

STUDY OF THE INFLUENCE OF REFRIGERANT MASS ON THE PERFORMANCE OF AUTOMOTIVE AIR CONDITIONING SYSTEMS

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***Abstract:** The performance of automotive air conditioning (A/C) systems is strongly influenced by the amount of refrigerant circulating within the system. This study investigates the effect of varying refrigerant charge on the thermodynamic performance, cooling capacity, and energy efficiency of an automotive A/C system operating under controlled conditions. Experimental tests were conducted using different refrigerant masses, ranging from undercharged to overcharged states, while monitoring system parameters. The results demonstrate that there exists an optimal refrigerant charge that maximizes cooling efficiency and minimizes energy consumption. The findings highlight the importance of precise refrigerant charging during maintenance and system design, contributing to improved energy efficiency, reduced emissions, and enhanced passenger comfort in automotive applications.*

***Keywords:** Automotive Air Conditioning, Refrigerant Charge, Coefficient of Performance (COP), Compressor Load, Thermal Management.*

INTRODUCTION

Automotive air conditioning systems are essential not only for passenger comfort, through the regulation of the thermal environment, but also have an impact on driving safety. The driver’s tendency toward drowsiness depends on the climate inside the vehicle cabin. This is an important factor that should not be overlooked, as it can help prevent road traffic accidents.

Air conditioning systems also play a role in the energy efficiency of vehicles, especially under high ambient temperature loads. The operation of these systems depends not only on the main components – the compressor, condenser, evaporator, and expansion device – but also on the quantity and condition of the circulating refrigerant. An incorrect refrigerant charge (either insufficient or excessive) can lead to reduced cooling capacity, increased energy consumption, higher compressor load, and degraded long-term system reliability.

Published studies report that the amount of refrigerant has a measurable impact on the performance indicators of automotive air conditioning systems. For example, in one study (Hanriot, S., & Vieira, B., 2011), it is noted that significant potential for improving system efficiency can be achieved by optimizing the refrigerant mass in automotive air conditioning systems. Another study (Pan, C., & Tang, Y., 2011) demonstrates how variations in the charged refrigerant mass affect parameters such as cooling capacity, compressor power consumption, and the coefficient of performance (COP).

Furthermore, with the introduction of new refrigerants and the increasing use of electric and hybrid vehicles, the issue of optimal refrigerant charge has become even more relevant. For instance, a study (Song, J., Eom, S., Lee, J., Chu, Y., Kim, J., Choi, S., Choi, M., Choi, G., & Park, Y., 2023) investigating a system using R1234yf refrigerant shows that the optimal refrigerant mass is 0.7 kg in heating mode and 0.9 kg in cooling and battery cooling modes. This

highlights that the optimal refrigerant charge in a system is not merely a function of a nominal value but depends on both the system's design characteristics and its operating conditions.

In (Macagnan, M., Copetti, J., Souza, R., Reichert, R., & Amaro, M., 2013), it is emphasized that when the refrigerant mass exceeds the optimal level, increased pressure, higher compressor work, and often reduced efficiency are observed. Conversely, when the refrigerant charge is insufficient, mass flow rate decreases, cooling capacity drops, and the degree of superheat either increases or becomes inadequate, disrupting heat transfer in the evaporator. In this sense, proper refrigerant dosing is a key factor both in system design and during maintenance operations.

From a maintenance perspective, (Meena, A., Kishore, K., Agarwal, R., & Parayil, P., 2023) emphasize that systems operating with deviations from the prescribed refrigerant mass require special attention. Moreover, the broader challenges facing automotive air conditioning systems — such as environmental requirements, the adoption of new refrigerants, and integration into thermal management systems for electric vehicles — are discussed in detail in (Sachelarie, D., Achitei, G., Munteanu, A., Sachelarie, A., Dontu, A., Tcaciuc, G., & Popescu, A., 2025).

The present study aims to address some of the existing research gaps by systematically analyzing the influence of refrigerant mass on the performance of an automotive air conditioning system under controlled laboratory conditions.

EXPOSITION

Research methodology

For the experimental research, a Renault Laguna II 2.0 dCi passenger car was used. Its air conditioning system features electronic control and a mechanical thermostatic expansion valve. The compressor is of the swash-plate (axial piston) type. Compressor flow rate regulation is achieved via an electromagnetic control valve, which adjusts the inclination of the compressor plate depending on the crankcase back pressure. The refrigerant mass recommended by the manufacturer is approximately 600 g of R134a, considered the nominal charge.

Before conducting the experimental tests, a visual inspection was performed on the pipelines, fittings, condenser, and evaporator to check for corrosion or deformation, and an electronic leak detector was used to ensure system integrity. To facilitate and improve the accuracy of refrigerant mass measurement during charging, a standard automotive air conditioning service station – Texa KONFORT 715 TOUCH – was employed (Fig. 1).



Fig. 1. Texa KONFORT 715 TOUCH car air conditioning system service machine

Usual the servicing process of an automotive air conditioning (A/C) system follows a systematic and automated sequence designed to ensure operational precision and environmental safety. Once the system is properly connected, the KONFORT 715 TOUCH initiates the recovery phase, extracting the existing refrigerant, filtering it, and storing it in a secure internal cylinder.

After the recovery process, the machine performs a vacuum and leak test to remove air and moisture from the system and to verify its integrity under negative pressure. The controlled vacuum phase ensures that no contaminants remain, while the automatic leak detection function identifies potential system defects that must be corrected before recharging. Subsequently, the precise quantity of compressor oil is injected into the circuit in accordance with the specifications stored in the machine's database.

The final stage involves charging the system with the exact amount of refrigerant specified by the manufacturer, monitored by the machine's electronic scale to ensure accuracy. Once the charging phase is complete, the system's performance is verified by measuring pressure values and outlet air temperatures during engine operation. This structured approach enhances reliability, minimizes human error, and ensures compliance with environmental and technical standards in the maintenance of modern automotive air conditioning systems.

To carry out the experiments, a series of standard procedures were performed, including:

- Extraction of the refrigerant content from the vehicle's air conditioning system and maintaining an absolute pressure of 0.1 kPa for 20 minutes;
- Recovery of the extracted refrigerant, which involves oil removal and purification;

Charging the air conditioning system with a refrigerant mass corresponding to the experimental test plan.

The experiments were carried out with the following refrigerant charge masses in the air conditioning system: 300 g, 420 g, 510 g, 600 g, and 690 g. For the construction of the graphical dependencies, these masses were referenced to the manufacturer's recommended value of 600 g. To measure the duty cycle of the pulse-width modulated (PWM) control signal for the compressor flow control valve, a Texa TwinProbe automotive oscilloscope was used.

Experimental studies

During the experiments, the ambient temperature was recorded at 35°C. The vehicle remained stationary, and the blower fan for the evaporator was set to the second speed level.

Figure 2 shows the waveforms of the pulse-width modulation (PWM) control signal of the compressor's electromagnetic valve for different relative refrigerant charge masses. D represents the ratio of the time at maximum voltage to the time at minimum voltage, which correspondingly indicates the compressor load. From this parameter, the power consumed by the compressor can be determined.

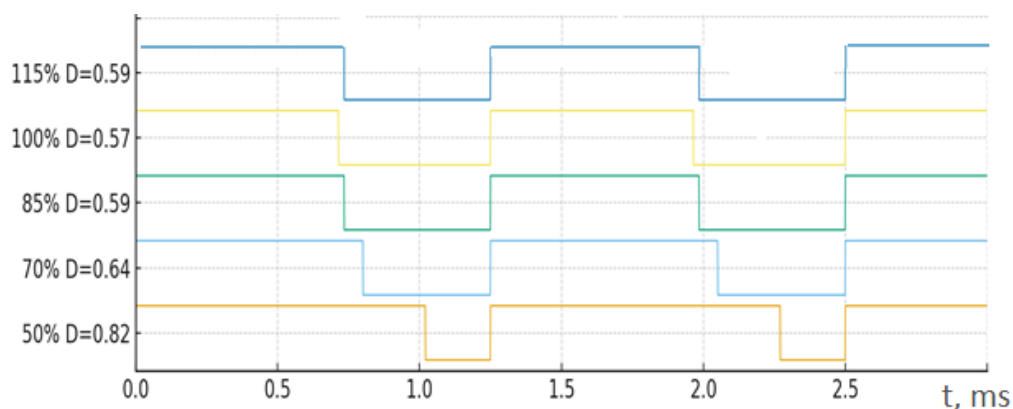


Fig. 2. Waveforms of the pulse-width modulation control signal of the compressor's electromagnetic valve for different relative refrigerant charge masses

To illustrate the influence of the relative refrigerant mass charged in the air conditioning system, the graph in Figure 3 was constructed. It shows that at lower relative masses (below nominal), a significantly higher **D** ratio is observed. Overcharging the system – with a relative mass above 100% – also results in an increase in the **D** ratio.

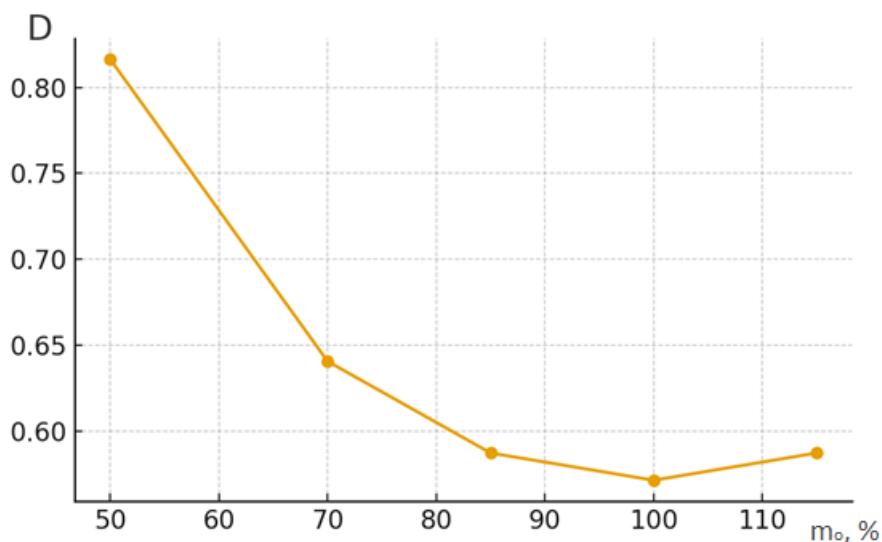


Fig. 3. Variation of the ratio of time at maximum voltage to time at minimum voltage of the PWM signal, **D**, as a function of the relative refrigerant mass m_o in the air conditioning system

CONCLUSION

From the analysis of the obtained results, the following conclusions can be drawn:

The optimal operating condition of the air conditioning system occurs at 100% relative mass of the charged refrigerant in the system. At this point, **D** – the ratio of the time at maximum voltage to the time at minimum voltage of the PWM signal – is at its lowest, specifically 0.57. This indicates the lowest compressor load.

If the refrigerant mass decreases by 50%, the **D** ratio increases by 23%. This sharp increase is likely due to a reduction in the coefficient of performance (COP).

When the system is overcharged with refrigerant by 15%, the **D** ratio increases only slightly by 2%. A decrease in COP is also observed when the refrigerant mass in the system exceeds the manufacturer's recommended value.

These results demonstrate that the mass of refrigerant charged into the air conditioning system plays a crucial role in its optimal operation. Large deviations from the prescribed values are not recommended.

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