Journal of Marine Technology and Environment
DOI:10.53464/JMTE.02.2025.07
ISSN (Print): 1844-6116
ISSN (Online): 2501-8795
https://www. jmte.eu

PROSPECTS FOR THE USE OF R290 REFRIGERANT IN MARINE REFRIGERATION EQUIPMENT

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Abstract : The need to replace traditional refrigerants in marine refrigeration equipment with low-GWP alternatives is growing due to international climate regulations. This paper discusses the current status and potential of R290 (propane) as a long-term substitute in marine air conditioning systems. Compared to other refrigerants, R290 offers higher energy efficiency, low environmental impact, and compatibility with existing system designs. Challenges related to flammability are addressed through compliance with safety standards and technical solutions approved by major classification societies. Calculations of performance parameters under different climatic conditions support the feasibility of switching to R290 as a sustainable alternative.
Key words : air conditioning system, climate impact, electricity consumption, energy efficiency, environmental friendliness, marine refrigeration, refrigerant.

1. INTRODUCTION

Global legislation such as the Paris Agreement, the Kigali Amendment, and the EU F-Gas Regulation aims to reduce hydrofluorocarbon (HFC) emissions, including those used in marine applications. The gradual phase-out of HFCs encourages the adoption of environmentally friendly alternatives. As one of the largest transport sectors, shipping must proactively implement green technologies.

Classification societies such as Lloyd's Register, DNV GL, and Bureau Veritas now promote refrigerants with a global warming potential (GWP) up to 2000, thereby excluding many traditional working fluids like R404A. Due to the need to reduce the environmental footprint of ship systems, there is increasing interest in natural refrigerants with zero or low GWP, such as CO2 (R744), ammonia (R717), and propane (R290) [2]. However, each of these options has specific limitations: R744 operates at high pressures, and R717 and R290 are flammable.

According to international standards (ISO 817, ASHRAE 34) and conventions (SOLAS, MARPOL, IGF, and IGC Codes), the use of flammable refrigerants onboard is not prohibited. Leading classification societies now allow their use, provided safety measures are followed. More regulators now recognize the safe use of R290 if refrigeration systems are properly designed and maintained.

2. R290 PROSPECTS AS A MARINE REFRIGERANT

R290 is currently regarded as one of the few refrigerants that meet the critical requirements of environmental friendliness, energy efficiency, and availability [2, 3]. With a GWP of around 5, it has minimal climate impact. It also has high energy efficiency: the coefficient of performance (COP) is 5…10% higher than that of R404A, R134a, and HFOs such as R1234yf, depending on the equipment. R290 can be integrated into traditional system designs without major modifications, unlike CO_2 or ammonia systems. It is also much cheaper than HFOs. Recently, R290 has been approved by Lloyd's Register, which is a significant milestone.

R290 is already in use in marine applications. For example, Thermo King and GIZ are working on a marine reefer container project called Greener Reefers, with new safety standards expected by 2026. Heinen & Hopman has proposed technical solutions for the safe use of R290 on board. Cooling Post and Johnson Controls are also developing propane- and propylene-based systems. Hydrocarbon refrigerants are already used in reliquefication systems on gas carriers and may be adapted for use in general marine refrigeration systems.

However, it is still debatable whether flammable refrigerants like R290 should be widely used before strict GWP limits are enforced. This paper analyses the advantages of R290 as a replacement for R404A and

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other alternatives in terms of energy and fuel savings in marine air conditioning systems.

3. EFFICIENCY ANALYSIS OF ALTERNATIVE REFRIGERANTS IN MARINE AIR CONDITIONING

A typical refrigeration unit for marine air conditioning systems, such as the "YORK Marine" plant manufactured by Hi Air Korea Co., Ltd., was selected for the comparative analysis of various refrigerants. The schematic of the refrigerant and cooling water circuit is shown in Figure 1. The general specifications are presented in Table 1.

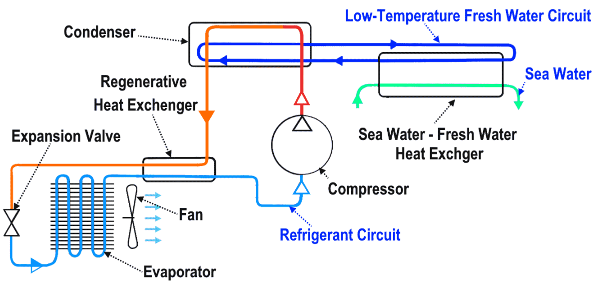

Figure 1 Schematic diagram of refrigerant and cooling water circuit in a marine air conditioning unit

Table 1. General specifications for the marine air-conditioning system

Parameter	Characteristics
Refrigerant	R404A
Compressor type	Sabroe SMC 106 S
Compressor ,Vh	339 m3/h at 1500 rpm
Condensing temperature, t_c	+42 °C
Evaporating temperature, t_{ev}	+7 °C

* *data was accepted according to the marine air-conditioning system manual*

It should be noted that due to their design, air conditioning systems on merchant ships can be installed in separate ventilated compartments, meeting the requirements of classification societies (e.g., Lloyd's Register) for systems using flammable refrigerants. However, this is not feasible for the provision refrigeration systems without an intermediate brine circuit.

To assess the feasibility of using low-GWP alternatives, the energy performance of the marine air conditioning unit operating on selected refrigerants was analysed. Table 2 summarizes their characteristics. R404A was used as a baseline, R407F as a widely used retrofit option, and R134a and R32 as common in air conditioning but not low-GWP. R290 and R1234yf were considered as promising long-term options with very low GWP.

Table 2. Main characteristics of selected alternative refrigerants

	R 404A	R 290	R 407F	R 1234 yf	R32	R 134a
GWP, kg CO_2/kg of refrigerant	3940	5	1670	<1	677	1300
The normal boiling point, °C	-46.6...-45.8	-42.1	-46.1 … -39.7	-29.45	-51.7	-26.07
Refrigerant safety class	A1	A3	A1	A2L	A2L	A1
Approved by classification societies	LR, BV, DNV	LR	LR, BV, DNV	DNV, BV	DNV, BV	LR, BV, DNV

Compressor power was estimated using RefProp 10.0 thermo-physical properties [5]. Volumetric and isentropic efficiencies of the reciprocating compressor were considered, with a shaft speed of 1410 rpm. The results of electrical COP and cooling capacity at varying condensing temperatures are presented in Figure 2 and Figure 3.

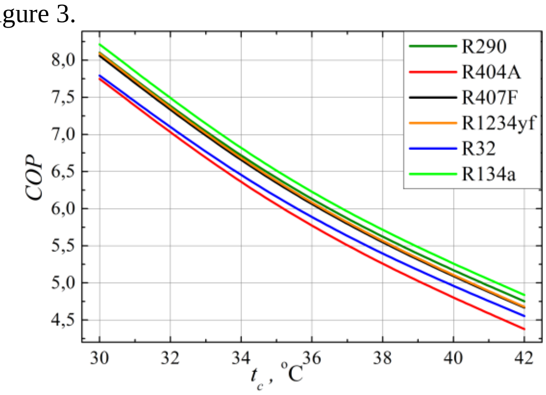

Figure 2 Electrical COP vs. condensing temperature for marine air conditioning system

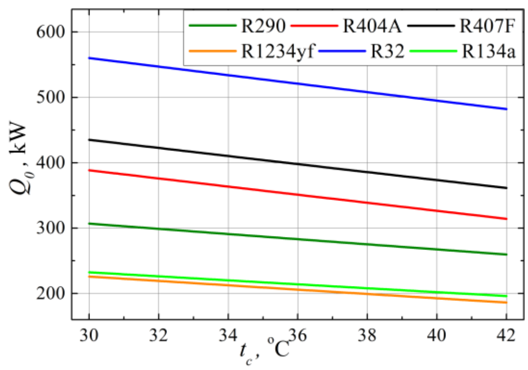

Figure 3 Cooling capacity vs. condensing temperature for marine air conditioning system (SMC 106 S compressor)

As shown in Figure 2, R134a provides the highest COP regardless of condensing temperature. However, it

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is not commonly used due to the industry trend of using a single refrigerant for both air conditioning and provision systems. R407F offers a higher COP than R404A and is a common short-term substitute. R1234yf and R290 show similar performance, with R290 slightly outperforming at higher condensing temperatures.

Figure 3 shows that the use of R1234yf, R290 and R134a in a system with an SMC 106 S compressor (V_h = 339 m^3/h) leads to a significant reduction in cooling capacity Q_0. Therefore, if the refrigeration machine is converted to one of these refrigerants, the compressor will need to be replaced. Unlike R1234yf, R290 and R134a , R407F provides an increase in cooling capacity, which is why it is currently used to directly replace R404A. A new compressor for each of the refrigerants under consideration was selected according to [7]. Table 3 lists the updated compressor parameters and resulting cooling capacities.

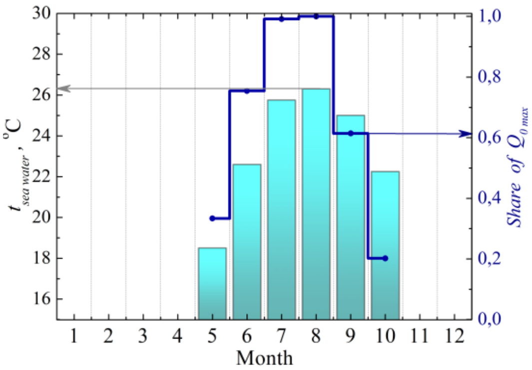
Table 3. Compressor parameters and cooling capacities of refrigeration machine

	R404A	R290	R407F	R1234 yf	R32	R134a
Compressor name	SMC 106 S	SMC 106 L	SMC 106 S	SMC 108 L	SMC 104 S	SMC 108 L
Compressor V_h at 1500 rpm, m^3/h	339	424	339	566	226	566
Q_0 at t_c=42 °C	314.2	324.7	361.4	310.8	321.3	327.3

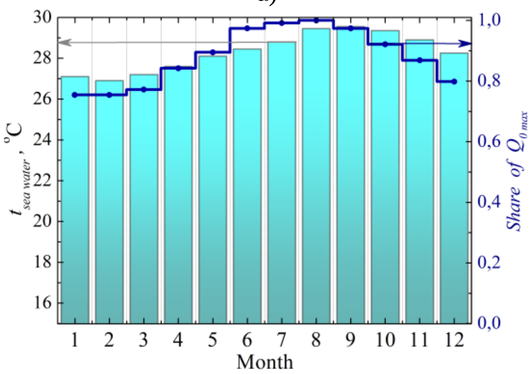
Next, we analysed the energy consumption of air conditioning systems using the refrigerants under consideration when operating in different climatic conditions:

- in a tropical climate (port Kingston, Jamaica, as an example);
- in a region with a temperate climate (port Piraeus, as an example).

The load (required cooling capacity Q_0) on the system was estimated for each month based on the average monthly outdoor air temperature (it was assumed that for the hottest month the load was 100 % and equal to Q_{0max} = 314.2 kW as for a system using R404A at t_c = 42 °C) - Figure 3. The temperature of the on board water is taken according to [8] - Figure 4. These data were used in the further analysis to determine the total annual electricity consumption by the air conditioning system's refrigeration machine.



a)



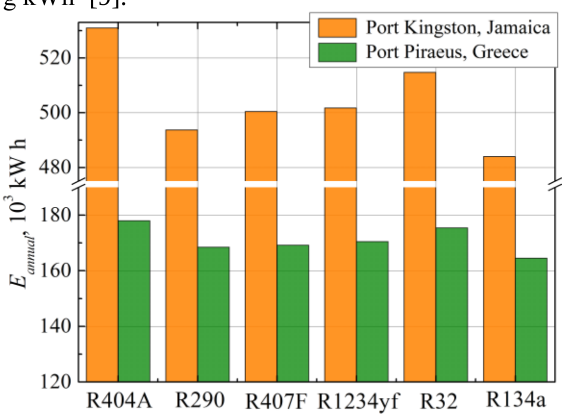
b)

Figure 4 The average monthly temperature of the seawater [8] and the share of the required cooling capacity of the air conditioning system from the maximum for the climatic conditions of two ports: a) Piraeus, Greece and b) Kingston, Jamaica.

The annual electricity consumption of the refrigeration compressor (including the energy consumption of the exhaust fan for flammable refrigerants) is shown in Figure 4.a.

Figure 4.b shows the annual fuel savings when the air conditioning refrigeration machine is converted to an alternative refrigerant. It was assumed that electricity is generated by a diesel generator (MDO as a fuel).

The base value of specific fuel consumption is 185 g·kWh^{-1}[9].



a)

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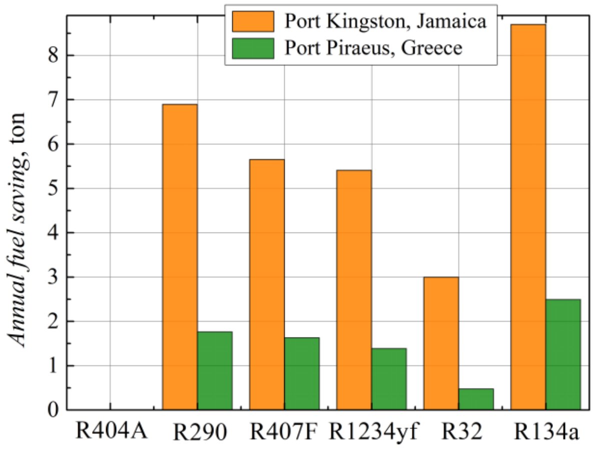

b)

Figure 5 Annual electricity consumption (a) and fuel savings (b) when operating a ship's air conditioning refrigeration machine with different refrigerants in regions with different climates

As can be seen from Figure 5, the lowest energy consumption by a refrigeration machine (8.9 % less than R404A) and the highest annual savings in ship fuel (8.9 tonnes) are achieved by using R134a refrigerant (based on the example of the Port of Kingston). The next most efficient refrigerant is R290 (7.0 % reduction in energy consumption and 6.9 tonnes of fuel savings). R32 has the least (but positive) effect of all refrigerants. R407F refrigerant, as a short-term alternative to R404A, provides a 5.8% reduction in energy consumption and 5.7 tonnes of fuel savings per year (based on the example of Kingston port). An interesting result was obtained: all alternative refrigerants provide greater energy savings for the refrigeration system compared to R404A when operating at high condensation temperatures (based on the example of the Port of Kingston).[10]

If we analyse the above results and calculation data, we can see that in the short term, R407F is an alternative refrigerant. It can be changed as part of a retrofit procedure (without replacing major components), and it provides fairly high COP values (Figure 2) and fuel economy (Figure 5). However, it cannot be considered in the long term due to its high GWP. R134a cannot be considered as a promising refrigerant in the short term due to the need to replace the compressor, although it has a lower GWP than R407F. R32 loses out in many respects: it has a low COP, is flammable and is not one of the refrigerants with a very low GWP.

R290 looks promising as a long-term replacement for R404A in the ship air conditioner under consideration. Compared to R1234yf, it provides greater fuel economy and is much cheaper.

The main disadvantage, flammability, is common to both of these refrigerants.

4. CONCLUSIONS

Despite the challenges associated with flammability, R290 is the most promising refrigerant for marine refrigeration. Its advantages in terms of energy efficiency, environmental friendliness, compatibility with existing systems and low cost make it inevitable that it will be adopted in the future. With proper compliance with technical standards and staff training, its introduction could become a benchmark for sustainable development in the shipping industry.

Safe implementation relies on proper engineering design and adherence to standards such as Lloyd's Register, EN 378, ISO 20854:2019, IEC 60079, etc. Currently, Lloyd's Register permits the use of R290 under conditions such as dedicated compartments, mechanical ventilation, and gas detection systems.

Transitioning to R407F is recommended as an interim solution, especially for existing ships where full modernization may not be practical.

A long-term strategy for marine refrigeration should focus on natural refrigerants, particularly R290.

5. ACKNOWLEDGMENTS

The authors are grateful to the Maritime University of Constanta for the financial support granted for the publication of the work.

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