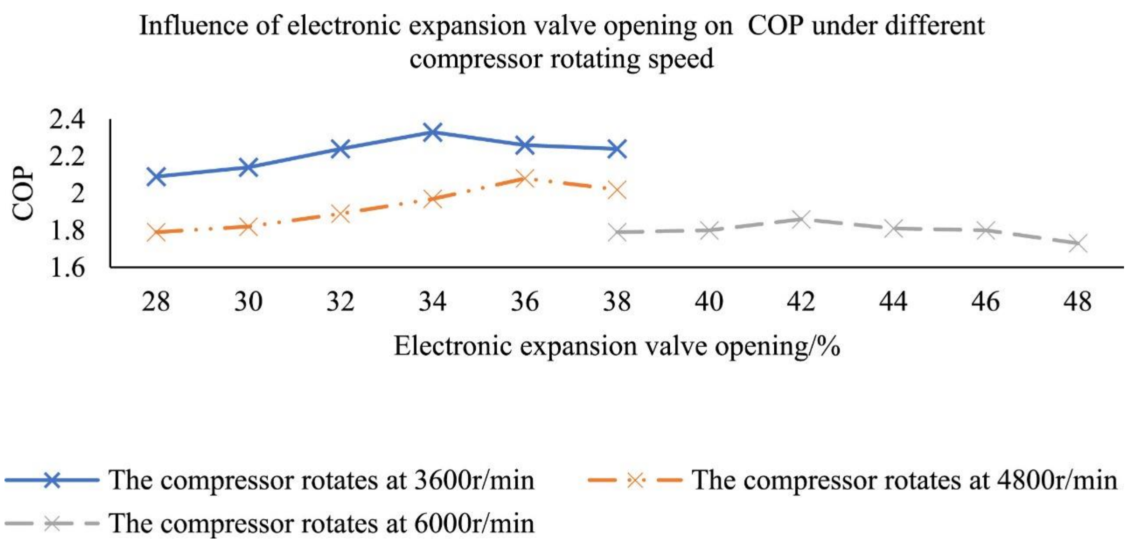


Interpretation:

The evaporator experiences fluctuations in power, possibly due to varying cooling demands or changes in the surrounding environment.

The compressor undergoes cycles of operation, with intermittent shutdowns or reduced load during certain intervals.

The cumulative energy consumption by the compressor steadily rises, reflecting the overall work done by the system.



Interpretation:

COP Trend with Valve Opening:

As the electronic expansion valve opens wider (increasing percentage), the COP generally improves.

Higher valve opening allows better refrigerant flow control, enhancing system efficiency.

Effect of Compressor Speed:

At each valve opening level, the COP varies with compressor speed.

Higher compressor speeds tend to yield better COP values.

Optimal Operating Point:

The optimal valve opening and compressor speed combination depends on system design and load conditions.

SOLUTIONS TO AIR CONDITIONING SYSTEM IN ELECTRIC VEHICLE :

- **Fuel heating with vapor compression refrigeration (VCR-FH) :**
  The fuel-fired heater is most often used as an auxiliary heater in cars, and it is known to have a high thermal efficiency. A fuel-fired heating system that doesn't need the main battery of the electric car and only uses the small amount of fuel needed for the climate control system could be used as a temporary fix.

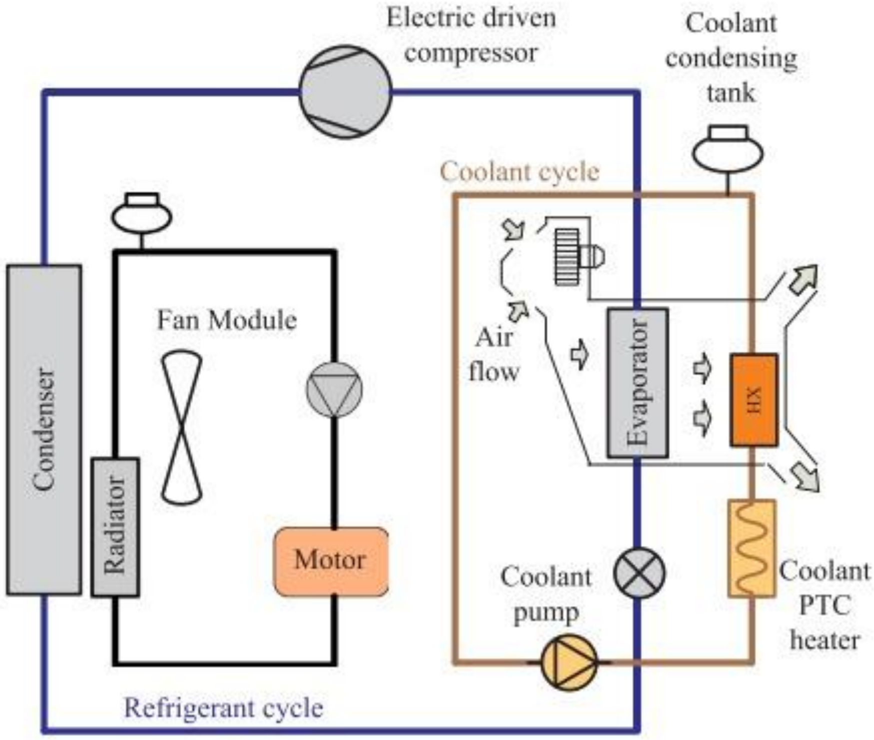


Fig.8. AC system configuration of i-MiEV (Mitsubishi electric vehicle)

- Vapor compression that can be undone the vapor compression cycle in a heat pump uses an inverter-driven compressor and a four-way valve (4 Wv) to change the direction of the flow of gas. This cycle can both cool and heat. The law of physics says that the heat pump system's coefficient of performance (COP) is greater than 1. In this way, it uses less energy than separate heater and air conditioning units.

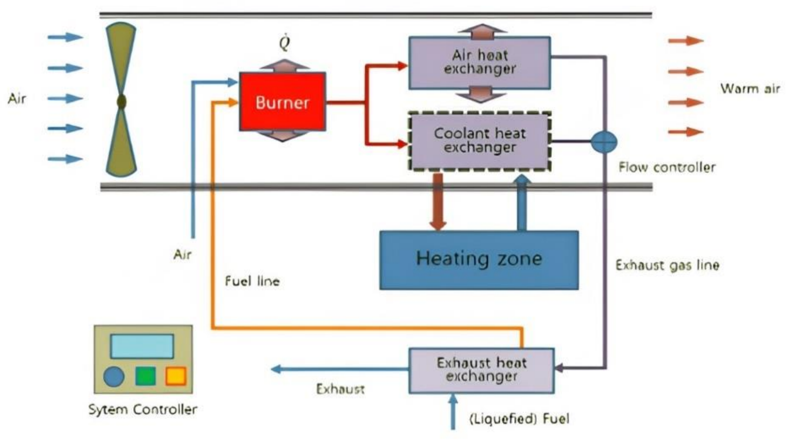


Fig.9. Schematic of the hybrid FH (fuel heating) system

There are two main types based on a larger definition:

i. The basic VC-HP AC systems.
ii. The enhanced VC-HP setup with demisting.

*(VC- HP : Vapour Compression Heat Pump)

- AC systems that use natural or low-GWP refrigerants—R134a is the most common refrigerant used in car AC systems right now. Although R134a has zero ozone depletion potential (ODP), its global warming potential (GWP) is up to 1300. The possible replacements for R134a that have a GWP below 150 can be put into two groups:
  A. Natural refrigerants like R744, R717, hydrocarbons,
  B. New environmentally friendly refrigerants like R1234yf, R1234ze, and R152a.
- Lightweight and Compact Components: Advancements in materials and component design have led to more lightweight and compact AC compressors, condensers, and evaporators. This not only reduces the overall weight of the vehicle but also frees up space for other components or increases cargo capacity.
- Variable Refrigerant Flow (VRF) Systems: Similar to those used in buildings, VRF systems can adjust the flow of refrigerant according to the cooling demands of different zones in the vehicle. This allows for more precise control and energy savings compared to traditional fixed-speed compressors.

CONCLUSION :

This work presents a comparative analysis of R290 refrigerant with R134a, R1234YF, R410A, R22, and R744 through theoretical research. The primary focus of the study is on the thermal characteristics, safety, environmental protection, and system performance. The analysis determines that R290 refrigerant is the optimal choice for the air conditioning system of electric vehicles with heat pump technology. The study of this system is beneficial for advancing the use of clean and eco-friendly refrigerants in electric vehicle heat pump air-conditioning systems. This will help achieve zero ozone depletion potential (ODP) and low global warming potential (GWP), while also reducing energy consumption and enhancing the operational efficiency of the heat pump air-conditioning system. Consequently, it will effectively extend the driving range of electric vehicles and address the obstacle that hampers their rapid development. The manufacturers of electric vehicles are presenting an innovative perspective by pushing the new technology outside the realm of electric vehicles. In doing so, they are advancing the framework for air conditioning and controlling the atmosphere. Turboexpanders are more efficient than throttle valves during the expansion process. Unfortunately, automobile air conditioning systems cannot accommodate the turboexpander due to its enormous size. The utilization of two distinct cycles in a cascade compression cycle increases the total system efficiency by allowing the high-temperature cycle to reject heat at a higher level than it would achieve alone, allowing us to cool a wide range of temperatures and pressures. It is possible to increase the vehicle's total energy efficiency with systems that utilize the electric motor's or power electronics' waste heat to augment the air conditioning system.

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5. Introduction to chemical engineering thermodynamics – J.M. Smith Davis, H. C. Van Ness, M. M. Abbott, M. T. Swihart.
6. Heat transfer by J.P. Holman.

APPENDIX :

The used refrigerants are :

1. R134a --> 1,1,1,2-Tetrafluoroethane (also known as norflurane (INN) R-134a, Klea 134a, Freon 134a, Forane 134a, Genetron 134a, Green Gas, Florasol 134a, Suva 134a, HFA-134a, or HFC-134a) is a hydrofluorocarbon (HFC) and haloalkane refrigerant.
2. R1234yf--> 2,3,3,3-Tetrafluoropropene, is a hydrofluoroolefin (HFO) refrigerant with the chemical formula CH_2=$CFCF_3$.
3. R-410A--> sold under the trademarked names AZ-20, EcoFluor R410, Forane 410A, Genetron R410A, Puron, and Suva 410A, is a zeotropic.
4. R744, also known as CO2, is a natural refrigerant. It's a collarless, odourless, and tasteless gas that's non-flammable, non-toxic, and non-corrosive.
5. R290, also known as propane, is a natural hydrocarbon refrigerant gas. It's a byproduct of refining natural gas and petroleum, and is a single-component hydrocarbon substance with the formula C3H8.
6. R401A, also known as Puron, is a hydrofluorocarbon (HFC) refrigerant.
7. R717, also known as ammonia (NH3), is a colorless, pungent, and highly toxic refrigerant used in low and medium-temperature refrigeration.
8. R152a, also known as difluoroethane (DFE), is a hydrofluorocarbon (HFC) refrigerant.
9. Chlorodifluoromethane or difluoromonochloromethane is a hydrochlorofluorocarbon (HCFC). This colorless gas is better known as HCFC-22, or R-22, or CHClF2.
10. R1234ze is a hydrofluoroolefin (HFO) refrigerant.

Some important terms definition used in this report:

- **The Coefficient of Performance (COP)** is a ratio that describes the efficiency of a system. COP = power output / power input.
- **Ozone depletion potential (ODP)** is a measure of how much damage a chemical can cause to the ozone layer relative to a similar mass of trichlorofluoromethane (CFC-11).

- **Global warming potential (GWP)** is a measure of how much heat a greenhouse gas traps in the atmosphere relative to carbon dioxide (CO_2) over a given period of time. GWP is calculated by comparing the amount of energy absorbed by the emissions of 1 ton of a gas to the emissions of 1 ton of CO_2.

Link for simulation : https://youtu.be/62XwioeCa_M

The simulation is modelled as a video and is uploaded on youtube. You can check it on clicking the above link.

Thankyou

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