# Comparison Of Refrigerant in Recirculation Air Conditioning System: A Review

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***Abstract*—The environmental impact of conventional refrigerants such as R22, CFCs, and HCFCs has driven the need for sustainable and energy-efficient alternatives in refrigeration and air-conditioning systems. This study reviews and evaluates various eco-friendly refrigerants including R134a, R407C, R410A, R448A, R404A, R507A, R410B, and natural refrigerants like ammonia ($NH_3$), carbon dioxide ($CO_2$), and hydrocarbons. Their performance was analyzed in Vapour Compression Refrigeration Systems (VCRS) using thermodynamic modeling and experimental investigations. [1,3,5,7]**

**Key parameters such as Coefficient of Performance (COP), volumetric cooling capacity (VCC), specific cooling capacity (SCC), compressor work, exergy destruction, Energy Efficiency Ratio (EER), and environmental indicators like Global Warming Potential (GWP) and Ozone Depletion Potential (ODP) were considered. Results show that R134a provides higher COP under certain conditions, while R410A offers higher volumetric cooling capacity. [2.7.9] R448A demonstrates a balanced performance in terms of efficiency and environmental impact, particularly in high ambient temperature regions.**

**The study concludes that refrigerant selection should balance thermodynamic performance, environmental responsibility, and system compatibility to ensure sustainable and efficient cooling solutions aligned with green building principles.**

## I. INTRODUCTION

Refrigeration and air-conditioning systems have become essential to modern life, supporting food preservation, healthcare, transportation, industrial processes, and human thermal comfort. However, the environmental impact of conventional refrigerants has raised serious global concerns. Early synthetic refrigerants such as CFCs and HCFCs were widely used due to their stability and efficiency, but they were later identified as major contributors to ozone layer depletion. This led to the adoption of the Montreal Protocol, which mandated the phase-out of ozone-depleting substances.

Hydrofluorocarbons (HFCs), including R134a, replaced these substances because of their zero-ozone depletion potential (ODP). [4,5,6] However, HFCs possess high Global Warming Potential (GWP), contributing significantly to climate change. International agreements such as the Kyoto Protocol, the Paris Agreement, and the Kigali Amendment have therefore emphasized the need to reduce high-GWP refrigerants. [11,6.9]

Automotive air-conditioning systems are particularly critical because they are prone to refrigerant leakage due to vibration and dynamic operating conditions. R134a, still widely used in vehicles, has a GWP of about 1430, making leakage environmentally significant. Natural refrigerants such as hydrocarbons offer promising alternatives. R600a (isobutane), with a GWP of approximately 3 and zero ODP, presents strong potential due to its favorable thermodynamic performance and lower energy consumption, though safety concerns related to flammability must be addressed. [3,1,9]

To evaluate such alternatives, both energy (First Law) and exergy (Second Law) analyses are essential to identify system inefficiencies and improve performance. The transition toward eco-friendly refrigerants is therefore not only a technical necessity but also a responsibility toward sustainable development and climate protection. [12,4,5]

## II. METHODOLOGY

The schematic diagrams of the experimental setup for the present study are illustrated in Fig1. The experimental rig includes window air conditioner with main four parts; rotary compressor, forced finned tube condenser, capillary tube as expansion valve and forced finned tube evaporator. In An auxiliary window AC nit is used to control the temperature that surrounded the condenser, Fig. 2. The pressures, temperatures, and electrical data at different locations of the system are measured using pressure gauges, thermometers (thermocouples), and Multimeter.


Fig.1[11]

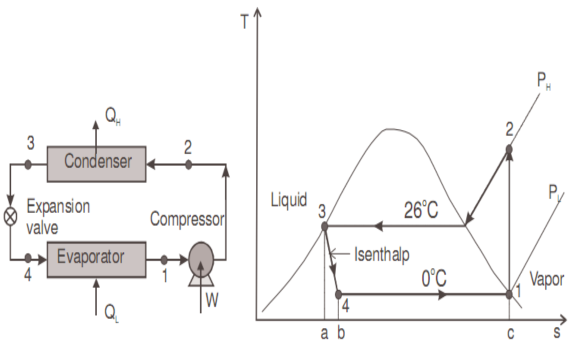


Fig.2[11]

High, low pressures and pressure drop in the evaporator and condenser in the system are measured using four pressure gages. The temperatures of the refrigerant are recorded using thermocouples at different locations that installed on the connection lines. Seven temperature measurements (thermocouples) are installed along the tube of the condenser to measure the temperature distribution along the condenser tube. Multimeter is used to measure the current and voltage readings of the compressor and the frequency meter is used to measure the frequency of the compressor. The whole system is operated using R22 as refrigerant and the data is collected at various operation conditions. The refrigerant R22 is replaced with R407C as substitute refrigerant, the compressor oil replaced using suitable oil for R407C. The test process consists of the following steps for both refrigerants: The main window AC unit in the experimental rig is operated and the fluid is circulated in the refrigeration cycle.

1. The other parts of the system are operated and the temperature of the air surrounded the condenser is specified at the desired temperature.
2. The measurement data are recorded when the whole system is reached to the steady state operation.
3. The ambient temperature is changed to other temperature the procedure is repeated.

## III. MATH

Then the heat transfer of the air across the condenser can be calculated according to the difference bulb temperature between the air inlet and air outlet temperatures was given in the following equation [8].

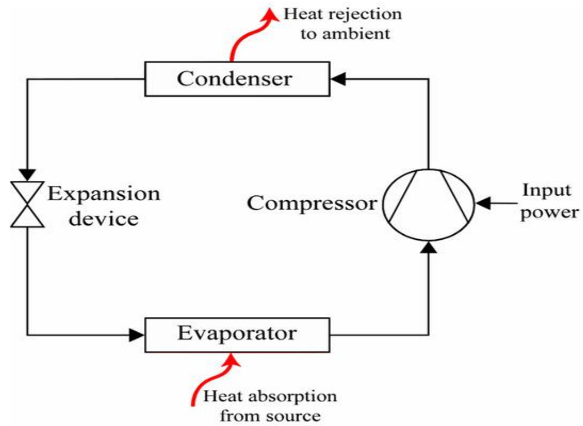


Fig.3

Then the heat transfer of the air across the condenser can be calculated according to the difference bulb temperature between the air inlet and air outlet temperatures was given in the following equation [8].

$$\dot{Q} = \dot{m}_a c_p (T_{out} - T_{in}) \qquad (1)$$

Where,

$$c_p = (\text{constant}) \qquad (2)$$

Also, the air mass flow rate that effect on the condenser coil can be calculated from the following expression:

$$\dot{m}_a = \rho V A \qquad (3)$$

While the surface temperature (Ts) is constant across the condenser, then the heat balance can be expressed by [8].

$$\dot{Q} = hA(T_s - T_a) \quad (4)$$

Where,

$$A = N \times \text{area} \quad (5)$$

Where, N = Number of refrigerant pipes in condenser
All the air properties can be taken at mean of the inlet and outlet of an air duct.

$$T_m = \frac{(T_{in} + T_{out})}{2} \quad (6)$$

The heat transfer coefficient for the air side of the condenser can be calculated from the following equation.

$$h = C(Re)^m (Pr)^n \quad (7)$$

Also $\dot{m}_a$ is the mass flow rate of the air, could be calculated from the following equation:

$$\dot{m}_a = \rho AV \quad (8)$$

Also, the heat transfer coefficient can be calculated using:

$$Nu = \frac{hD}{k} \quad (9)$$

If the number of rows less than 10, the Nusselt number is:

$$Nu = C_1 (Re)^n (Pr)^{1/3} \quad (10)$$

Reynolds and Prandtl numbers can be calculated as:

$$Re = \frac{\rho VD}{\mu} \quad (11)$$

The maximum velocity:

$$V_{max} = \frac{V}{(1-\sigma)} \quad (12)$$

Where,

$$\sigma = \left[\frac{S_p - D}{S_p}\right] \quad (13)$$

$$Pr = \frac{c_p \mu}{k} \quad (14)$$

For Turbulent flow, Dittus-Boelter correlation:

$$Nu = 0.023 Re^{0.8} Pr^{0.4} \quad (15)$$

Heat transfer rate over condenser (refrigerant side):

$$\dot{Q} = \dot{m}(h_{in} - h_{out}) \quad (16)$$

3.1 Capillary Tube

$$h_3 = h_4 \quad (17)$$

3.2 Evaporator
Coefficient of Performance:

$$COP = \frac{\dot{Q}_{evap}}{\dot{W}_{comp}} \quad (18)$$

$$\dot{Q} = \dot{m}(h_1 - h_4) \quad (19)$$

$$\dot{W} = \dot{m}(h_2 - h_1) \quad (20)$$

## IV. UNITS

Units and Measurement System (SI Units)
$\dot{Q}$: Heat transfer $\dot{m}$: Mass flow rate — kg·s⁻¹
$T$: Temperature — K (or °C)
H: Specific heat capacity — J·kg⁻¹·K⁻¹ $h$: Heat transfer coefficient — W·m⁻²·K⁻¹
$A$: Surface area — m²
$V$: Velocity — m·s⁻¹
$\rho$: Density — kg·m⁻³

Thermophysical Properties
$k$: Thermal conductivity — W·m⁻¹·K⁻¹
$\mu$: Dynamic viscosity — kg·m⁻¹·s⁻¹
$D$: Characteristic diameter — m
$S_p$: Tube pitch — m

Dimensionless Numbers
$Re$: Reynolds number — Dimensionless
$Pr$: Prandtl number — Dimensionless
$Nu$: Nusselt number — Dimensionless
$\sigma$: Porosity factor — Dimensionless
$COP$: Coefficient of performance Dimensionless

Refrigeration Cycle Parameters
$h_1, h_2, h_3, h_4$: Enthalpy — J·kg⁻¹
$\dot{W}$: Compressor work — W

Standard Notes
All quantities are expressed in SI (MKS) units.
Compound units use a center dot (·) (e.g., W·m⁻²·K⁻¹).
Temperature difference may be expressed in K or °C.
No mixing of SI and CGS units is used to maintain dimensional consistency

## V. CONCLUSION

The comparative analysis of various refrigerants confirms that the transition toward environmentally sustainable cooling technologies is both necessary and technically feasible. Performance evaluations of R22, R407C, and R290 indicate that while R22 often exhibits slightly higher cooling capacity and COP, natural refrigerants such as R290 offer superior environmental advantages due to negligible ODP and very low GWP. Although R290 shows lower mass flow rate and cooling capacity because of its low density, it demonstrates competitive energy performance and strong potential as a sustainable alternative.

Further comparisons among alternative refrigerants—including R410A, R448A, and R134a—reveal that no single refrigerant satisfies all technical, environmental, and safety requirements. However, R448A emerges as a promising replacement for R22 in residential systems, particularly in high ambient temperature regions, due to its balanced COP and reduced environmental impact.

Overall, natural refrigerants such as hydrocarbons, $CO_2$, and ammonia provide significant long-term environmental benefits, though challenges related to flammability, toxicity, and system design remain. Continued research, technological innovation, and supportive policies are essential to ensure safe, efficient, and sustainable refrigeration systems for the future.

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