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Theme

Thermodynamic Evaluation of a Heat Pump Employing R1234yf as an Alternative to R134a Refrigerant

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Abstract

In view of the increasing demand for energy efficient and environmentally friendly heating technologies, this work presents a numerical thermodynamic investigation of a heat pump for the assessment of the system performance under different operating conditions and comparison of the performance of two different refrigerants, R134a and its possible alternative R1234yf. The system was modeled and simulated using MATLAB software along with the REFPROP database developed by NIST for accurate calculation of thermodynamic and transport properties, enhancing the reliability of the simulation, particularly in the two-phase region. A single-stage heat pump based on the standard vapor compression cycle was considered. The heat pump consists of a compressor, condenser, expansion valve and evaporator. The analysis makes some simplifying assumptions: steady state, negligible pressure losses, isenthalpic expansion, and the compressor isentropic efficiency at varied values. System performance was evaluated through COP_h (heating coefficient of performance) considering evaporation and condensation temperatures at different values too. The results indicate that the performance increases as the evaporating temperature increases. The coefficient of performance (COP_h) increases from 2.541 to 3.031 for R134a and from 1.982 to 2.410 for R1234yf as the evaporating temperature increases from 20 °C to 30 °C. The reduction in the work of the compressor is responsible for this improvement, while the increase in the condensing temperature decreases the COP_h due to the higher work of compression. The comparison results show that R134a has a better thermal performance while R1234yf has lower discharge temperatures and better environmental properties especially in terms of global warming potential. Therefore, as a final result of this investigation, it is obvious that R1234yf despite its lower performance compared to R134a, it can be proposed as an environmentally friendly alternative to R134a, in which future improvements such as integrating nanoparticles and the study of this refrigerant as a nanorefrigerant within the heat pump system could give promising results.

Keywords: Simulation, Heat pump, COP, R134a, R1234yf, GWP.

الملخص

نظراً للطلب المتزايد على تقنيات التدفئة الموفرة للطاقة والصديقة للبيئة، يقدم هذا العمل دراسة حرارية ديناميكية عددية لمضخة حرارية بهدف تقييم أداء النظام في ظل ظروف تشغيل مختلفة، ومقارنة أداء سائلي عمل مختلفين، هما R134a وبديله المحتمل R1234yf. تم نمذجة النظام ومحاكاته باستخدام برنامج MATLAB جنبًا إلى جنب مع قاعدة بيانات REFPROP التي طورها المعهد الوطني للمعايير والتقنية (NIST) من أجل الحساب الدقيق للخصائص الديناميكية الحرارية وخصائص النقل، مما يعزز موثوقية المحاكاة، لا سيما في منطقة الطورين. تم النظر في مضخة حرارية أحادية المرحلة تعتمد على دورة ضغط البخار القياسية. تتكون المضخة الحرارية من ضاغط ومكثف وصمام تمدد ومبخر. ويستند التحليل إلى بعض الافتراضات المبسطة: الحالة المستقرة، وفقدان الضغط الضئيل المتجاهل، والتمدد الإيزنتالبي، وكفاءة الضاغط الإيزنتروبية عند قيم متنوعة. تم تقييم أداء النظام من خلال معامل الأداء الحراري (COP_h) مع الأخذ في الاعتبار درجات حرارة التبخر والتكثيف عند قيم مختلفة أيضًا. تشير النتائج إلى أن الأداء يزداد مع ارتفاع درجة حرارة التبخر. . يرتفع معامل الأداء (COP_h) من 2.541 إلى 3.031 بالنسبة لـ R134a ومن 1.982 إلى 2.410 بالنسبة لـ R1234yf مع ارتفاع درجة حرارة التبخر من 20 درجة مئوية إلى 30 درجة مئوية. ويُعزى هذا التحسن إلى انخفاض عمل الضاغط، في حين أن ارتفاع درجة حرارة التكثيف يؤدي إلى انخفاض معامل الأداء (COP_h) بسبب زيادة عمل الضغط. وتُظهر نتائج المقارنة أن مادة R134a تتمتع بأداء حراري أفضل، في حين تتمتع مادة R1234yf بدرجات حرارة تفريغ أقل وخصائص بيئية أفضل، خاصة من حيث إمكانية إحداث الاحترار العالمي. لذلك، كنتيجة نهائية لهذا البحث، من الواضح أن R1234yf، على الرغم من أدائه الأقل مقارنة بـ R134a، يمكن اقتراحه كبديل صديق للبيئة لـ R134a، حيث يمكن أن تؤدي التحسينات المستقبلية، مثل دمج الجسيمات النانوية ودراسة هذا المبرد كمبرد نانوي داخل نظام المضخة الحرارية، إلى نتائج واعدة.

الكلمات المفتاحية:المحاكاة، المضخة الحرارية، معامل الأداء(COP) ، R134a، R1234yf، إمكانية احداث الاحتباس الحراري.

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إهداء

بسم الله الرحمن الرحيم، والحمد لله الذي بنعمته تتمّ الصالحات،

إلى من أنار لي دروب العلم، ووجّه خطاي بحكمته وصبره، أستاذي الفاضل، لك مني أسمى عبارات الشكر والتقدير.

إلى زميلتي **عيدي مسعودة** التي شاركتني مشوار التعب والسعي، فكانت خير رفيقة درب، لكِ مني خالص الامتنان على كل لحظة دعم ومساندة.

إلى **نفسي**... التي صبرت واجتهدت، وواجهت الصعاب حتى وصلت، أهديكِ هذا النجاح فخرًا بما بذلتِه من جهد.

إلى **أمي و أبي** سندي الدائم ومصدر قوتي، أنتم الحلم الذي كبر معي حتى تحقق، لكم أهدي هذا الإنجاز بكل حب واعتزاز.

إلى إخوتي **أسامة،سهيل،راما،محمد**، الذين كانو دائما بجانبي بقربهم استمد القوة ومعهم يهون الطريق ادامكم الله لي سندا لا ينتهي.

وأسأل الله أن يجعل هذا التخرج بداية خيرٍ لما هو أجمل، وأن يوفقنا جميعًا لما فيه الخير والنجاح

اتقدم بشكر خاص ل **خالتي الحكيمة لهرم اميرة وحرمها** على اعتنائهما بي خلال مشواري الجامعي والى **الاستاذ الدكتوررهيوي سليم**

الى اصدقائي مباركي **سيف الدين، رحال عبد السلام، شويخي عبد الله.**

باسمي وباسم زميلتي اهدي هذا التعب والعمل لمن فارقو هذه الحياة الى صديقي وأخي المرحوم **شطي العطافي** وعائلته والى الطفلة **سلامي تسنيم** وعائلتها رحمهما الله واسكنهما فسيح جناته.

جروني صهيب

إهداء

إلى من كلل العرق جبينه وعلمني أن النجاح لا يأتي إلا بالصبر والإصرار إلى النور الذي أنار دربي وسراج الذي لا ينطفي نوره بقلبي ابدا الى من بذل الغالي والنفيس واستمديت منه قوتي واعتزازي بذاتي

والدي العزيز

إلى من جعل الجنه تحت أقدامها وسهلت لي الشدائد بدعائها إلى الإنسانه العظيمة التي لطالما تمنت أن تقر عينها لرؤيتي في يوم كهذا.

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صديقاتي الغاليات

عيدي مسعودة

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Nomenclature

COP	Coefficient of Performance
COP_h	Heating Coefficient of Performance
GWP	Global Warming Potential
ODP	Ozone Depletion Potential
VCRS	Vapor Compression Refrigeration System
LV	Lower Value
UV	Upper Value
AAC	Automotive Air Conditioning
HP	Heat Pump

General Introduction

Looking at energy and environmental issues globally, there's a clear and growing need to make heating and cooling systems more efficient. Most refrigeration systems rely on vapor compression technology. The problem is, these systems use a lot of energy and can also damage the environment, mainly because of the power sources they use and the specific fluids inside them. Given all this, it's crucial to boost their performance and fine-tune them. There is a need to make these systems better and optimize them by analyzing either their energy use through different scenarios [1].Heat pumps and vapor compression systems are really important for saving energy and maintaining the use of heat in different situations. Numerous studies have pointed out that heat pump technology is one of the most promising technologies that make heating and cooling uses much more energy-efficient [2].

However, standard refrigerants have some significant environmental problems. As an example; a commonly used refrigerant named R134a has a relatively high Global Warming Potential (GWP) [3]. Existing data further underscores the environmental implications and mounting regulatory scrutiny concerning these agents. Consequently, given that R134a exhibits a 100-year global warming potential of 1430, considerable research efforts are presently focused on evaluating alternative refrigerants [2].

Therefore, research efforts have increasingly concentrated on developing alternatives characterized by a low global warming potential (GWP). Among these, hydrofluoroolefins (HFOs) have garnered substantial interest, principally owing to their inherently low GWP [3]. One of the proposed alternatives, R1234yf has been widely considered as a successor to R134a. This particular hydrofluoroolefin refrigerant has, in fact, established itself as a viable replacement for R134a [1]. Similarly, various comparative studies have affirmed its potential suitability. "Low GWP refrigerants R1234y are potential replacements for R134a." Furthermore, investigations have indicated its effective performance under analogous operating conditions. Thus, R1234yf seems to be an adequate drop-in refrigerant for R134a [2].

Additionally, Numerous analyses conducted with this particular refrigerant offers a foundational understanding for thermodynamic assessment. In this work, a comparative study that investigates the thermodynamic performances of a heat pump employing R1234yf as a possible replacement for R134a has been conducted. The analysis incorporates variations in relevant operational parameters. These include the evaporation temperature, the condensation temperature, the heat source outlet temperature, and the efficiency of the compressor of the system, where the efficiency of R1234yf was examined alongside R134a across the various mentioned operating conditions.

Within this work, this introduction is followed by a comprehensive literature review and detailed explanation of heat pump systems in Chapter I including the thermodynamic model of the heat pump system. Chapter II presents the environmental challenges related to the selected refrigerants as working fluids in heat pumps. In Chapter III, the selected case study and the simulation methodology using appropriate software tools are introduced. Finally, Chapter IV presents, analyzes, and discusses the obtained results in detail.

Chapter I: Heat Pumps – Fundamental Principles

I.1. Overview of heat pump systems

I.1.1. Definition

A heat pump is a device that transfers heat from one place to another through the application of work. The most common form of heat pump technology can move heat from a ‘source’ of low temperature to a ‘sink’ of higher temperature.

A reversible cycle heat pump that is designed to heat and cool a building is the most common form of heat pump. Food refrigerators, freezers, and air conditioners are other forms of heat pumps [4].

Air source, ground source, and water source heat pumps utilize natural, available heat that can be upgraded to a usable heat of suitable temperatures for the purpose of space heating and/or cooling. Heat pumps require some form of electricity to run, which is 25 to 40 percent of the available heat, thus enabling efficiencies of 250 to 400 percent to be achieved [4].

I.1.2. Concepts

A heat pump works through a sealed loop filled with refrigerant. An electric compressor and a heat exchanger raise the refrigerants temperature and pressure.

A key element influencing how well a heat pump works is the gap between the evaporator's average temperature and the condenser's temperature.

The main thermodynamic parameter of a heat pump is The coefficient of performance (COP) is the primary thermodynamic parameter used to assess the efficiency of a heat pump.

. It compares heat output to electricity input at given operating temperatures for both the heat source and heating systems [5].

Heat pumps function on principles akin to those governing refrigerators and air conditioners. These systems employ a refrigerant cycle to draw low-temperature warmth, typically below 25 °C, and convert it into heat at a higher temperature.

A heat pump system involves three interconnected parts: a heat source (like air or water), a refrigeration system that heats the extracted energy, and a heat distribution system (such as radiators) that delivers the heat where it is needed [5].

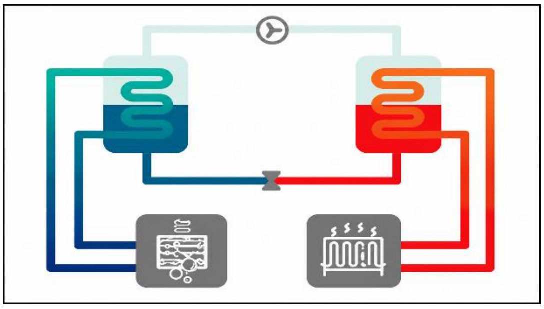


Figure I.1. *Basic diagram of a heat pump [5]*

I.2. Applications of heat pump systems

In the following, the most important applications of heat pumps are reviewed.

I.2.1. Heat yield with geothermal collectors/geothermal probes

I.2.1.1. Heat yield with geothermal collectors

Near-surface geothermal systems, known as geothermal collectors, are used with brine/water heat pumps to get heat from the ground at depths of about 1 to 2 meters. These are good when deep drilling is not allowed. In all geothermal collectors, a brine medium moves around, taking heat from the ground and bringing it to the brine/water heat pump. The usual collector types are surface, trench, spiral, and basket collectors. These collectors are placed horizontally, near the surface and under the frost line, much like underfloor heating. The frost line changes from place to place, but usually, they are placed 1.0 to 1.5 meters down. Depending on the collector and how it's installed, digging or drilling as deep as 5 meters may be enough. When putting down the pipes, make sure they are spaced evenly. If the pipes are too close, the collectors might take too much heat from the ground in certain spots, possibly freezing the area [6].

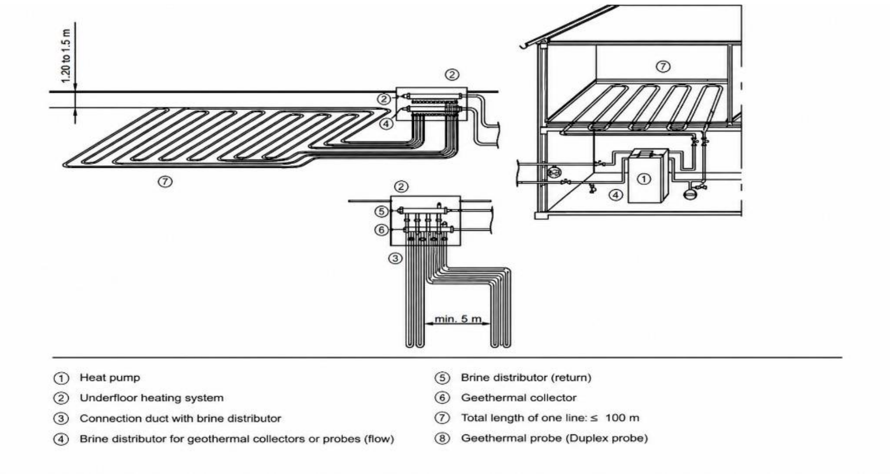


Figure I.2. *Heat yield with geothermal collectors [6]*

I.2.1.2. Heat yield with geothermal probes

Geothermal probes can extract heat from deep ground layers for brine/water heat pumps. A circulating brine solution within the probes absorbs ground heat and moves it to the heat pump. A key reason to use these probes is their small footprint. A probe's diameter is about 15 cm; space is mainly needed for drilling. Another benefit is high yearly because the temperature deep underground stays consistently warm. Installing a geothermal probe system requires one or more boreholes. Double U-pipes go into these holes, which are then sealed with concrete.

Under typical hydrogeological conditions, expect an average extraction rate of 50 W/m of probe length [6].

I.2.2. Drying buildings/drying screed (higher heat demand)

New buildings, especially those using monolithic construction, have a lot of water in materials like tile, cement, and plaster. Before putting on top layers like tiles or wood floors, the base needs to be mostly dry. To avoid damage, this water has to evaporate through heating. This process needs more heat than regular central heating. Often, standard heat pumps can't meet this higher demand. So, you might need to use on-site drying equipment or a fast-heating water heater to get the job done [6].

I.2.3. Cooling

I.2.3.1. Utilisation of the primary source

Reversible air/water heat pumps, or brine/water and water/water heat pumps, can cool actively because the compressor runs and uses its cooling ability. The heat made goes away by the main source (or a consumer). During warmer months, brine/water and water/water heat pumps might cool buildings using the heat source's temperature (main source) for natural cooling. Underground temperatures stay pretty steady throughout the year. In undisturbed ground, expect only small temperature changes of about ±1.5 K around 10 °C below 5 m [6].

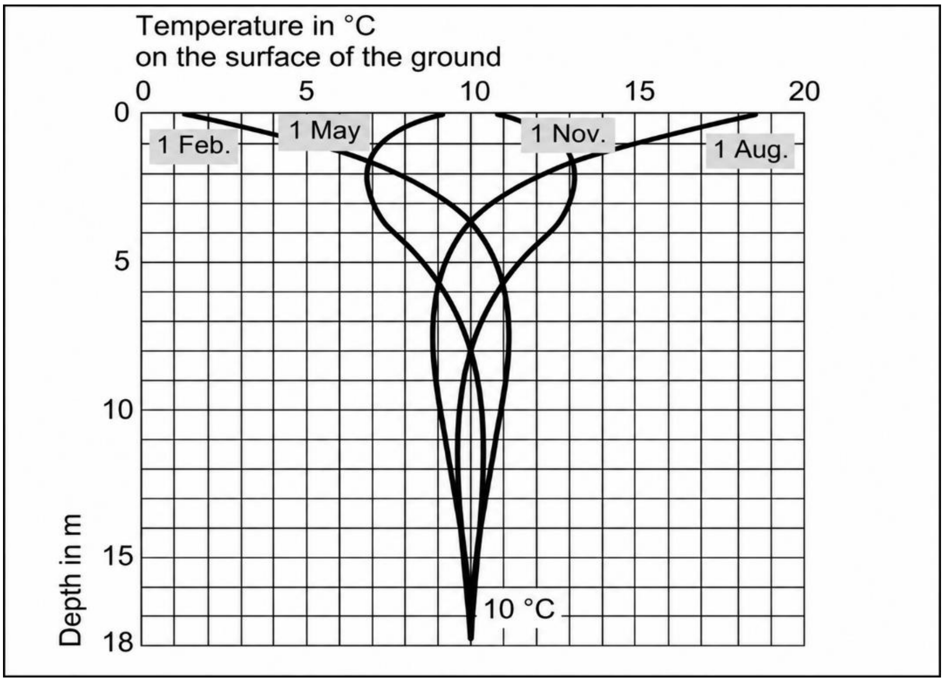


Figure I.3. *Temperature curve in undisturbed ground subject to depth and time of year*

I.3.Historical development of heat pump technology

In 1824, the French scientist Sadi Carnot proposed the Carnot cycle, a theory that became the basis for heat pump tech. Later, in 1852, British scientist L. Kelvin suggested using freezing devices for heating, imagining a heating system he termed a heat multiplier. Following this initial concept, many scientists and engineers researched heat pumps for about 80 years. In 1912, Zurich, Switzerland, successfully installed a heat pump system using river water as a heat source for heating, representing an early water-source heat pump and the world's first operational heat pump system. The heat pump industry grew quickly from the 1940s to the early 1950s, with heat pumps for homes and industrial buildings entering the market, marking the early stage of heat pump tech development. The 1970s saw even more growth, with countries worldwide prioritizing heat pump study. Organizations like international energy agencies and European communities created large-scale heat pump development plans, leading to new tech and widespread in air conditioning and industrial applications, playing a key part in energy saving and environmental protection. In the 21st century, rising fuel prices driven by the energy crisis have improved mature heat pumps, because these heat pumps had features such as recycling low-temp thermal energy, saving energy, and protecting environment. The former International Thermal Energy Administration established a heat pump programmed at its international heat pump center to promote the tech to countries worldwide. Governments in the U.S., Canada, Sweden, Germany, Japan, and South Korea issued guidelines to push the application of heat pump tech. China's heat pump research began about 20 to 30 years after the rest of the world. After the founding of the People’s Republic of China, the country started to introduce heat pump tech with the start of more industrial construction. Entering the 21st century, because of the rapid growth of cities in China's coastal areas, the rise in per capita GDP, the 2008 Beijing Olympic Games, and the 2010 Shanghai World Expo, the Chinese air conditioning market grew significantly. Heat pump tech developed quickly, with continuous innovation. Starting in 2001, the Chinese heat pump industry moved from introduction to growth in just five years. This rapid development is because energy issues made the energy-saving benefits of heat pumps stand out. Also, the collaboration of many groups promoted tech innovation in the industry [7].

I.4. Vapor compression heat pump configurations.

I.4.1. Carnot VCRS (Heat Pump)

The Vapor Compression Refrigeration System (VCRS) is the most common refrigeration/heat pump cycle. It includes four processes: compression, condensing, expansion, and evaporation (Figure I.4). Understanding this cycle is key to understanding the Gas Absorption Heat Pump (GAHP), which will be discussed later

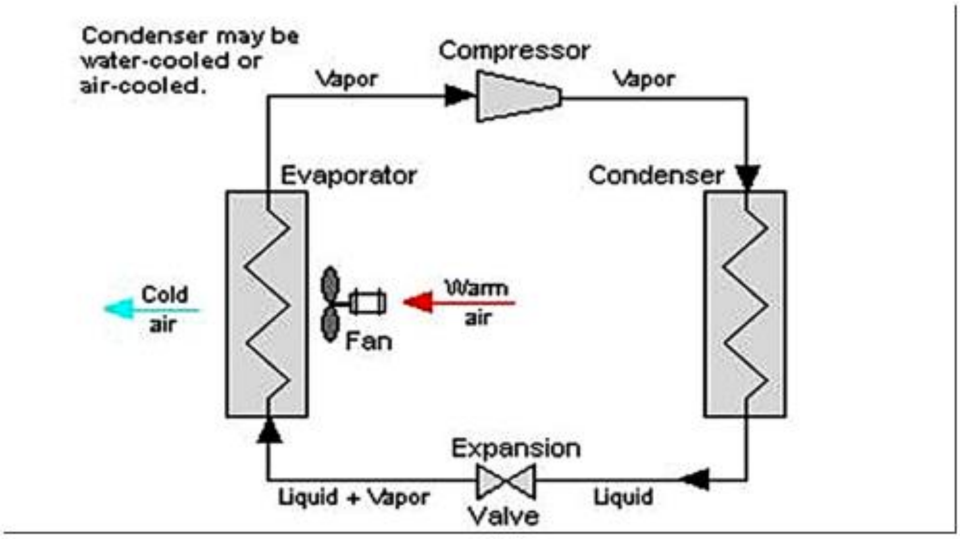


Figure I.4. *Schematic diagram of vapour compression refrigeration system [20]*

I.4.2. Carnot Cycle T-s diagram for VCRS

Referencing real-world systems to the ideal Carnot Cycle can be helpful. The Carnot Cycle can be seen through a standard [8].

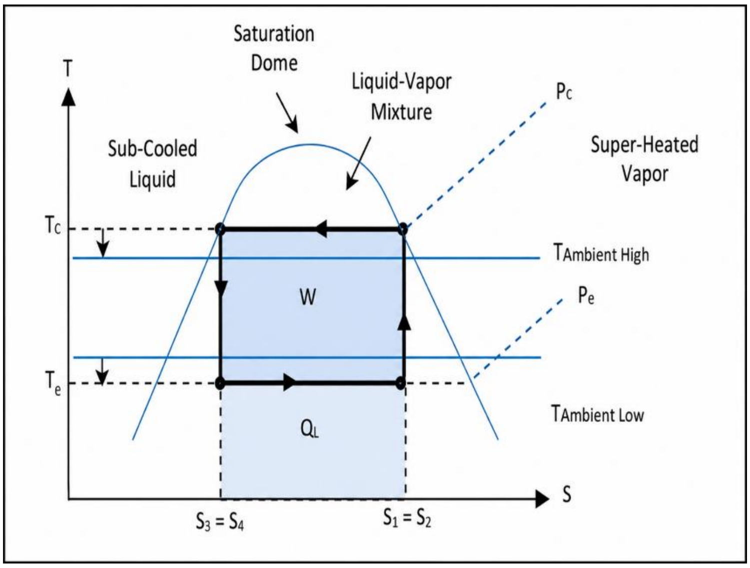


Figure I.5. *T-S diagram ideal Carnot vapor compression cycle [8]*

I.4.3. Carnot VCRS Cycle with Dry Compression

The Carnot Cycle, as shown in Figure I.4 has some problems:

1. Because of natural irreversibilities, it's not possible to create a machine that actually uses a Carnot Cycle.

2. Figure I.6 shows a Carnot refrigeration cycle with dry compression, which gets rid of the wet compression issue. This system uses one isentropic compression process (1-2) from evaporator pressure PE to an intermediate pressure PI and temperature TC, followed by an isothermal compression process (2-3) from the intermediate pressure Pi to the condenser pressure PC. While this change avoids wet compression, the isothermal condensation process needs two compressors: one for PE to PI and another for PI to PC. This isn't a good solution. The next part will introduce a more useful VCRS that fixes these issues [8].

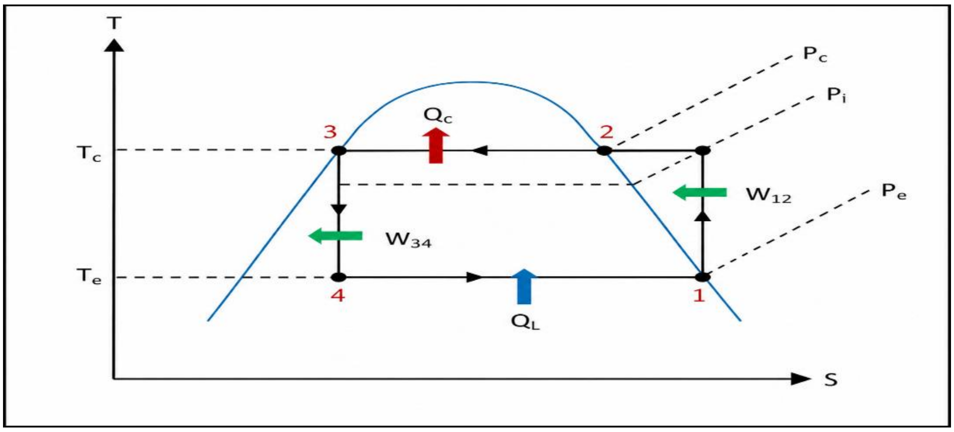


Figure I.6. Diagram Carnot vapor compression cycle with dry compression [8]

I.5. Description of main components and thermodynamic cycle.

I.5.1. Systems

Figure I.7 shows the four main types of thermodynamic systems, sorted by how they interact with mass (Δm), work (W),and heat Q [8].

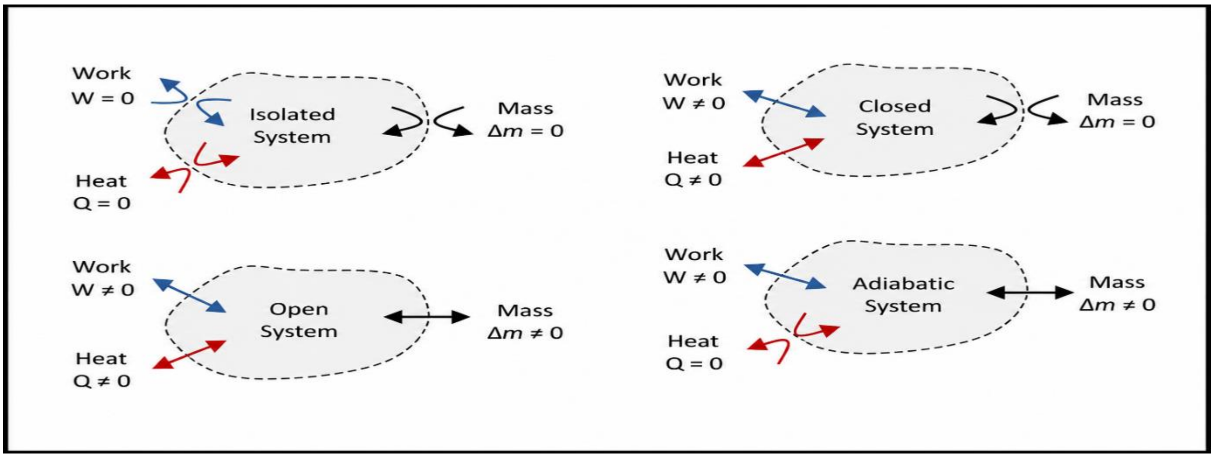


Figure I.7. Permeability of systems [8]

Figure I.8 Illustrates the sign conventions for work and heat. These conventions come from early studies of heat engines, where the goal was to produce work from heat input. Some books, note that heat and work entering a system are positive, while heat and work leaving a system are negative [8].

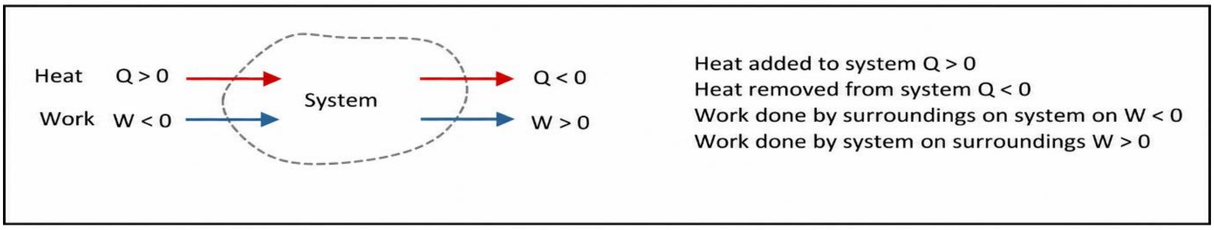
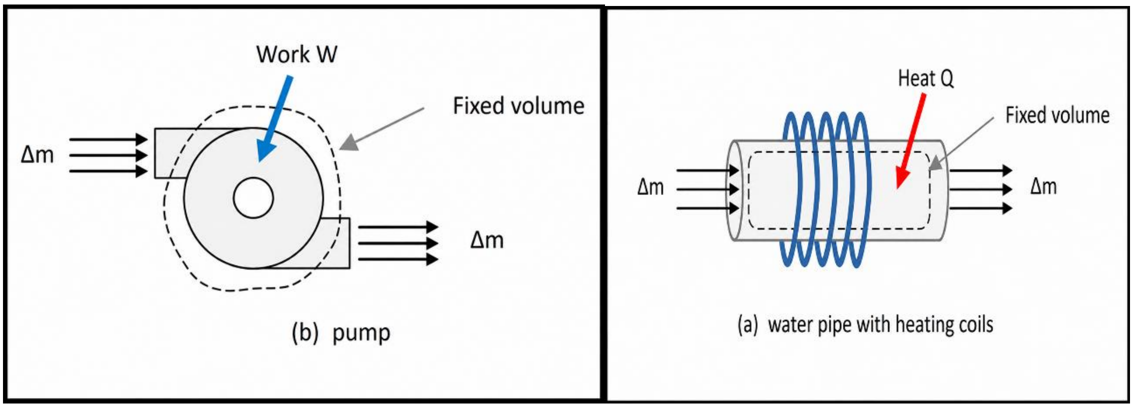


Figure I.8. *Signs for work and heat, based on heat engine convention [8]*

Figure I.8 Signs for work and heat, based on heat engine convention, an isolated system does not allow the transfer of mass, work, or heat. It cannot interact with its surroundings. Once an isolated system is in equilibrium, it remains in that state indefinitely. For example, imagine a thermos that is perfectly insulated and at rest The universe is also thought of as an isolated system since there is nothing outside of it. On the other hand, an open system does allow the transfer of mass, work, and heat. It is also called a control volume system. The borders of a control volume may change, but the volume itself stays the same. Some common examples are heat exchangers, pumps, turbines, and boilers. For instance, a section of water pipe with a heater coil around it is an open system. Mass moves through the pipe, which has a fixed volume, and heat can be added [8].



(b) pump

(a) water pipe with heating coils

Figure I.9. *Signs for work and heat, based on heat engine convention [8]*

A closed system, also known as a control mass system, allows energy transfer as work and heat but prevents mass transfer. While the mass remains constant, the volume can change. For instance, imagine a gas inside a cylinder fitted with a piston. Compressing the gas by moving the piston requires work input. Here, the volume changes, but the mass does not. The system can exchange heat and work with its surroundings [8].

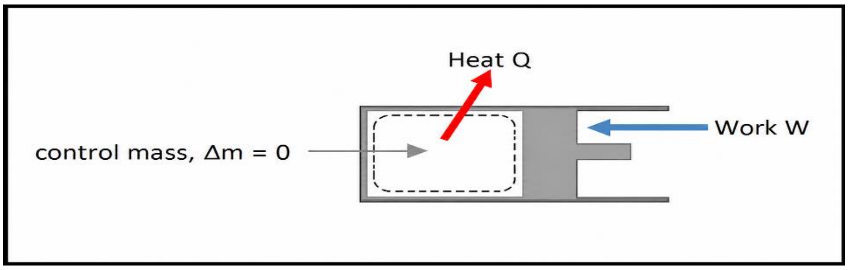


Figure I.10. *Piston: closed, control mass system [8]*

An adiabatic system does not allow heat to pass through it. Any barrier that stops heat flow is an adiabatic barrier, while one that allows heat flow is a diathermal barrier. A common example of an adiabatic system is a standard thermos; its walls act as adiabatic barriers [8]

I.5.2. Performance indicators: COP, heating capacity, compressor work

I.5.2.1. COP = Coefficient of performance

- **Definition of COP**

To reduced energy consumption and lower running expenses. is as follows The Coefficient of Performance (COP) for heating and cooling systems is the ratio of useful heating or cooling power provided to the work input. COP is a dimensionless quantity. The equation for COP in these systems:

$$\text{cop}=\frac{|Q|}{W} \tag{1}$$

The coefficient of performance (COP) is defined as Q divided by W, where Q represents the desired heating or cooling output, and W is the net work input. A higher COP means greater energy efficiency, which translates [9]

- **COP for Heating and Cooling**

- **Heating:** The coefficient of performance is found by dividing a heat pump's heating power by the compressor's power consumption [10].

$$\frac{Qk}{Pk} \tag{2}$$

Qk: Beneficial heat provided

Pk: Electrical power input to the compressor

- **Cooling:** The heat pumps cooling capacity is divided by the compressors power input [10].

$$\eta= \frac{\mathrm{Q0}}{\mathrm{Pk}} \tag{3}$$

Q0: Heat absorbed at the evaporator

Pk: Electrical power input to the compressor

❖ **Ideal and Real COP**

- **Ideal**

$$\mathrm{COP}_{\mathrm{R,rev}} = \frac{1}{(\mathrm{TH}/\mathrm{TL} - 1)} \tag{4}$$

$$\mathrm{COP}_{\mathrm{hP,rev}} = \frac{1}{(1 - \mathrm{TL}/\mathrm{TH})} \tag{5}$$

The coefficient of performance (COP) for a reversible refrigerator or heat pump represents the highest possible value given certain temperature conditions [11].

- **Real**

Refrigerators and heat pumps working within these temperature ranges (TL and TH) all show reduced performance coefficients.

COPR <COPR, rev irreversible refrigerator [11]

❖ **Effect of Operating Conditions on COP**

In sum, lower values of TL lead to reduced coefficients of performance (COPs) for both refrigerators and heat pumps. Extracting heat from colder sources needs more input. When the refrigerated space nears zero temperature, achieving even a limited amount of cooling needs a huge work input, causing the COPR to approach zero [11].

I.5.2.2. Heat capacity

❖ **Definition of Heat Capacity**

Heat capacity refers to the amount of heat needed to change a material's temperature by a specific value. It’s a key part of thermodynamics, and its size depends on how the material stores heat at a tiny level. In solids, heat capacity is closely tied to how atoms vibrate, which is how they store heat as phonons. Electrons or phase changes can also play a role in the total heat capacity [12].

❖ **Extensive and Intensive Properties**

- **Extensive Property:**

An extensive property relies on the amount of material in the system. Mass, total volume, and total energy serve as illustrations of extensive properties [13].

- **Intensive Property:**

An intensive property is a characteristic that does not depend on the system's mass. Temperature and pressure serve as examples of such properties [13].

In most cases, dividing a system and reassessing its characteristics shows that intensive properties stay the same, but extensive properties are halved [13].

- **Thermodynamic Relations**

Since most experiments characterizing solids happen at constant pressure, this study will focus on heat capacity at constant pressure. This is expressed as an intrinsic value (adjusted for volume) as:

$$\mathbf{Cp = \frac{1}{V}(\frac{\partial H}{\partial T})P} \tag{6}$$

where H is the total enthalpy of the material with volume V. While enthalpy is often due to thermal activity, phase changes can also play a role. Without phase changes, the constant pressure heat capacity Cp (in units of J·m− 3·K− 1) is defined by the equation:

$$\mathbf{Cp = CV + B\alpha 2T = CV\ (1 + \gamma\alpha T)} \tag{7}$$

This equation relates it to heat capacity at constant volume CV, the isothermal bulk modulus B, and volumetric thermal expansion coefficient α, or with the thermodynamic Gruneisen parameter γ. All parts of Equation 3 depend on temperature. Looking at Equation 3, we can see that Cp can be approximated in different ways. CV is a decent initial estimate that can be refined by accounting for the dilation part, which has a direct linear relationship with temperature (Bα2T). Because CV is helpful when finding the size of Cp, it is important to remember that CV is defined using the total internal energy U (at constant volume) as

$$\mathbf{Cp = \frac{1}{V}(\frac{\partial U}{\partial T})\ V} \tag{8}$$

which is particularly beneficial as U is often accessible to estimatefrom theoretical considerations [12]

- **Heating Capacity**

Heating capacity is defined as the useful thermal power supplied by a heat pump to the heating medium or conditioned space. In a vapor-compression heat pump, it corresponds to the heat released by the refrigerant in the condenser. Therefore, it depends mainly on the refrigerant mass flow rate and the enthalpy difference between the condenser inlet and outlet. The heating capacity is commonly expressed in kW and is calculated as:

$$\dot{Q}_h = \dot{m}(\mathrm{h_2 - h_3}) \tag{9}$$

I.5.2.3. Compressor work

Compressor work is considered to be a significant performance parameter in heat pumps. Compressor work is defined as the amount of energy needed by the compressor to compress the refrigerant from low pressure to high pressure during the cycle [14]. The performance analysis in the study is carried out in terms of compressor work for the selected refrigerants, and other performance parameters such as COP, discharge temperature [15].

$$\mathbf{W_{Comp} = h_2 - h_1} \tag{10}$$

Chapter II: Refrigerants and Environmental Challenges

II.1. Classification of refrigerants (CFCs, HCFCs, HFCs, HFOs)

II.1.1. Historical Development of Refrigerants

The history of refrigerants can be divided into four periods based on specific selection standards:

1830s-1930s – Any substance that worked, which mainly included common solvents and other unstable liquids like ethers, carbon dioxide (CO2, R-744), ammonia (NH3, R-717), sulfur dioxide (SO2, R-764), methyl formate (HCOOCH3, R-611), HCs, water (H2O, R-718), carbon tetrachloride (CCl4, R-10), hydrochlorocarbons (HCCs), and others. Many are now called “natural refrigerants.

1931-1990s – Focus on safety and how long they lasted. The main choices were chlorofluorocarbons (CFCs), HCFCs, HFCs, ammonia, and water. 1990-2010s – Protection of the ozone layer became a key factor. This period saw a focus on HCFCs (for temporary use), HFCs, ammonia, water, hydrocarbons, and carbon dioxide.

2011-present – The goal is to lessen global warming. The best option is still being decided, but it will probably include coolants with very low or no ozone depletion potential (ODP), low global warming potential (GWP), and high efficiency. Possible choices, at least at first, are low-GWP HFCs, unsaturated hydrofluorochemicals (hydrofluoro-olefins, HFOs, and hydrochlorofluoro-olefins, HCFOs), ammonia, carbon dioxide, hydrocarbons, and water [16].

II.1.2. Chemical Classification of Refrigerants

In this section; a table with the primary refrigerant chemical groups currently in use for cooling and heating systems like heat pumps is presents. This table lists examples plus environmental info like ozone depletion potential (ODP), global warming potential (GWP) [17].

TableII.1. *Summary of different types of refrigerant and main properties [17]*

Substance type	Abbreviation	ODP	GWP 100 [-]	GWP20[-]	Atmospheric Life time [years]	Instance (blowingagent for foams /refrigerant)
SaturatedchloroFluorocarbons	CFCs	0.6-1	4750–14400	6730–14400	45–1700	R11, R12
Saturatedhydrochloro-fluorocarbons	HCFCs	0.02-0.11	77–2310	273–5490	1.3–17.9	R141b, R22
Average			1502	4299	11.4	
SaturatedhydroFluorocarbons	HFCs	-	120–14800	437–12000	1.4–270	R134a, R32
Average			2362	4582	21.7	
UnsaturatedhydroFluorocarbons	u-HFCs	-	<1–12	-	days	R1234yf, R1234ze and R1234yz
Natural refrigerants		-	0–20		3	R600a, R717 R744

The subsequent table presents a summary of major refrigerant chemical classes alongside examples and key environmental properties like ODP, GWP, and atmospheric lifetime

II.1.3. Environmental Classification Parameters

II.1.3.4. Environmental Data

Here's a breakdown of the metrics provided for each refrigerant

❖ **Ozone DepletionPotential (ODP)**

ODP values show how well refrigerants (and other substances) can destroy ozone in the stratosphere, relative to R-11 (a CFC). The numbers here represent the most recent scientific agreement in the WMO Scientific Assessment. Where available, extra ODP information is included from other studies or publications for refrigerants lacking agreed-upon ODPs. ODPs for mixtures are calculated as mass-weighted averages, using the newest IUPAC atomic weights for the components [16]

❖ **Global WarmingPotential (GWP)**

GWP relates to CO2 over a 100-year span, based on the IPCC (The Intergovernmental Panel on Climate Change, a United Nations body, Evaluates scientific research on climate change.) Assessment Report and the WMO (The World Meteorological Organization, also under the UN. Monitors global climate, weather, and the atmosphere) Scientific Assessment updates. These are direct GWPs. The IPCC and WMO talk about indirect and net GWPs, but don't mix these up with TEWI (Total Equivalent Warming Impact, an environmental index that evaluates the total global warming impact of a refrigerant in a system. and LCCP-type analyses. Those analyses are specific to particular applications and combine direct-GWP data with energy-related impacts. Even though GWP values are reported with three digits of precision, keep in mind that the uncertainties are about ±35%, and even greater for some refrigerants. So, the real precision isn't as good as the numbers suggest. Future studies will probably keep improving this data. Similar to ODP, extra GWP data is taken from other studies or publications for refrigerants without agreed GWPs. GWP values for mixtures are figured out by calculating mass-weighted averages using the newest IUPAC atomic weights for the components. The GWP values of roughly 20 or below 20 that are given in Tables 1 and 2 for hydrocarbons show some calculation uncertainty; there's no scientific agreement on average global values right now. The approximations given are within the scopes of uncertainty. For chemicals with really short atmospheric lifetimes, further investigation with three-dimensional (3D) models is needed across different discharge scenarios to get representative GWPs; this includes most saturated and especially unsaturated hydrocarbons, which are discussed later [16].

II.2. Thermophysical properties and limitations of R134a

II.2.1. Thermophysical Properties of R134a

In this section a table shows key thermophysical properties and safety information for R134a refrigerant. The data has been extracted from [17] and represents current information for design and safety assessments

TableII.2. *Available physical properties and safety class of the refrigerant R134a[17]*

ASHRAEdesignationofRefrigerants	Chemical formula orComposition(% by mass)	Molecularweight[***gmol***–1]	Boilingpoint [°C]	Criticaltemperature[°C]	Criticalpressure[MPa]	Safety class	GWP [-]	ODP[-]
R134a	CF3CH2F	102	–26.1	101.1	4.06	A1	1430	0

II.2.2. Limitations of R134a

II.2.2.1. Environmental and Regulatory Limitations

R134a, a common refrigerant in auto air conditioning, is regulated by the Kyoto Protocol (1997) [18]. The UN banned air conditioning systems using refrigerants with a Global Warming Potential (GWP) above 150 back in 2011. India also plans to prohibit refrigerants with higher GWP soon. The substance in question has a high global warming potential (GWP) and its use is being discontinued under the Kyoto Protocol [18].

II.2.2.2. Safety Limitations

Mixtures with air of the gas 1,1,1,2-tetrafluoroethane are not flammable at atmospheric pressure and temperatures up to 100 °C (212 °F). However, mixtures with high concentrations of air at elevated pressure and/or temperature can be ignited. Contact of 1,1,1,2-tetrafluoroethane with flames or hot surfaces in excess of 250 °C (482 °F) may cause vapor decomposition and the emission of toxic gases including hydrogen fluoride and carbonyl fluoride [18].

II.2.2.4. Economic Limitations

The Kyoto Protocol (GCRP, 1997) addresses cutting emissions. Rising global worries about refrigerants with high global warming potential (GWP) have spurred research into low-GWP alternatives to hydrofluorocarbons (HFCs) in vapor compression systems. One example is R134a, which has a GWP of 1430 over 100 years. It's widely used in cooling, though Europe has banned it in new mobile air conditioners under Directive 2006/40/EC [19].

II.3. Thermophysical, environmental, and safety characteristics of R1234yf

II.3.1. Thermophysical Characteristics of R1234yf

Table II.3 presents a summary of the thermodynamic data for the alternative refrigerant R1234yf.

Table II.3. *Available physical properties and safety class of selected refrigerants used as substitutions of R134a [17]*

ASHRAE designation of Refrigerants	Chemical formula or Composition (% by mass)	Molecularweight [gmol–1]	Boiling point [°C]	Critical temperature [°C]	Critical pressure [MPa]	Safety class
R1234yf	CH2 CFCF3	114.04	–29.4	94.7	3.382	A2L

II.3.2. EnvironmentalCharacteristics of R1234yf

II.3.2.1. Global Warming Potential of R1234yf

R1234yf refrigerant has no chlorine, so it has an Ozone Depletion Potential of zero (WMO, 2007). It also has a low Global Warming Potential of 4. In terms of safety, R1234yf has low toxicity, like R134a, and is mildly flammable, less so than R152a [19]

II.3.2.2. Proposal as Low GWP Substitute

R1234yf has been proposed as the substitute due to its low GWP and ease of retrofitting with existing systems [18].

The 1234yf refrigerant presents key benefits, including a very low Global Warming Potential (GWP) of 4, compared to R134a's GWP of 1430, and a low discharge temperature. Also, it can be used as a replacement in current automotive air conditioning (AAC) systems without needing changes because its saturation curve is similar to R134a [18].

II.4. Safety Characteristics of R1234yf

II.4.1. Basic Description and Flammability

Tetrafluoropropene (HFO-1234yf) is a hydrofluoroolefin (HFO) with the chemical formula CH2=CFCF3. This clear gas is being considered as a substitute for R134a. While ASHRAE categorizes it as mildly flammable, tests over years by SAE showed it would not catch fire under typical vehicle conditions. Several independent groups have looked into how safe it is, and some think it is as safe as R134a [18].

II.4.2. Safety Classification

SAE testing over several years showed the product isn't easily ignited, even though ASHRAE classifies it as slightly flammable. Several independent safety reviews agreed, with some finding it as safe as R134a, which is currently used widely [18].

II.5. Comparative assessment of R134a and R1234yf

II.5.1. Environmental and compliance

R1234yf is a synthetic refrigerant. It has zero ozone depletion potential (ODP) and a global warming potential (GWP) of less than 4, so it meets current environmental regulations [18].

II.5.2. Comparison of the performance of R134a and R1234yf refrigerants in air conditioning systems

R1234yf, a synthetic refrigerant, has zero ozone depletion potential (ODP) and a global warming potential (GWP) of less than 4, making it compliant with current environmental regulations. Due to R1234yf's thermo physical properties being like those of R134a, it can serve as a suitable replacement for R134a. There is better thermal performance. The specific impacts of mass flow rate, saturation temperature, and surface roughness on the heat transfer coefficient (HTC) during R134a and R1234yf condensation require more research [21].

II.5.3. Thermodynamic Properties Comparison.

Table II.4. *Thermodynamic Properties for Various Refrigerants [22]*

ThermodynamicProperty	**R1234yf**	**R134a**
Chemical Formula	C3F4H2	CF3CH2F
Molar Mass (kg/kmol)	114.04	102.03
Boiling Point at 1 atm (K)	243.70	247.08
Freezing Point (K)	NA	169.85
Critical Temperature (K)	367.85	374.21
Critical Pressure (MPa)	3.38	4.06
Critical Density (kg/m3)	478.01	511.90

Table II.4 presents the thermodynamic properties of refrigerants commonly used in cars. R1234yf and R134a share similar critical temperatures and molar masses, which makes R1234yf a possible direct replacement for R134a [21].

II.5.4. Safety comparison

Even though the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) classifies the product as slightly flammable, SAE testing over several years showed that typical vehicle conditions would not cause it to ignite. Also, independent evaluations of the product's safety in vehicles all came to the same conclusion: it is as safe as R134a [21].

Chapter III: Modeling and Case Study

III.1. Selected case study

The selected case study is a company that produces ammonia named Fertial, formally known as the Société des fertilisantsd'Algérie, this company uses natural gas as a feedstock. This process results in the release of emissions into the atmosphere [23].

so, the aim is to use this exhaust gas within the heat pump as a means to release a higher temperature that can be used for other parts of the process.

The exhaust gas exiting the decarbonation unit at around a temperature 78 °C and a pressure of 0.28 [23]. and with a mixture of compositions showed in table III.1.

Table III.1. *Exhaust gas composition*

Component	**Composition in mole fraction**
CO2	0.7672
H2	0.0200
N2	0.0000
Steam	0.2128
Ammoniac	0.0000

III.2. Selected software (Matlab Software + Refprop)

III.2.1. Why MATLAB is Used

MATLAB serves as the primary computational platform integrated within the curriculum [24]. In manyt technical fields, it functions as the conventional software for conducting analysis and design. Its widespread adoption can be attributed in part to its extensive developmental history, which has contributed to its maturity and reliability. Consequently, users place considerable confidence in the results it produces [24].

III.2.2. The importance of MATLAB in simulation

MATLAB is a programming language designed for technical computing that offers high performance. It combines computational capabilities, data visualization, and programming within a user-friendly environment, enabling problems and solutions to be formulated using conventional mathematical notation [25].

Common applications typical involve mathematical operations and computational tasks:

- The process of designing and refining computational procedures
- The processes of developing representations, conducting simulations, and creating preliminary versions
- The processes of analyzing, exploring, and visualizing data

❖ **Scientific and engineering graphics**

Application development, which involves constructing graphical user interfaces [25].

Simulation within MATLAB offers a practical approach for examining system behaviour and anticipating performance across varied conditions. This environment is widely employed to address engineering challenges that require numerical computation [25].

III.2.3. MATLAB's advantages in process simulation

- **Power**

MATLAB provides users with remarkable capabilities, enabling them to utilize nearly every mathematical technique available while also allowing for the creation of customized programs to suit specific needs [31].

- **Transparency**

Experienced users can access all MATLAB functions, formulas, and data. This ensures transparency, with no hidden or "black box" calculations. Even intermediate and temporary data being processed within a function file can be examined using the debugger [31].

- **Flexibility**

The modular design of the commands empowers knowledgeable users to develop virtually any application they can imagine [31]

- **Simulation Capabilities of MATLAB**

The system offers a robust platform for precise, multiperiod computations, utilizing an extensive range of mathematical formulas. Within the Simulink environment, models can be constructed and visualized graphically, providing users with a clear understanding of how variables interact and influence each other. Comprehensive graphical and diagnostic tools are available, facilitating the analysis and reporting of both the model and its underlying data. This environment is purpose-built as a genuine simulation model, incorporating parameters, algorithms, and a dedicated software interface tailored for simulation tasks [31].

III.2.4. MATLAB Features

The MATLAB system consists of five main elements: the development environment, a collection of mathematical functions, the MATLAB programming language, graphical functionalities, and the application programming interface. Within MATLAB, a comprehensive set of mathematical functions is provided to enable the performance of complex computations with notable efficiency. Moreover, the system incorporates sophisticated graphical tools designed to assist in the visualization of data and the results generated by computations [25].

III.2.5. Definition of REFPROP

REFPROP, an acronym for Reference Fluid Properties, is a software program developed by the National Institute of Standards and Technology (NIST). It is designed to calculate the thermodynamic and transport properties of fluids and fluid mixtures commonly used in industrial applications. The software offers a graphical user interface for displaying these properties in the form of tables and plots, while also enabling access through spreadsheets or custom user applications via the REFPROP dynamic link library. The program relies on highly accurate models for pure fluids and mixtures. For pure substances, it supports three thermodynamic property models: equations of state based on Helmholtz energy, the modified Benedict-Webb-Rubin equation of state, and an extended corresponding states (ECS) model. For fluid mixtures, REFPROP employs a model that applies mixing rules to the Helmholtz energy of individual components, with adjustments made using a departure function to address deviations from ideal mixing behaviour. Viscosity and thermal conductivity are determined using fluid-specific correlations, the ECS method, or, in certain cases, the friction theory method [26].

III.2.6. Why linking REFPROP with MATLAB

In this work, MATLAB R2014a was linked to NIST REFPROP V10 to combine MATLAB’s strengths in numerical computation, scripting, optimization, and parametric analysis with REFPROP’s high-fidelity thermodynamic and transport-property routines. In practical terms, the coupling allows the MATLAB model to call the REFPROP library and return properties such as enthalpy, entropy, density, viscosity, thermal conductivity, and saturation states from chosen independent variables; the current MathWorks interface does this through a MATLAB-based interface to the REFPROP library, while NIST notes that the only MATLAB pathway it directly supports today is via Python and treats the earlier direct MATLAB wrapper as legacy. This linkage is particularly important for heat-pump simulation because vapor-compression heat pumps involve repeated property evaluations through the evaporator, compressor, condenser, and expansion device, often in the two-phase region where property variations are highly nonlinear and strongly affect predicted compressor work, heating capacity, pressure ratio, and COP. REFPROP is especially suitable in this context because NIST describes it as providing some of the most accurate thermophysical-property models for industrially important pure fluids and mixtures, and MathWorks further supports REFPROP-based workflows in Simscape by allowing generation of two-phase property tables, with the tabulated formulation making block calculations simpler and faster. Therefore, coupling MATLAB with REFPROP improves the physical realism and reliability of heat-pump models, especially when studying refrigerant selection, off-design operation, transient response, or performance optimization; this approach is also reflected in recent heat-pump literature, where MATLAB models explicitly linked to REFPROP have been used to obtain refrigerant state properties in simulation [26] [30].

III.3. Selected configuration of the heat pump

III.3.1. Basic configuration of the heat pump system

A heat pump is a system designed to absorb heat from a low-temperature area, effectively cooling it, and transfer that heat to a high-temperature area, thereby warming it. This process is facilitated by the circulation of a refrigerant, which undergoes compression to generate heat and expansion to produce cooling. In its liquid state, the refrigerant evaporates within a low-temperature heat exchanger, drawing heat from the surrounding environment. Once in vapor form, it is compressed and subsequently condenses within a high-temperature heat exchanger, releasing heat into its surroundings [27].

III.3.2. Main components of the selected configuration

Heat pumps typically consist of several key components: a compressor, an expansion valve, and two heat exchangers, namely the evaporator and the condenser. Depending on the specific design, additional components may also be incorporated to enhance functionality [27].

III.3.3. Operating cycle of the basic heat pump

During the compression stage, the refrigerant in its vapor state is pressurized, resulting in an increase in both pressure and temperature. In the condensation stage, the high-temperature vapor refrigerant is transferred to the condenser, where it releases heat to a cooler environment, or sink. The expansion stage follows, during which the refrigerant's pressure and temperature drop as it passes through the expansion valve. Finally, in the evaporation stage, the cold liquid refrigerant absorbs heat from the source and transitions into a cold vapor state [27].

III.3.4. Heat source and sink in the configuration

The selection of a heat source and sink for a heat pump depends on various factors, including location, climate, and the availability of resources. Potential options for these thermal environments include air, water, ground, solar energy, or even industrial waste heat [27].

III.3.5. Working principle (thermodynamic description)

A heat pump is a thermodynamic system designed to move thermal energy from a cooler source to a warmer sink by utilizing mechanical work, often through a vapor-compression refrigeration cycle. Rather than producing heat directly, heat pumps redistribute it efficiently, lowering energy consumption and minimizing related emissions [28].

III.3.6. Basic steps of the selected configuration cycle

- **Evaporation :**

occurs when the refrigerant, maintained at a low pressure and temperature, absorbs heat from the ground loop and transitions into a gaseous state [28].

- **Condensation :**

occurs when the heated, high-pressure vapor transfers its heat to the building's air or water distribution system, transforming into a liquid in the process [28].

- **Expansion :**

The refrigerant flows through an expansion valve, where its pressure and temperature decrease before it cycles back to the evaporator [28].

III.3.7. Justification of selecting basic configuration

Configurations offer a variety of advantages and limitations, making the selection of the most suitable option essential based on the application and objectives of the study. Given the wide range of heat pump systems, each with its own benefits and drawbacks, this study focuses on the basic vapor compression configuration. This choice is driven by its simplicity and compatibility with thermodynamic analysis and performance evaluation. Moreover, system configuration plays a pivotal role in influencing both efficiency and cost. For example, the design and setup of a ground heat exchanger (GHE) significantly affect the overall performance and installation expenses of geothermal heat pump systems. The selection process for an appropriate configuration is guided by a variety of factors, including system requirements, operating conditions, and economic feasibility. Additionally, considerations such as building architecture, retrofit potential, indoor climate control needs, and budget constraints also play a critical role in the decision-making process [28].

III.4. Modeling assumptions and operating conditions

III.4.1. System configuration (used in modeling)

In this study, a standard single-stage heat pump was used as the baseline system (Figure III.1). The system consists of four main parts: the compressor, condenser, expansion valve, and evaporator [29].

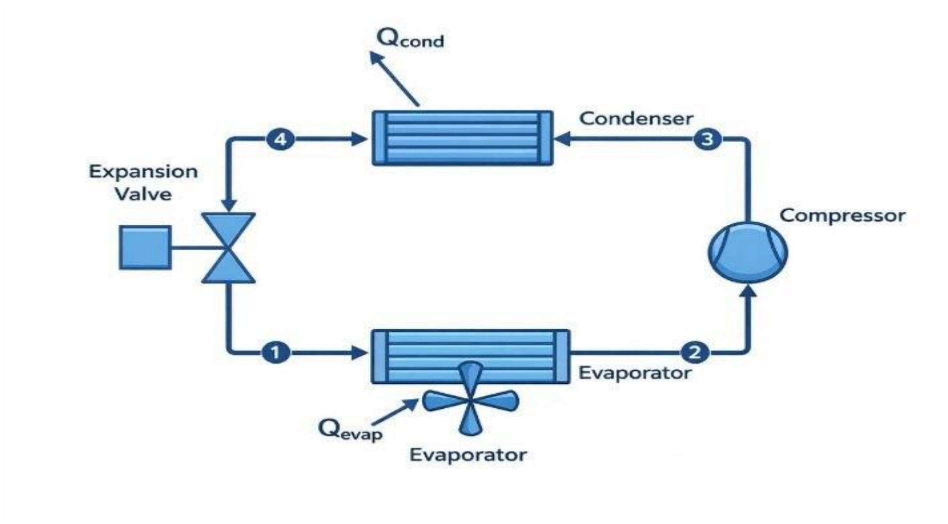


Figure III.1. *Heat pump scheme*

III.4.2. Operating conditions

- **Compressor efficiency**

The compressor isentropic efficiency is set to be 80%, based on insights gained from prior research and manufacturer data [29], after that it increases till 90% to evaluate the selected configuration under improved compressor performance. The upper value of 90% is not taken directly from the literature; rather, it is personally selected as a theoretical assumption for the purpose of theoretical performance evaluation.

- **Temperature ranges and constraints**

Table III.2. *UV and LV used in the evaluation of the VCRS [29]*

Parameter	LB	UB
Evaporation temperature, T_{ev} (°C)	20	30
Condensation temperature, T_{cond} (°C)	90	100
Min. temperature difference in the evaporator, $\Delta Tpp,eva$ (°C)	10	20
Min. temperature difference in the condenser, $\Delta Tpp,cond$ (°C)	10	20
Compressor efficiency (%)	80	90

- **Additional conditions**

The remaining adopted parameters for the evaluation process are taken from the literature [29].

III.4.3. Simulation Methodology

The simulation methodology follows a structured sequence starting with the initialization of the MATLAB R2014a environment and its coupling with the REFPROP 10 database. The required input parameters, including refrigerant type, evaporation and condensation temperatures, compressor isentropic efficiency, pinch point limits, water temperatures, and nanoparticle concentration, are first defined. Thermophysical properties such as pressure, temperature, enthalpy, entropy, and density are then calculated using REFPROP 10. The vapor compression heat pump cycle is modeled through its main processes: evaporation, superheating, compression, condensation, subcooling, and expansion. Afterward, the system performance is evaluated by calculating energy consumption, heat transfer rates, coefficients of performance, and pinch point temperatures. Finally, comparative analysis between refrigerants is performed, and the results are generated in the form of tables, graphs, TXT files, and Excel sheets for further interpretation under different operating conditions, the explicative flowchart of the simulation methodology is presented in Figure III.2.

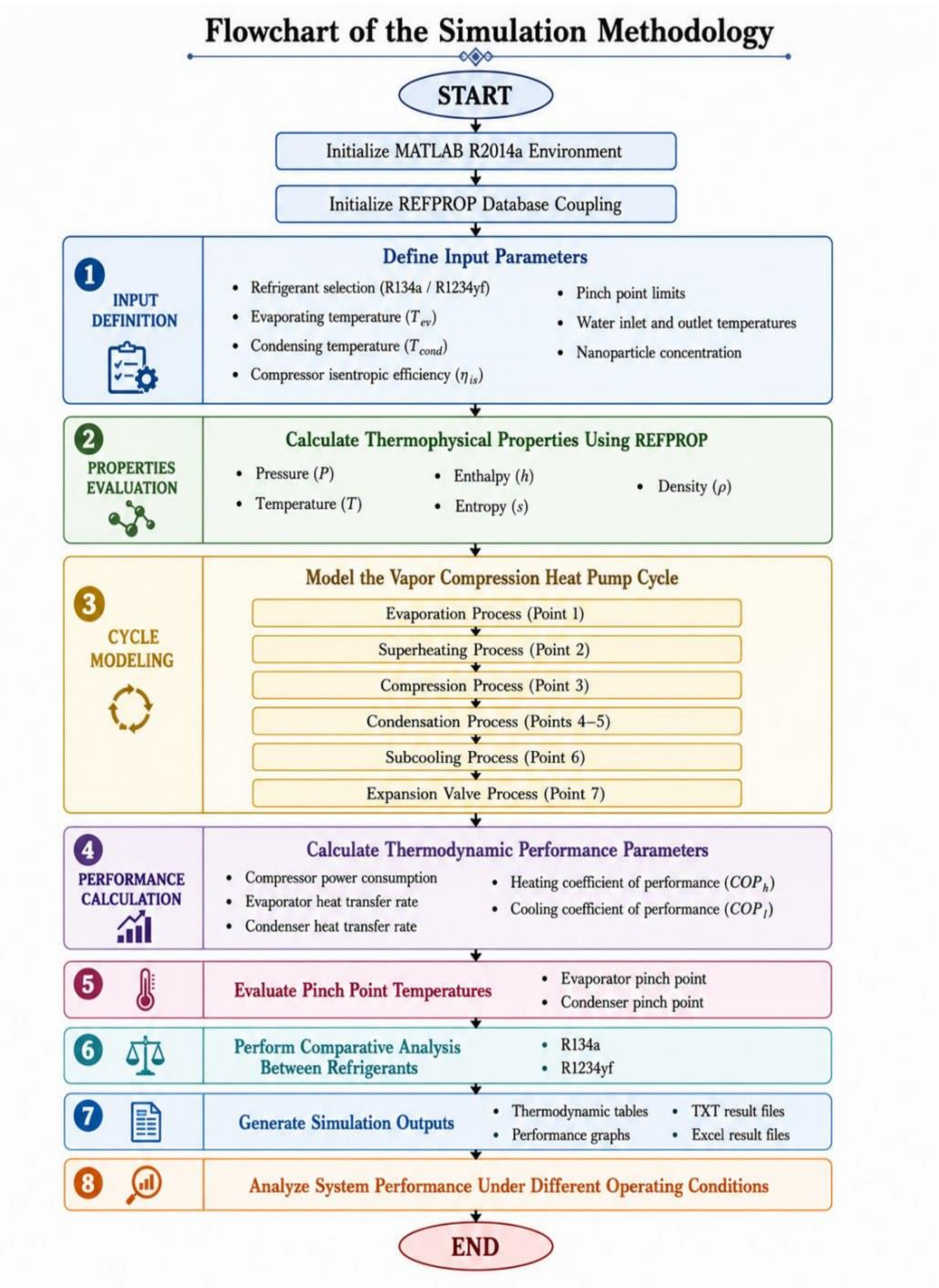


Figure III.2. *Flowchart of the Simulation Methodology*

Chapter IV: Results and Performance Analysis

IV. Results and Discussion

IV.1. Introduction

This part of the chapter will go into detail about what we found from simulating the heat pump system. We mainly wanted to see how well the system worked in various situations and figure out which things really make a difference to its efficiency. To judge its performance, we mostly looked at something called the heating coefficient of performance (COP_h). This basically tells us how much useful heat the system puts out compared to the energy it takes in. We specifically looked at how a few operating factors affect things, such as the evaporating temperature, condensing temperature, and how efficient the compressor is. These factors are really important because they directly impact things like pressure, changes in heat content (enthalpy), and how much work the compressor does, which in turn affects how well the whole system performs. We also compared R134a and R1234yf to see which one might be better to use as a working fluid in heat pumps. R134a is known to work well when it comes to heat transfer, but R1234yf looks like a good alternative because it's much better for the environment. So, by looking at how both behave under the same conditions, we can get a good idea of the balance we need to strike between how well something performs and how kind it is to the planet. We'll show our findings using tables and charts. We looked at each factor individually to clearly show how it affects the COP_h and the system's overall performance. After that, we'll go into detail about what these trends mean and compare how the two refrigerants performed in the various situations.

IV.2. Simulation results obtained using MATLAB

The following results were obtained using numerical simulation carried out in MATLAB for different evaporating temperatures.

T_{evap}: 20:02:30 (best values)

TableIV.1. *Thermodynamic properties and performance parameters of R134a and R1234yf at different evaporator temperatures* (T_{evap}*=20 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	103.38	95.07
T_3 (°C)	90	90
p_1 (bar)	5.72	5.92
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	453.122	409.608
h_3 (kJ/kg)	425.415	393.323
ρ_1	28	33
ρ_2	167	217
$T_{hot,out}$ (°C)	35	35
η_{comp}	0.8	0.8
COP_h	2.541	1.982

TableIV.2. *Thermodynamic properties and performance parameters of R134a and R1234yf at different evaporator temperatures* (T_{evap}*=22 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	22	22
T_2 (°C)	103.02	95.05
T_3 (°C)	90	90
p_1 (bar)	6.08	6.27
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	410.794	377.091
h_2 (kJ/kg)	452.517	409.556
h_3 (kJ/kg)	425.415	393.323
ρ_1	30	35
ρ_2	168	217
$T_{hot,out}$(°C)	35	35
η_{comp}	0.8	0.8
COP_h	2.627	2.056

TableIV.3. *Thermodynamic properties and performance parameters of R134a and R1234yf at different evaporator temperatures (T_{evap}=24 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	24	24
T_2 (°C)	102.66	95.03
T_3 (°C)	90	90
p_1 (bar)	6.46	6.64
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	411.824	378.278
h_2 (kJ/kg)	451.925	409.510
h_3 (kJ/kg)	425.415	393.323
ρ_1	31	37
ρ_2	168	217
$T_{hot,out}$ (°C)	35	35
η_{comp}	0.8	0.8
COP_h	2.718	2.136

TableIV.4. *Thermodynamic properties and performance parameters of R134a and R1234yf at different evaporator temperatures (T_{evap}=26 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	26	26
T_2 (°C)	102.31	95.01
T_3 (°C)	90	90
p_1 (bar)	6.85	7.02
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	412.839	379.452
h_2 (kJ/kg)	451.343	409.466
h_3 (kJ/kg)	425.415	393.323
ρ_1	33	39
ρ_2	169	217
$T_{hot,out}$ (°C)	35	35
η_{comp}	0.8	0.8
COP_h	2.816	2.221

Table IV.5. *Thermodynamic properties and performance parameters of R134a and R1234yf at different evaporator temperatures (T_{evap}=28 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	28	28
T_2 (°C)	101.97	94.99
T_3 (°C)	90	90
p_1 (bar)	7.27	7.42
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	413.837	380.609
h_2 (kJ/kg)	450.771	409.425
h_3 (kJ/kg)	425.415	393.323
ρ_1	35	41
ρ_2	170	218
$T_{hot,out}$ (°C)	35	35
η_{comp}	0.8	0.8
COP_h	2.920	2.312

Table IV.6. *Thermodynamic properties and performance parameters of R134a and R1234yf at different evaporator temperatures (T_{evap}=30 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	30	30
T_2 (°C)	101.64	94.98
T_3 (°C)	90	90
p_1 (bar)	7.70	7.84
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	414.818	381.751
h_2 (kJ/kg)	450.208	409.386
h_3 (kJ/kg)	425.415	393.323
ρ_1	38	44
ρ_2	171	218
$T_{hot,out}$ (°C)	35	35
η_{comp}	0.8	0.8
COP_h	3.031	2.410

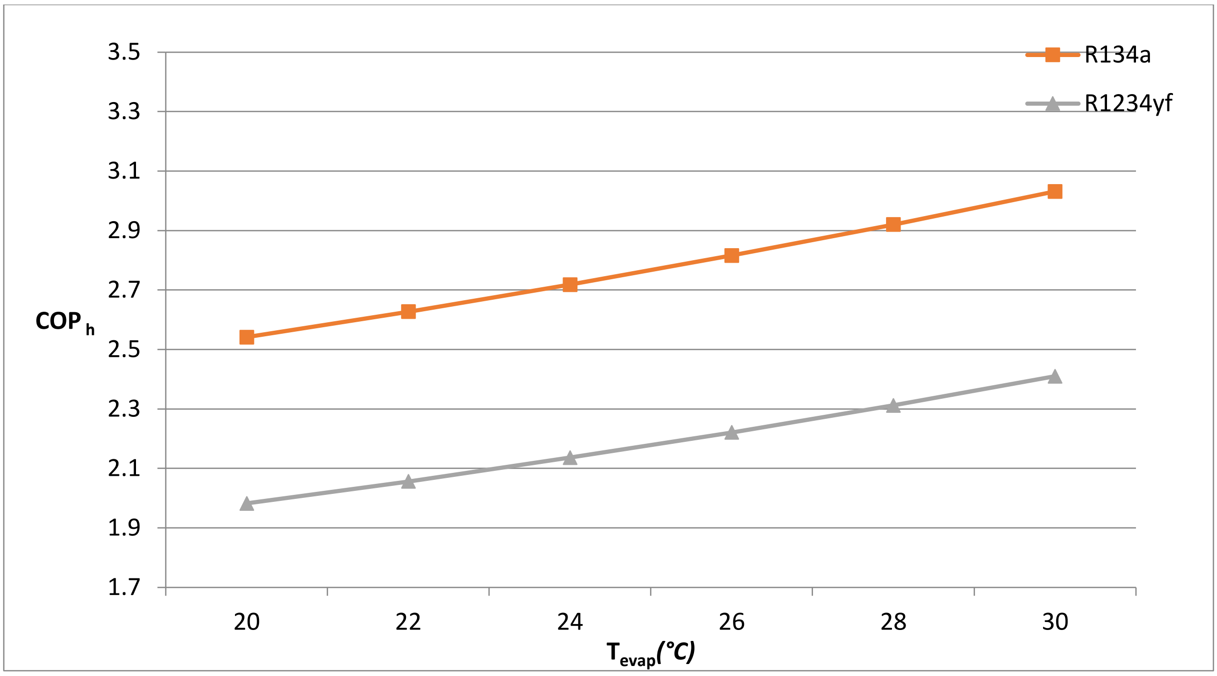


Figure IV.1. *Variation of the heating coefficient of performance (COP_h) with evaporator temperature (T_{evap}) for R134a and R1234yf*

Results and discussion of the effect of evaporating temperature (T_{evap})

The effect of evaporating temperature (T_{evap}) on the heating performance (COP_h) of a heat pump was investigated. Results consistent with the typical operation of vapor compression heat pumps were obtained. It was observed that, as Tevap increases, a gradual improvement in COP_h is achieved for both refrigerants, R134a and R1234yf. Specifically, for R134a, the COP_h was increased from approximately 2.54 at 20 °C to 3.03 at 30 °C. Similarly, for R1234yf, the COP_h was raised from 1.98 to 2.41 over the same temperature range.

This improvement is mainly attributed to the increase in evaporating pressure. As a result, less work is required by the compressor, which directly leads to an enhancement in COP_h. It was also found that higher performance is consistently exhibited by R134a compared to R1234yf under all conditions. This behavior is primarily explained by the more favorable thermodynamic properties of R134a, particularly the greater amount of heat released in the condenser (enthalpy difference, $h2 - h3$). Consequently, more heat is transferred to the heated medium.

On the other hand, a higher vapor density at the compressor inlet is presented by R1234yf, which could allow a greater mass flow rate through the system. However, this advantage is not sufficient to compensate for its lower specific enthalpy. Therefore, a lower heating capacity is delivered, resulting in a reduced COP_h. It was also observed that a lower discharge temperature

(T_2) is exhibited by R1234yf compared to R134a. This characteristic is considered beneficial, as reduced thermal stress is imposed on the compressor, thereby improving system reliability.

Overall, a noticeable decrease in heating performance is observed when R134a is replaced by R1234yf. Although R1234yf is recognized as a more environmentally friendly refrigerant, a trade-off between energy performance and environmental impact is highlighted when a refrigerant is selected.

T_{cond}: 90:01:100(best values)

Table IV.7. *Thermodynamic properties and performance parameters of R134a and R1234yf at different condensing temperatures (T_{cond}=90 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	103.38	95.07
T_3 (°C)	90	90
p_1 (bar)	5.72	5.92
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	453.122	409.608
h_3 (kJ/kg)	425.415	393.323
ρ_1	28	33
ρ_2	167	217
$T_{hot,out}$ (°C)	35	35
η_{comp}	0.8	0.8
COP_h	2.541	1.982

Table IV.8. *Thermodynamic properties and performance parameters of R134a and R1234yf at different condensing temperatures (T_{cond}=91 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	104.57	96.25
T_3 (°C)	91	91
p_1 (bar)	5.72	5.92
p_2 (bar)	33.11	31.42
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	453.584	409.932
h_3 (kJ/kg)	424.718	391.854
ρ_1	28	33
ρ_2	171	223
$T_{hot,out}$ (°C)	35	35
η_{comp}	0.8	0.8

COP_h	2.472	1.889

Table IV.9. *Thermodynamic properties and performance parameters of R134a and R1234yf at different condensing temperatures (T_{cond}=92 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	105.76	97.44
T_3 (°C)	92	92
p_1 (bar)	5.72	5.92
p_2 (bar)	33.79	32.05
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	454.043	410.252
h_3 (kJ/kg)	423.916	389.939
ρ_1	28	33
ρ_2	175	229
$T_{hot,out}$ (°C)	35	35
η_{comp}	0.8	0.8
COP_h	2.403	1.789

Table IV.10. *Thermodynamic properties and performance parameters of R134a and R1234yf at different condensing temperatures (T_{cond}=93 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	106.96	98.63
T_3 (°C)	93	93
p_1 (bar)	5.72	5.92
p_2 (bar)	34.49	32.69
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	454.499	410.571
h_3 (kJ/kg)	422.993	387.263
ρ_1	28	33
ρ_2	179	235
$T_{hot,out}$ (°C)	35	35
η_{comp}	0.8	0.8
COP_h	2.334	1.677

Table IV.11. *Thermodynamic properties and performance parameters of R134a and R1234yf at different condensing temperatures (T_{cond}=94 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	108.15	99.83
T_3 (°C)	94	94
p_1 (bar)	5.72	5.92
p_2 (bar)	35.19	33.35
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	454.952	410.888
h_3 (kJ/kg)	421.922	382.792
ρ_1	28	33
ρ_2	183	241
$T_{hot,out}$ (°C)	35	35
η_{comp}	0.8	0.8
COP_h	2.265	1.529

Table IV.12. *Thermodynamic properties and performance parameters of R134a and R1234yf at different condensing temperatures (T_{cond}=95 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	-
T_2 (°C)	109.35	-
T_3 (°C)	95	-
p_1 (bar)	5.72	-
p_2 (bar)	35.91	-
h_1 (kJ/kg)	409.748	-
h_2 (kJ/kg)	455.402	-
h_3 (kJ/kg)	420.669	-
ρ_1	28	-
ρ_2	187	-
$T_{hot,out}$ (°C)	35	-
η_{comp}	0.8	-
COP_h	2.194	-

Table IV.13. *Thermodynamic properties and performance parameters of R134a and R1234yf at different condensing temperatures (T_{cond}=96 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	-
T_2 (°C)	110.55	-
T_3 (°C)	96	-
p_1 (bar)	5.72	-
p_2 (bar)	36.64	-
h_1 (kJ/kg)	409.748	-
h_2 (kJ/kg)	455.850	-
h_3 (kJ/kg)	419.184	-
ρ_1	28	-
ρ_2	192	-
$T_{hot,out}$ (°C)	35	-
η_{comp}	0.8	-
COP_h	2.121	-

Table IV.14. *Thermodynamic properties and performance parameters of R134a and R1234yf at different condensing temperatures (T_{cond}=97 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	-
T_2 (°C)	111.75	-
T_3 (°C)	97	-
p_1 (bar)	5.72	-
p_2 (bar)	37.39	-
h_1 (kJ/kg)	409.748	-
h_2 (kJ/kg)	456.295	-
h_3 (kJ/kg)	417.386	-
ρ_1	28	-
ρ_2	196	-
$T_{hot,out}$ (°C)	35	-
η_{comp}	0.8	-
COP_h	2.045	-

Table IV.15. *Thermodynamic properties and performance parameters of R134a and R1234yf at different condensing temperatures (T_{cond}=98 °C)*

Parameter	R134a	R1234yf
T_1 (°C)	20.00	-
T_2 (°C)	112.96	-
T_3 (°C)	98	-
p_1 (bar)	5.72	-
p_2 (bar)	38.15	-
h_1 (kJ/kg)	409.748	-
h_2 (kJ/kg)	456.738	-
h_3 (kJ/kg)	415.137	-
ρ_1	28	-
ρ_2	201	-
$T_{hot,out}$ (°C)	35	-
η_{comp}	0.8	-
COP_h	1.964	-

Table IV.16. *Thermodynamic properties and performance parameters of R134a and R1234yf at different condensing temperatures (T_{cond}=99 °C)*

Parameter	R134a	R1234yf
T_1 (°C)	20.00	-
T_2 (°C)	114.17	-
T_3 (°C)	99	-
p_1 (bar)	5.72	-
p_2 (bar)	38.93	-
h_1 (kJ/kg)	409.748	-
h_2 (kJ/kg)	457.179	-
h_3 (kJ/kg)	412.158	-
ρ_1	28	-
ρ_2	205	-
$T_{hot,out}$ (°C)	35	-
η_{comp}	0.8	-
COP_h	1.873	-

Table IV.17. *Thermodynamic properties and performance parameters of R134a and R1234yf at different condensing temperatures (T_{cond}=100 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	-
T_2 (°C)	115.39	-
T_3 (°C)	100	-
p_1 (bar)	5.72	-
p_2 (bar)	39.72	-
h_1 (kJ/kg)	409.748	-
h_2 (kJ/kg)	457.620	-
h_3 (kJ/kg)	407.683	-
ρ_1	28	-
ρ_2	210	-
$T_{hot,out}$ (°C)	35	-
η_{comp}	0.8	-
COP_h	1.761	-

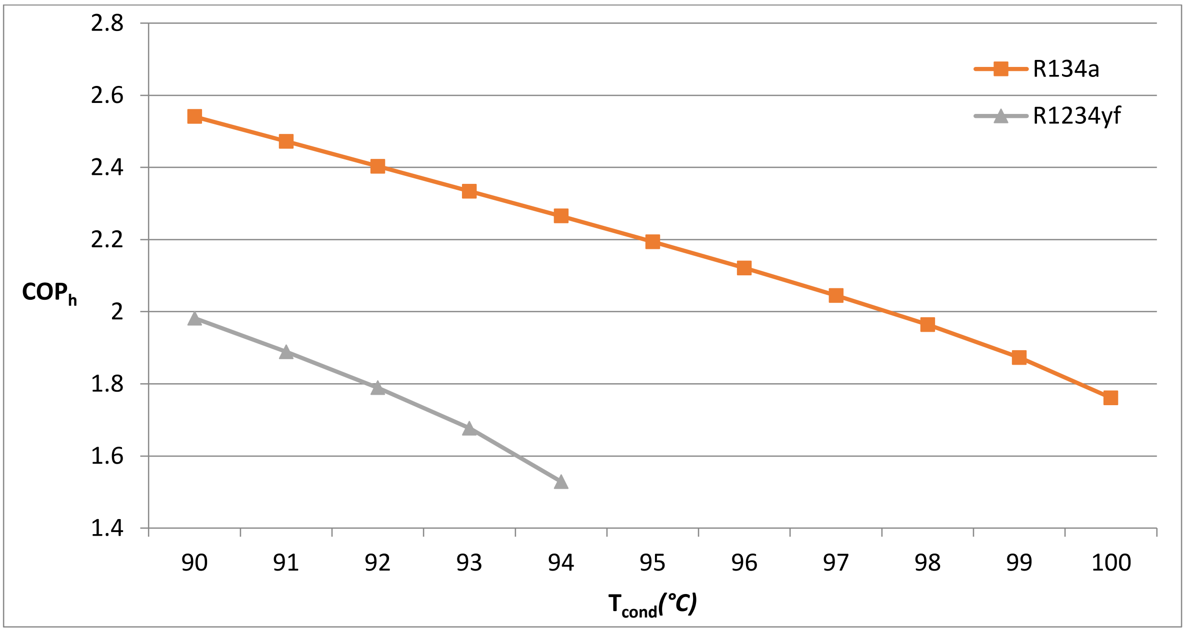


Figure IV.2. *Variation of the heating coefficient of performance (COP_h) with condensing temperature (T_{cond}) for R134a and R1234yf*

Results and discussion of the effect of condensing temperature(T_{cond})

The performance of heat pumps, expressed in terms of COP_h, was examined as a function of condenser temperature. A clear and consistent trend was observed for both refrigerants, R134a and R1234yf. It was found that, as the condenser temperature increased from 90 °C to 100 °C, a continuous decrease in heating performance was obtained. For R134a, the COP_h was reduced from approximately 2.54 to 1.76. Similarly, for R1234yf, a decrease from about 1.98 to values ranging between 1.53 and 1.79 was recorded, depending on the specific conditions.

This reduction in performance is mainly attributed to the increase in condensation temperature. As a result, higher pressures are generated, leading to an increased compressor pressure ratio. Consequently, greater work is required by the compressor, while the corresponding increase in useful heat output remains limited, resulting in an overall decrease in COP_h.

It was also consistently observed that superior heating performance is exhibited by R134a compared to R1234yf, regardless of the condenser temperature. This behavior is primarily explained by the more favorable thermodynamic properties of R134a, particularly its higher capacity for heat absorption and release in the condenser, as well as its more effective heat transfer characteristics. Therefore, a greater amount of heat is delivered per unit of work input.

On the other hand, certain advantages are associated with R1234yf, including its lower environmental impact and its distinct pressure–temperature behavior. However, a lower heat-carrying capacity and reduced overall cycle efficiency are exhibited, which lead to inferior heating performance.

It should also be noted that R1234yf has a critical temperature of $T_{crit} = 94.7$ °C, and therefore only four data points were considered in the analysis, up to approximately 94 °C, in order to remain within the thermodynamically valid operating range below the critical point.

Overall, a clear deterioration in heat pump performance is observed with increasing condenser temperature for both refrigerants. Although R1234yf is recognized as a more environmentally friendly option, higher efficiency is consistently achieved with R134a.

$T_{hot, out}$: 35:02:55

Table IV.18. *Variation of thermodynamic properties and heating performance of R134a and R1234yf with hot outlet temperature ($T_{hot, out}$=35 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	103.38	95.07
T_3 (°C)	90	90
p_1 (bar)	5.72	5.92
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	453.122	409.608
h_3 (kJ/kg)	425.415	393.323
ρ_1	28	33
ρ_2	167	217
$T_{hot,out}$ (°C)	35	35
η_{comp}	0.8	0.8
COP_h	2.541	1.982

Table IV.19. *Variation of thermodynamic properties and heating performance of R134a and R1234yf with hot outlet temperature ($T_{hot,out}$=37 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	103.38	95.07
T_3 (°C)	90	90
p_1 (bar)	5.72	5.92
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	453.122	409.608
h_3 (kJ/kg)	425.415	393.323
ρ_1	28	33
ρ_2	167	217
$T_{hot,out}$ (°C)	37	37
η_{comp}	0.8	0.8
COP_h	2.541	1.982

Table IV.20. *Variation of thermodynamic properties and heating performance of R134a and R1234yf with hot outlet temperature ($T_{hot,out}$=39 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	103.38	95.07
T_3 (°C)	90	90
p_1 (bar)	5.72	5.92
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	453.122	409.608
h_3 (kJ/kg)	425.415	393.323
ρ_1	28	33
ρ_2	167	217
$T_{hot,out}$ (°C)	39	39
η_{comp}	0.8	0.8
COP_h	2.541	1.982

Table IV.21 *Variation of thermodynamic properties and heating performance of R134a and R1234yf with hot outlet temperature ($T_{hot,out}$=41 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	103.38	95.07
T_3 (°C)	90	90
p_1 (bar)	5.72	5.92
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	453.122	409.608
h_3 (kJ/kg)	425.415	393.323
ρ_1	28	33
ρ_2	167	217
$T_{hot,out}$ (°C)	41	41
η_{comp}	0.8	0.8
COP_h	2.541	1.982

Table IV.22.*Variation of thermodynamic properties and heating performance of R134a and R1234yf with hot outlet temperature ($T_{hot,out}$=43 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	103.38	95.07
T_3 (°C)	90	90
p_1 (bar)	5.72	5.92
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	453.122	409.608
h_3 (kJ/kg)	425.415	393.323
ρ_1	28	33
ρ_2	167	217
$T_{hot,out}$ (°C)	43	43
η_{comp}	0.8	0.8
COP_h	2.541	1.982

Table IV.23. *Variation of thermodynamic properties and heating performance of R134a and R1234yf with hot outlet temperature ($T_{hot,out}$=45 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	103.38	95.07
T_3 (°C)	90	90
p_1 (bar)	5.72	5.92
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	453.122	409.608
h_3 (kJ/kg)	425.415	393.323
ρ_1	28	33
ρ_2	167	217
$T_{hot,out}$ (°C)	45	45
η_{comp}	0.8	0.8
COP_h	2.541	1.982

Table IV.24. *Variation of thermodynamic properties and heating performance of R134a and R1234yf with hot outlet temperature ($T_{hot,out}$=47 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	103.38	95.07
T_3 (°C)	90	90
p_1 (bar)	5.72	5.92
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	453.122	409.608
h_3 (kJ/kg)	425.415	393.323
ρ_1	28	33
ρ_2	167	217
$T_{hot,out}$ (°C)	47	47
η_{comp}	0.8	0.8
COP_h	2.541	1.982

Table IV.25. *Variation of thermodynamic properties and heating performance of R134a and R1234yf with hot outlet temperature ($T_{hot,out}$=49 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	103.38	95.07
T_3 (°C)	90	90
p_1 (bar)	5.72	5.92
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	453.122	409.608
h_3 (kJ/kg)	425.415	393.323
ρ_1	28	33
ρ_2	167	217
$T_{hot,out}$ (°C)	49	49
η_{comp}	0.8	0.8
COP_h	2.541	1.982

Table IV.26. *Variation of thermodynamic properties and heating performance of R134a and R1234yf with hot outlet temperature ($T_{hot,out}$=51 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	103.38	95.07
T_3 (°C)	90	90
p_1 (bar)	5.72	5.92
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	453.122	409.608
h_3 (kJ/kg)	425.415	393.323
ρ_1	28	33
ρ_2	167	217
$T_{hot,out}$ (°C)	51	51
η_{comp}	0.8	0.8
COP_h	2.541	1.982

Table IV.27. *Variation of thermodynamic properties and heating performance of R134a and R1234yf with hot outlet temperature ($T_{hot,out}$=53 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	103.38	95.07
T_3 (°C)	90	90
p_1 (bar)	5.72	5.92
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	453.122	409.608
h_3 (kJ/kg)	425.415	393.323
ρ_1	28	33
ρ_2	167	217
$T_{hot,out}$ (°C)	53	53
η_{comp}	0.8	0.8
COP_h	2.541	1.982

Table IV.28. *Variation of thermodynamic properties and heating performance of R134a and R1234yf with hot outlet temperature ($T_{hot,out}$=55 °C)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	103.38	95.07
T_3 (°C)	90	90
p_1 (bar)	5.72	5.92
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	453.122	409.608
h_3 (kJ/kg)	425.415	393.323
ρ_1	28	33
ρ_2	167	217
$T_{hot,out}$ (°C)	55	55
η_{comp}	0.8	0.8
COP_h	2.541	1.982

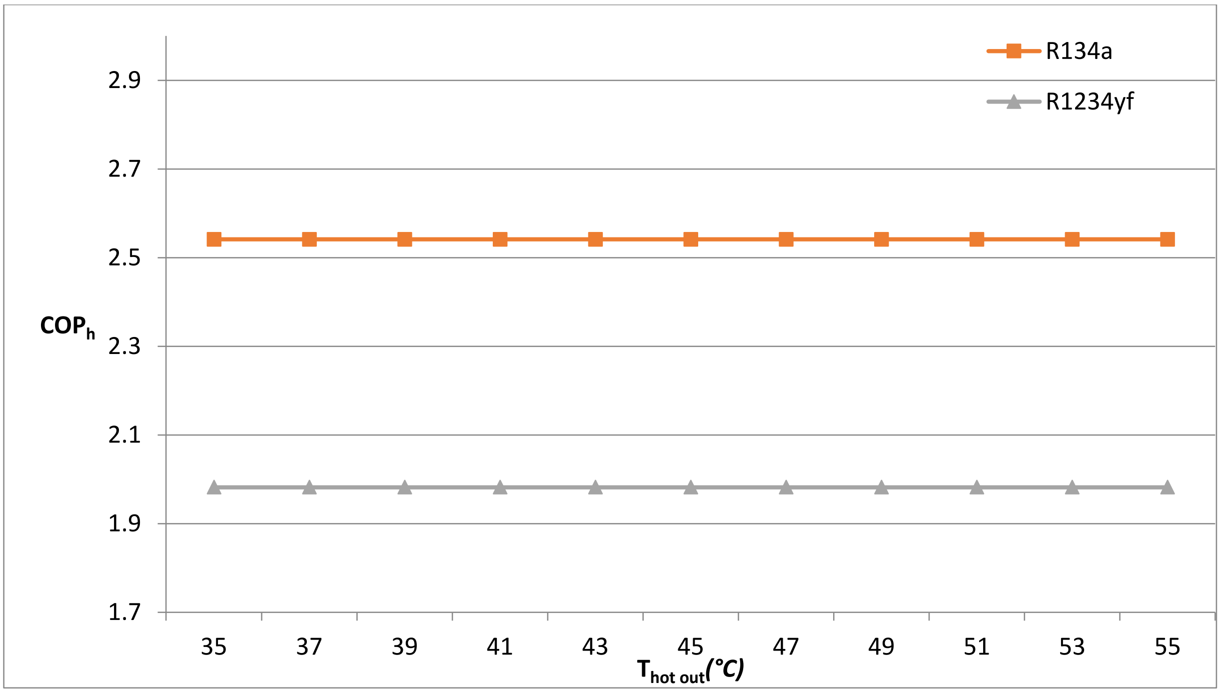


Figure IV.3. *Variation of the heating coefficient of performance (COP_h) with hot outlet temperature ($T_{hot,out}$) for R134a and R1234yf*

- **Results and discussion of hot gas outlet temperature effect($T_{hot,out}$)**

The relationship between COP_h and the hot outlet temperature ($T_{hot,out}$) was analyzed using tables and charts, allowing a clear comparison between R134a and R1234yf when used in a heat pump system. It was observed from the obtained data that higher heating performance ($COP_h \approx 2.54$) was consistently achieved with R134a compared to R1234yf ($COP_h \approx 1.98$). This trend was maintained across all investigated condenser temperatures ranging from 35 °C to 55 °C. In percentage terms, an improvement of approximately 22–25% in favor of R134a was obtained. This behavior is mainly attributed to the greater amount of heat released in the condenser by R134a, as indicated by a higher enthalpy difference ($h_2 - h_3$), even though a slightly higher compressor work input ($h_2 - h_1$) was also required.

In contrast, lower heating capacity was exhibited by R1234yf due to its smaller enthalpy rise through the condenser, which consequently resulted in reduced COP_h values. It was also observed that the COP_h variation with $T_{hot,out}$ appeared almost constant for both refrigerants, forming nearly horizontal trends over the entire temperature range. Thermodynamically, such behavior is not typically expected, since a decrease in COP_h is usually produced when condenser temperature increases, due to higher compressor work and increased compression ratios.

This inconsistency was explained by the fact that no variation was introduced in key thermodynamic properties (enthalpies, pressures, and state temperatures) within the used tables, regardless of $T_{hot,out}$. Therefore, it was concluded that fixed operating conditions were used in the simulation model instead of temperature-dependent property updates, which limits the physical accuracy of the results.

In addition, a lower discharge temperature ($T_2 \approx 95$ °C for R1234yf compared to approximately 103 °C for R134a) and a higher vapor density were observed for R1234yf. These characteristics may be beneficial in terms of compressor durability and environmental impact. However, these advantages were not sufficient to compensate for its lower overall heating performance.

Finally, although R1234yf was identified as a more environmentally friendly alternative to R134a, a clear reduction in heating capacity was confirmed, along with a modeling limitation that should be corrected to properly reflect the influence of condenser temperature on heat pump efficiency.

η_{comp} Efficiency of the compressor: 0.8:0.02:0.9

Table IV.29. *Variation of thermodynamic properties and COP_h of R134a and R1234yf with compressor efficiency (η_{comp}=0.8)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	103.38	95.07
T_3 (°C)	90	90
p_1 (bar)	5.72	5.92
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	453.122	409.608
h_3 (kJ/kg)	425.415	393.323
ρ_1	28	33
ρ_2	167	217
$T_{hot,out}$ (°C)	35	35
η_{comp}	0.8	0.8
COP_h	2.541	1.982

Table IV.30. *Variation of thermodynamic properties and COP_h of R134a and R1234yf with compressor efficiency (η_{comp}=0.82)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	102.74	94.72
T_3 (°C)	90	90
p_1 (bar)	5.72	5.92
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	452.064	408.786
h_3 (kJ/kg)	425.415	393.323
ρ_1	28	33
ρ_2	168	219
$T_{hot,out}$ (°C)	35	35
η_{comp}	0.82	0.82
COP_h	2.579	2.006

Table IV.31. *Variation of thermodynamic properties and COP$_h$ of R134a and R1234yf with compressor efficiency (η_{comp}=0.84)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	102.14	94.40
T_3 (°C)	90	90
p_1 (bar)	5.72	5.92
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	451.056	408.003
h_3 (kJ/kg)	425.415	393.323
ρ_1	28	33
ρ_2	169	221
$T_{hot,out}$ (°C)	35	35
η_{comp}	0.84	0.84
COP_h	2.618	2.031

Table IV.32. *Variation of thermodynamic properties and COP$_h$ of R134a and R1234yf with compressor efficiency (η_{comp}=0.86)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	101.57	94.10
T_3 (°C)	90	90
p_1 (bar)	5.72	5.92
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	450.096	407.256
h_3 (kJ/kg)	425.415	393.323
ρ_1	28	33
ρ_2	171	223
$T_{hot,out}$ (°C)	35	35
η_{comp}	0.86	0.86
COP_h	2.656	2.055

Table IV.33. *Variation of thermodynamic properties and COP_h of R134a and R1234yf with compressor efficiency (η_{comp}=0.88)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	101.04	93.81
T_3 (°C)	90	90
p_1 (bar)	5.72	5.92
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	449.179	406.543
h_3 (kJ/kg)	425.415	393.323
ρ_1	28	33
ρ_2	172	225
$T_{hot,out}$ (°C)	35	35
η_{comp}	0.88	0.88
COP_h	2.695	2.080

Table IV.34. *Variation of thermodynamic properties and COP_h of R134a and R1234yf with compressor efficiency (η_{comp}=0.9)*

Parameter	**R134a**	**R1234yf**
T_1 (°C)	20.00	20.00
T_2 (°C)	100.53	93.55
T_3 (°C)	90	90
p_1 (bar)	5.72	5.92
p_2 (bar)	32.44	30.80
h_1 (kJ/kg)	409.748	375.889
h_2 (kJ/kg)	448.302	405.862
h_3 (kJ/kg)	425.415	393.323
ρ_1	28	33
ρ_2	173	227
$T_{hot,out}$ (°C)	35	35
η_{comp}	0.9	0.9
COP_h	2.733	2.104

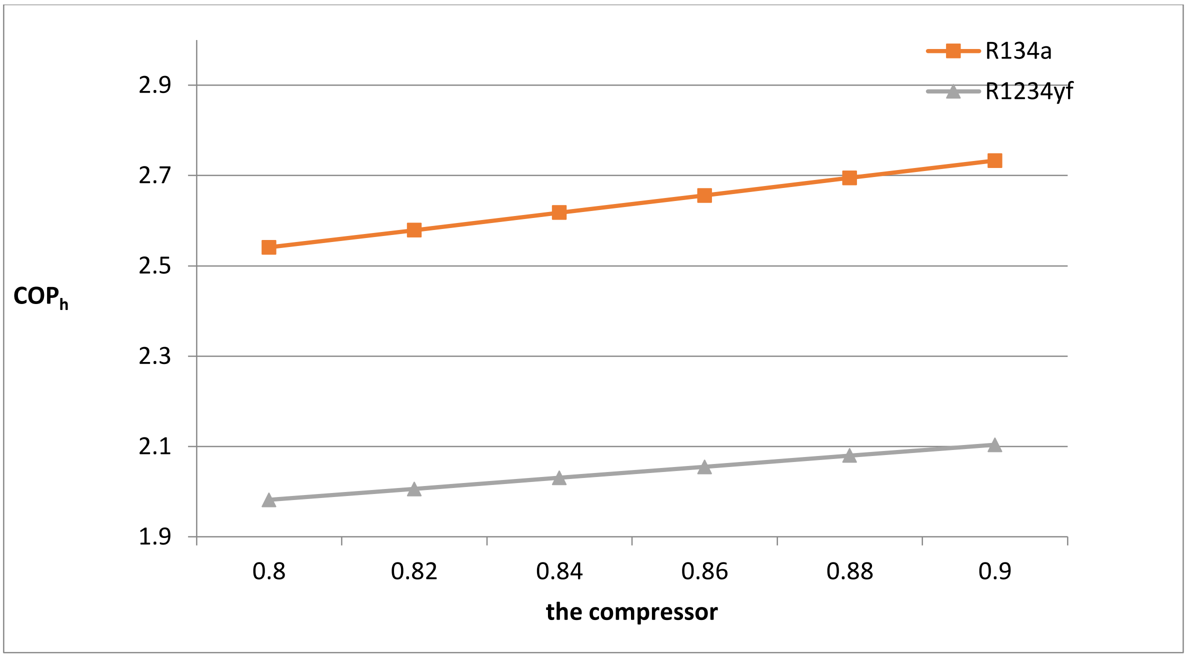


Figure IV.4. *Variation of COP$_h$ with compressor efficiency (C) for R134a and R1234yf*

- **Results and discussion of the effect of compressor efficiency(η_{comp})**

The relationship between COP$_h$ and compressor efficiency was analyzed using tables and graphs, allowing a clear comparison between R134a and R1234yf when applied in a heat pump system. A consistent trend was observed for both refrigerants, where an increase in compressor efficiency from 0.8 to 0.9 led to an improvement in heating performance (COP$_h$). Specifically, for R134a, the COP$_h$ was increased from approximately 2.54 to 2.73, while for R1234yf, an increase from around 1.98 to 2.10 was obtained.

This behavior is thermodynamically explained by the reduction in energy losses during the compression process when higher compressor efficiency is achieved. As a result, the required compressor work ($h_2 - h_1$) is reduced, while the useful heat output ($h_2 - h_3$) remains nearly unchanged. Consequently, an overall increase in COP$_h$ is obtained for both refrigerants.

It was also consistently observed that higher COP$_h$ values are achieved with R134a compared to R1234yf under all compressor efficiency conditions. This difference is mainly attributed to the greater heat release capacity of R134a in the condenser, due to a larger enthalpy variation. In contrast, lower heat output is produced by R1234yf because of its smaller enthalpy lift, even though slightly lower discharge temperatures and higher vapor densities are exhibited in the thermodynamic states.

In addition, a slight decrease in discharge temperature (T_2) was observed for both refrigerants as compressor efficiency increased. This indicates reduced compression work and lower energy losses in the system.

Overall, a nearly linear increase in COP_h with compressor efficiency was obtained for both refrigerants, with consistently superior performance being exhibited by R134a. From a practical point of view, it was shown that improving compressor efficiency enhances heat pump performance regardless of the refrigerant used. However, even under optimal conditions, lower heating performance is still exhibited by R1234yf compared to R134a.

Finally, it was concluded that a trade-off exists between environmental impact and energy efficiency. Although R1234yf is recognized as a low-GWP and more environmentally friendly refrigerant, a reduction in heating performance is still observed compared to R134a under identical operating conditions.

IV.3. Global Performance Assessment and Feasibility of R1234yf as a Sustainable Alternative to R134a in Heat Pump Systems

A comprehensive summary of the obtained results indicates that the performance of the heat pump system is strongly influenced by operating conditions and refrigerant type. It was consistently observed that higher heating performance (COP_h) was exhibited by R134a under all investigated cases, due to its more favorable thermodynamic behavior and higher enthalpy variation in the condenser, which allowed greater heat transfer.

In contrast, lower COP_h values were obtained with R1234yf across all conditions; however, several advantages were also associated with its use, including lower discharge temperature, reduced compressor thermal stress, and significantly improved environmental performance due to its low global warming potential (low-GWP). It was also found that COP_h was increased for both refrigerants when evaporating temperature and compressor efficiency were increased, while a clear decrease in performance was observed when condensing temperature was increased.

From an environmental perspective, a major reduction in climate impact was achieved when R1234yf was used instead of R134a, which is considered a high-GWP refrigerant. This environmental advantage was identified as a key factor influencing refrigerant selection, especially in modern systems where regulatory and sustainability requirements are increasingly prioritized. However, this benefit was found to be accompanied by a reduction in heating efficiency.

Overall, a clear trade-off between energy performance and environmental impact was demonstrated. While higher thermal efficiency was achieved with R134a, the use of R1234yf was identified as a viable alternative, particularly in applications where environmental considerations are prioritized over maximum system performance. Therefore, the refrigerant selection was shown to be strongly dependent on the balance between energy efficiency requirements and environmental constraints.

General Conclusion

This study provides a detailed thermodynamic analysis of a heat pump system employing R134a and R1234yf refrigerants, based on numerical simulations conducted with MATLAB inconjunction with REFPROP. The results indicate that system performance is heavily dependenton operating conditions. Specifically, raising the evaporating temperature from 20 °C to 30 °C significantlyenhances the heating coefficient of performance (COP_h), increasingit from 2.541 to 3.031 for R134a and from 1.982 to 2.410 for R1234yf.

Conversely, raising the condensing temperature from 90 °C to 97 °C leadsto a performancedecrease, with COP_h dropping from 2.541 to 2.045 for R134a and from 1.982 to 1.529 for R1234yf. Additionally, the findingsshow that R134a consistently outperforms R1234yf thermodynamically due to its higher enthalpy difference during phase changes, whereas R1234yf offers the advantage of lower compressor discharge temperatures, contributing to improved system reliability and extended compressor lifespan.

In line with the primaryaim of evaluatingR1234yf asan alternative refrigerant to R134a, the study concludes that while R1234yf is technically viable, it resultsin a moderatedecrease in system performance, evidencedbyconsistently lower COP_h values across all conditions analyzed. However, this reductioninefficiencyisoffsetby the significant environmental benefitsof R1234yf, whichhasa much lower global warming potential (GWP). Assuch, it emergesasan appropriate replacement refrigerant in light of strict environmental regulations and sustainabilityobjectives. Using R1234yf represents a compromise between energy efficiency and environmental responsibility. Based on these observations, R1234yf canberecommended as a suitable alternative refrigerant for heat pump systems inscenarioswhere environmental considerations are pivotal. Future research should aim to optimize the system's performance byexploringadvanced cycle designs, improving heat exchanger efficiency, and employing novel approaches such as nanorefrigerants to enhance overall functionality.

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