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Optimizing the Performance of Automotive Air-Conditioning System by Using Cooling Fluid Mist

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ABSTRACT : *This study explores the application of* cooling fluid *mist, which is used as a coolant for the condenser, and its effect on the overall performance of automotive air-conditioning systems. Experimental analysis was conducted on two vehicles, a Toyota Camry 2014 and a Nissan Pathfinder 2012, under varying outdoor temperatures. Among the key parameters were low-side and high-side pressures at standard operation, as well as when the mist was applied. The results demonstrate that the use of refrigerant mist both substantially increases condenser efficiency and helps minimize pressure on both sides, consequently improving the system. They are better efficiency of power, less thermal stress, and consequently longer service life. Hence, the findings have provided the groundwork and support adoption of such technology for air-conditioning systems mainly in the regions with high-temperature. Recommendations focus on supporting the research efforts in the area of proper integration of technology as well as drawing conclusions based on trials with alternative refrigerants for the so-called technology-based pattern.*

KEYWORDS: *cooling fluid mist, R-134a refrigerant, Automotive air-conditioning*

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I. INTRODUCTION

In scorching hot weather, an automotive air-conditioning system becomes an indispensable companion for both drivers and passengers. This system, commonly known as air conditioning, plays a pivotal role in maintaining a comfortable and safe interior environment within a vehicle. When temperatures soar, the air-conditioning system operates by drawing in hot air from the surroundings, passing it through a condenser, where refrigerant gas is compressed and condensed, releasing heat in the process. The cooled and dehumidified air is then circulated into the car's cabin through vents, offering respite from the oppressive heat. This not only enhances the comfort of those inside but also contributes to driver alertness and concentration, ensuring a safer and more pleasant journey during the hottest of days. So, in the midst of a blazing summer, an efficient automotive air-conditioning system serves as a vital component, providing a welcome oasis of relief on the open road.

Automotive air-conditioning systems can face several challenges in very hot weather conditions. These problems can affect the comfort and performance of the system, as well as the overall driving experience. Some common issues include:

- Reduced Cooling Efficiency: Extremely high temperatures can strain the air conditioning system, making it less effective at cooling the interior of the vehicle. The difference between the outside and inside temperatures can be substantial, leading to longer cooling times and less effective cooling.
- Overheating of Components: The air conditioning system relies on various components, including the compressor, condenser, and evaporator. In very hot weather, these components can become overheated, leading to reduced efficiency and potential damage over time. Overheating may also lead to increased wear and tear on the system.
- Refrigerant Issues: High temperatures can cause the refrigerant in the system to evaporate more quickly, reducing its cooling capacity. It can also put extra stress on the system's refrigerant lines and seals, potentially leading to leaks. If the refrigerant level drops, the system's performance will suffer.

- Increased Energy Consumption: To maintain the desired interior temperature in hot weather, the air conditioning system has to work harder and consume more energy. This results in decreased fuel efficiency and more strain on the vehicle's engine.
- Cabin Air Quality: In hot weather, the cabin air conditioning system can also struggle to maintain air quality. If the system is not functioning optimally, it may not filter and circulate the air effectively, leading to decreased air quality inside the vehicle.
- Increased Wear and Tear: Hot weather can accelerate wear and tear on the air conditioning system's components, such as the blower motor and cooling fan. The system may need more frequent maintenance to ensure it continues to operate effectively.
- Unpleasant Odors: In very hot conditions, moisture can accumulate in the system, potentially leading to the growth of mold and bacteria. This can result in foul odors when the air conditioning is turned on.

To address these issues, it's essential to perform regular maintenance on your vehicle's air conditioning system, including checking the refrigerant level, cleaning or replacing filters, and inspecting the various components for wear and tear. Additionally, you can take steps to reduce the impact of extreme heat, such as using sunshades or parking in the shade to reduce the initial heat load on the vehicle's interior.

II. BACKGROUND

An automotive air conditioning system consists of several key components that work together to cool and dehumidify the air inside a vehicle. These components include:

- Compressor: The compressor is the heart of the air conditioning system. It pressurizes and circulates the refrigerant (usually a gas) through the system. The refrigerant absorbs heat from the interior of the vehicle and releases it outside.
- Condenser: The condenser is located in front of the vehicle's radiator. It helps dissipate the heat absorbed by the refrigerant from the interior. As the refrigerant flows through the condenser, it releases heat, causing it to change from a gas to a high-pressure liquid.
- (Receiver/Drier) or Accumulator: Depending on the type of system, there may be a receiver/drier or an accumulator. These components remove moisture from the refrigerant and store excess refrigerant, ensuring that only dry and pure refrigerant enters the evaporator.
- Expansion Valve or Orifice Tube: These components regulate the flow of the refrigerant into the evaporator. They create a pressure drop, causing the refrigerant to expand and cool rapidly.
- Evaporator: The evaporator is typically located inside the vehicle, often behind the dashboard. As the low-pressure refrigerant enters the evaporator, it absorbs heat from the interior air. This causes the air to cool and dehumidify, providing a comfortable climate inside the vehicle.
- Blower Fan: The blower fan, often located in the dashboard or under the dash, circulates air across the evaporator and into the interior of the vehicle. The speed of the fan can be adjusted to control the temperature and airflow.
- Control Panel: The control panel in the vehicle's dashboard allows the driver and passengers to set the desired temperature, fan speed, and air distribution.
- Refrigerant Lines and Hoses: These are the pipes and hoses that connect the various components, allowing the refrigerant to circulate within the system.
- Electrical and Wiring Components: These are essential for controlling and powering the air conditioning system. They include sensors, switches, and wiring harnesses.
- Belts and Pulleys: The air conditioning system is often driven by a belt connected to the engine's crankshaft via a pulley. The compressor, with its clutch, is engaged or disengaged as needed to control the cooling.

Fig,1 demonstrates the fundamental working cycle of a refrigeration or an air conditioning system. It shows the components which make up the refrigeration cycle and the refrigeration fluid circulating through these parts. These components work together to cycle refrigerant through the system, absorbing heat from the interior and releasing it outside, thus cooling and dehumidifying the air in the vehicle. Proper maintenance and repair of these components are essential to ensure the system operates effectively.

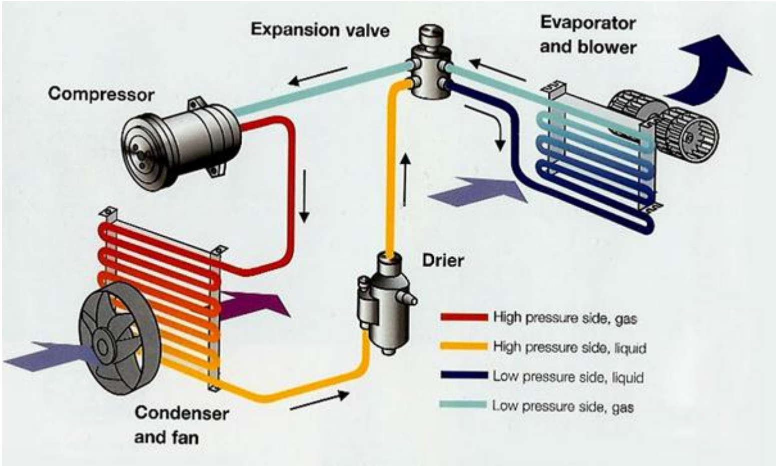

Fig.1. Basic Components and Flow of a Refrigeration System

The following points are set to enhance the automotive air-conditioning system performance:

- The automotive air-conditioning components will be studied to know how to operate it.
- Misting cooling fluid on condenser side for different car in hot weather (46^{o} c and above).
- The results will be analyzed to predict the best operation condition.

III. METHODOLOGY

The main aim of this research is sustaining the right cooling performance of an automotive air-conditioning (AC) system by means of a cooling fluid mist technique which is being integrated and by evaluating its impact on the system's efficiency. The methodology is divided into three parts to achieve the aims of the project:
1.Literature Review: a comprehensive literature review will be conducted, gathering information from a wide range of sources such as books, booklets, previous research, and related projects. This phase will provide the necessary theoretical background and insights into existing methods for enhancing AC performance, serving as a foundation for the experimental phase.
2. Experimental Work: The experimental phase will involve real cars to test the modified AC system. A misting mechanism will be integrated to introduce a cooling fluid into the system. The Coefficient of Performance (COP) equation will serve as the primary metric for evaluating efficiency:
COP= $(p_{low})/(P_{high} - P_{low})$
3. The last stage will concentrate on the documentation of the whole project consisting of the literature review, the experimental process, the results, and the conclusions. This write-up is going to consist of a detailed view of the obtained results and the recommendations for the future work.

IV. RESULTS

The misting valve was installed on the cooling circuits of both the 2014 Toyota Camry and Nissan Pathfinder. This device was installed near the condenser units of both vehicles and used windshield washer pumps, hoses and sprayers that sprayed a small amount of water mist onto the surface of the condensers. This installation is convenient in that it allows for increased heat removal from the coolant with a high temperature, especially in conditions of high ambient temperatures. It was planned that this method of using water mist would helpimprove increase the efficiency ofRefrigeration cycle for both vehicles.Table.1 and table.2 shows the performance of the air conditioning system of a 2014 Toyota Camry and 2012 Nissan Pathfinder using R-134a refrigerant under two different conditions: normal conditions and during the use of cooling fluid mist. Low Side Pressure and High Side Pressure readings are recorded at different outside temperatures

Toyota Camry 2014 - Refrigerant R-134a						
Outdoor Temperature (C)	**Normal Condition**			**During mist**		
	Low side Pressure (Psi)	**High side pressure (Psi)**	**Cop**	**Low side pressure (Psi)**	**High side pressure (Psi)**	**Cop**
40	**65**	**310**	**.2653**	**53**	**256**	**.2611**
43	**67**	**325**	**.2593**	**58**	**267**	**.2775**
45	**70**	**330**	**.2692**	**58**	**272**	**.2710**

47	**75**	**345**	**.2778**	**60**	**277**	**.2765**
50	**77**	**348**	**.2841**	**63**	**280**	**.2803**
52	**78**	**363**	**.2737**	**65**	**293**	**.2851**
55	**80**	**365**	**.2807**	**67**	**295**	**.2939**
	Mist time is 5 second - we are using windshield pump with hose and nuzzles					

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Table.1: performance of the air conditioning system of a 2014 Toyota Camry using R-134a refrigerant under two different conditions: normal conditions and during the use of a water mist

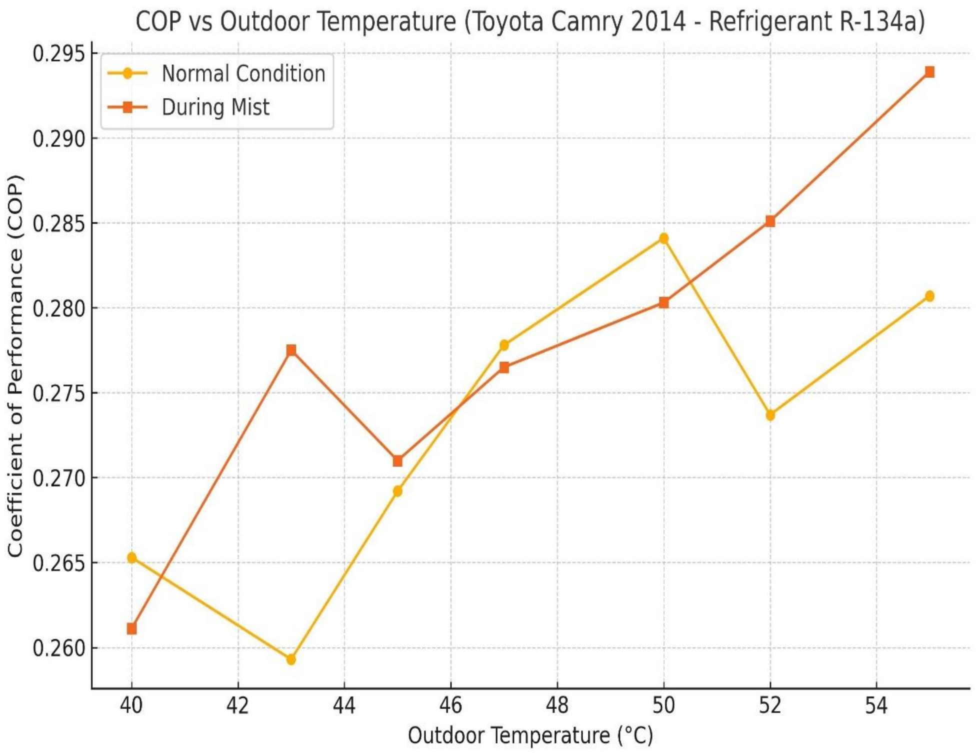

Fig.2: Comparison of the Cop of air conditioning system of a 2014 Toyota Camry using R-134a refrigerant under two different conditions: normal conditions and during the use of a water mist

The analysis examines the performance of the air conditioning system in a 2014 Toyota Camry using R-134a refrigerant, under two scenarios: normal operation and when mist is applied to the condenser. The data illustrates the system's behavior by looking at the low-pressure and high-pressure sides at various outdoor temperatures.

Low-Pressure Side

Under normal conditions, the low-side pressure rises steadily with the outdoor temperature, starting at 65 psi at 40°C and reaching 80 psi at 55°C. This pattern occurs because the refrigerant evaporation rate in the evaporator increases as the outdoor temperature goes up. In mist conditions, the low-side pressure begins lower than in normal conditions, starting at 53 psi at 40°C, but it gradually climbs, eventually exceeding normal conditions and hitting 67 psi at 55°C. The initial lower pressure in mist suggests a different operational dynamic, likely due to better heat rejection at the condenser. While both scenarios show an upward trend in low-side pressure, the lower starting values in mist conditions indicate improved refrigerant flow and system performance during the initial operation phase

High-Pressure Side

Under normal conditions, the high-side pressure steadily increases with temperature, starting at 310 psi at 40°C and climbing to 365 psi at 55°C. This rise indicates the growing demand on the condenser as it works to release heat in warmer ambient temperatures. However, in mist conditions, the high-side pressure is significantly lower, starting at 256 psi at 40°C and reaching 295 psi at 55°C. This decrease is attributed to the cooling effect of the mist, which enhances the condenser's ability to dissipate heat. The notable drop in high-side pressure when mist is applied highlights its role in reducing the compressor's workload and boosting overall system efficiency.

Cop In normal condition

The data shows the connection between low side pressure (in psi), high side pressure (in psi), and the coefficient of performance (COP) under various system conditions. At 65 psi, the high side pressure is 310 psi, and the COP is 0.2653, indicating that the system is operating inefficiently at this lower pressure range, suggesting it may be struggling to perform at its best. When the low side pressure increases to 67 psi, the high side pressure rises to 325 psi, and the COP decreases slightly to 0.2593. This decline, despite the increase in high side pressure, suggests diminishing returns in efficiency, where the system does not significantly enhance its performance with rising pressure. At 70 psi, with the high side pressure at 330 psi, the COP improves to 0.2692, indicating a slight recovery in efficiency as the system starts to operate more effectively. Although the COP is still low, it reflects a positive change in performance. As the pressure increases further to 75 psi (high side pressure 345 psi), the COP rises to 0.2778, showing a clear improvement in efficiency. This indicates that the system benefits from higher pressure, enhancing its heat exchange capabilities and overall performance. At 77 psi, with a high side pressure of 348 psi, the COP increases to 0.2841, demonstrating further improvement and a stabilization of performance at a higher level. However, at 78 psi, with the high side pressure increasing to 363 psi, the COP drops slightly to 0.2737, indicating diminishing returns as the pressure continues to rise. This could be attributed to inefficiencies such as refrigerant overheating or reduced heat transfer at elevated pressures. At 80 psi, with the high side pressure at 365 psi, the COP improves slightly to 0.2807, but it still falls short of the peak value of 0.2841 recorded at 77 psi. This indicates that although there are some minor performance enhancements at higher pressures, the system is approaching its optimal operating pressure, where additional increases in pressure result in only marginal benefits.

Cop In Mist Condition

The data shows how the Coefficient of Performance (COP) changes with variations in low side and high side pressures under mist conditions, where high humidity or partial vaporization of refrigerant can lead to reduced system efficiency. At 53°C, with a high side pressure of 256 psi, the COP is 0.2611, indicating low efficiency due to mist or humidity. This suggests that the system struggles to operate effectively in higher ambient temperatures. At 58°C, with a high side pressure of 267 psi, the COP increases slightly to 0.2775, reflecting a minor improvement in efficiency. However, at 272 psi, the COP drops to 0.2715, indicating diminishing returns as pressure increases. At 60°C, with a high side pressure of 277 psi, the COP holds steady at 0.2765, showing that mist conditions continue to impede efficiency despite the higher pressure. At 63°C, with a high side pressure of 280 psi, the COP rises to 0.2903, suggesting a modest improvement in efficiency, possibly due to a better balance between pressure and heat load. At 65°C, with a high side pressure of 293 psi, the COP slightly decreases to 0.2851, indicating that mist conditions may offset the benefits of increased pressure. Finally, at 67°C, with a high side pressure of 295 psi, the COP increases slightly to 0.2947, suggesting a small recovery in efficiency.

However, the minimal rise in COP highlights the persistent inefficiencies caused by mist or high humidity. In conclusion, under mist conditions, the COP initially improves with rising temperatures, peaking around 63°C, after which the system faces diminishing returns. The increase in high side pressure does not consistently lead to a proportional rise in COP, indicating that the system struggles to maintain efficiency as mist conditions worsen.

For the 2014 Toyota Camry that uses R-134a refrigerant, applying mist improved the air conditioning system's performance by lowering high-side pressure and increasing the Coefficient of Performance (COP). The highest COP observed under mist conditions was 0.2947, which was better than the 0.2841 recorded under normal conditions. This indicates that mist can effectively boost efficiency by reducing the compressor's workload and optimizing system performance at moderate pressure levels. However, the advantages were less pronounced at higher pressures, suggesting there are limits to how much performance can be improved with mist under those conditions.

Nissan Pathfinder 2012 - Refrigerant R-134a							
Outdoor Temperature (C)		Normal Condition			During mist		
		Low side pressure (Psi)	High side pressure (Psi)	cop	Low side pressure (Psi)	High side pressure (Psi)	cop
1	40	63	306	0.2593	52	254	0.2574

2	**43**	**67**	**322**	**0.2627**	**55**	**268**	**0.2582**
3	**45**	**70**	**329**	**0.2703**	**58**	**274**	**0.2685**
4	**47**	**75**	**341**	**0.2820**	**62**	**275**	**0.2911**
5	**50**	**76**	**347**	**0.2804**	**63**	**278**	**0.2930**
6	**52**	**78**	**360**	**0.2766**	**66**	**291**	**0.2933**
7	**55**	**81**	**363**	**0.2872**	**68**	**293**	**0.30222**
Mist time is 5 second - we are using windshield pump with hose and nuzzles							

Table.2: performance of the air conditioning system of a 2012 Nissan Pathfinder using R-134a refrigerant under two different conditions: normal conditions and during the use of a water mist

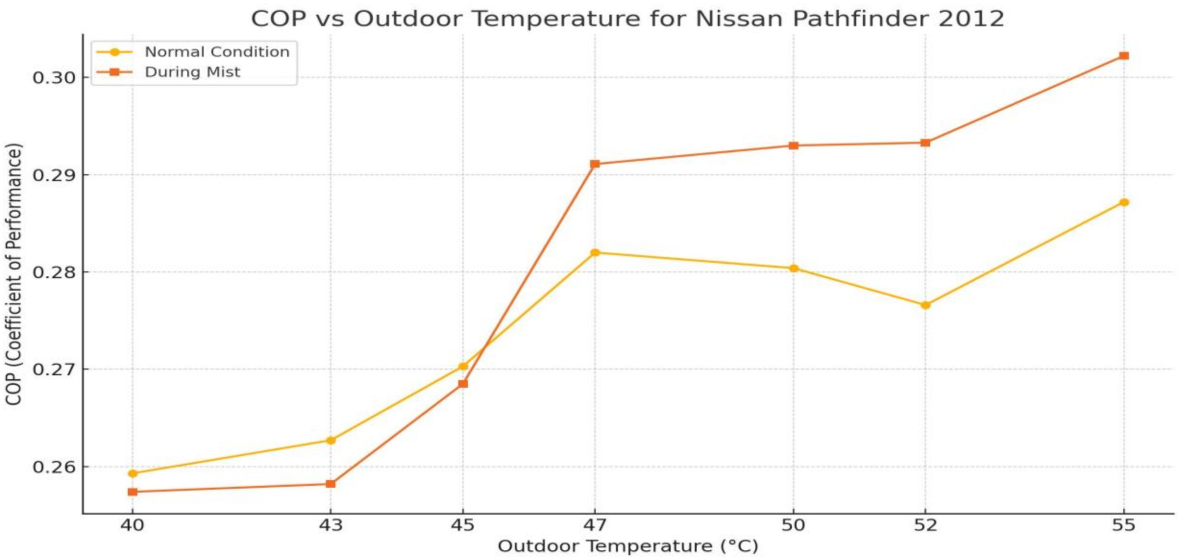

Fig.3: performance of the air conditioning system of a 2012 Nissan Pathfinder using R-134a refrigerant under two different conditions: normal conditions and during the use of a water mist

The data illustrates how a system, probably a cooling or air conditioning unit, performs under typical conditions. It demonstrates the effect of varying outdoor temperatures (°C) on low side pressure, high side pressure, and the coefficient of performance (COP)

Low-Pressure Side

The low side pressure refers to the pressure on the evaporator side of the system, where the refrigerant absorbs heat from the indoor environment. The data indicates that as outdoor temperatures increase, the low side pressure also rises. At 40°C, it starts at 63 psi, then climbs to 67 psi at 43°C, and reaches 81 psi at 55°C. This trend suggests that higher outdoor temperatures necessitate higher pressure in the evaporator to effectively take in heat. Additionally, the increase in low side pressure points to a greater load on the system, as it must work harder to maintain its performance under these conditions.

High-Pressure Side

The high side pressure refers to the pressure on the condenser side of the system, where the refrigerant expels heat to the outside air. Data indicates that as the outdoor temperature climbs, the high side pressure also increases. For instance, at 40°C, the pressure is 306 psi, which rises to 322 psi at 43°C and reaches 363 psi at 55°C. This rise in high side pressure suggests that the system is exerting more effort to release heat into a warmer environment. As outdoor temperatures increase, the efficiency of heat exchange decreases, leading the system to operate at higher pressures to compensate for this challenge.

Cop

Cop in normal conditions

At 40°C, the COP is 0.2593, which shows that the efficiency is relatively low at this temperature. The low-side pressure is 63 psi and the high-side pressure is 306 psi, both of which are moderate, indicating that the system is functioning within standard pressure ranges but hasn't yet achieved optimal performance. When the temperature increases to 43°C, the COP improves slightly to 0.2627, suggesting a small gain in efficiency as the temperature rises. At 45°C, the COP increases more significantly to 0.2703, indicating better performance as the system adapts to the higher temperature. The COP peaks at 0.2820 at 47°C, suggesting that the system operates most efficiently at this temperature, as evidenced by the higher COP and relatively elevated pressure values (75 psi low-side and 341 psi high-side). At 50°C, the COP drops slightly to 0.2804, indicating a minor decline in efficiency. Nevertheless, the system continues to function at a relatively high level, with pressures (76 psi and 347 psi) comparable to those at the previous temperature, suggesting that it is managing the load effectively, although higher temperatures are starting to test its efficiency. At 52°C, the COP decreases further to 0.2766, which shows a slight reduction in performance. The pressures (78 psi and 360 psi) have increased a bit, pointing to added strain on the system. Still, it operates efficiently, albeit not as well as it did at 47°C. At 55°C, the COP rises again to 0.2872, marking the highest efficiency recorded in the dataset. The pressures (81 psi and 363 psi) are at their maximum, but the system is well-suited for this temperature, indicating it can still manage the load with optimal efficiency. In summary, the COP increases slightly from 40°C to 47°C, peaking at 0.2820 at 47°C, which signifies optimal efficiency. Beyond 47°C, the COP experiences a slight decline at 50°C and 52°C, yet the system remains efficient. The COP rises again at 55°C, demonstrating that the system is built to handle high temperatures and can maintain peak efficiency under these conditions.

Cop in mist

At 68 psi, the coefficient of performance (COP) reaches its peak at 0.3022, marking the highest value in this dataset and indicating optimal system performance at this pressure. To summarize, the COP shows a steady increase from 0.2574 at 52 psi to 0.3022 at 68 psi, reflecting a gradual improvement in system efficiency as pressure rises. The system's highest efficiency is achieved at 68 psi, while the lowest is recorded at 52 psi. Overall, the data indicates that higher pressures lead to better performance, with optimal efficiency occurring at elevated pressure levels. The introduction of mist has notably enhanced the efficiency of the air conditioning system in the 2012 Nissan Pathfinder, which operates with R-134a refrigerant. Under mist conditions, the highest COP recorded was 0.3022, suggesting that mist has a beneficial effect on the system's performance, particularly in warmer outdoor temperatures. This implies that using mist could be a simple and effective method to boost air conditioning efficiency in similar vehicle systems.At 68 psi, the coefficient of performance (COP) reaches its peak at 0.3022, marking the highest value in this dataset and indicating optimal system performance at this pressure. To summarize, the COP shows a steady increase from 0.2574 at 52 psi to 0.3022 at 68 psi, reflecting a gradual improvement in system efficiency as pressure rises. The system achieves its maximum efficiency at 68 psi, while the lowest recorded value is at 52 psi. Overall, the data indicates that higher pressures lead to better performance, with optimal efficiency attained at elevated pressure levels. The introduction of mist has significantly enhanced the efficiency of the air conditioning system in the 2012 Nissan Pathfinder, which operates with R-134a refrigerant. The highest COP observed under mist conditions was 0.3022, suggesting that mist has a beneficial effect on the system's performance, particularly in warmer outdoor temperatures. This implies that using mist could be a simple and effective method to improve air conditioning efficiency in similar vehicle systems.

V. CONCLUSION

This study highlights how applying cooling fluid mist to the condenser can enhance the performance of automotive air-conditioning systems. Tests on the 2014 Toyota Camry and the 2012 Nissan Pathfinder showed that this technique improves thermal efficiency, lowers system pressures, and reduces the strain on key components, especially in high-temperature conditions.

Key Finding

For both the 2014 Toyota Camry and the 2012 Nissan Pathfinder, which use R-134a refrigerant, the introduction of water(cooling fluid) mist significantly improved the performance of their air conditioning systems. It resulted in lower high-side pressure and a higher Coefficient of Performance (COP). In the Camry, the highest COP recorded under mist conditions was 0.2947, compared to 0.2841 in standard conditions, indicating better efficiency at moderate pressure levels, although the advantages decreased at higher pressures. Similarly, in the Pathfinder, the COP peaked at 0.3022 under mist, demonstrating a notable performance boost, particularly in warmer outdoor temperatures. These findings suggest that using mist is a simple and effective method to enhance air conditioning efficiency in comparable vehicle systems.

Recommendations

Using mist on air conditioning condensers is a practical and cost-effective method to enhance cooling efficiency by reducing high-side pressure and improving the Coefficient of Performance (COP). This technique is particularly beneficial in high-temperature environments, where systems face greater thermal loads. To optimize mist systems, further research is necessary in areas such as developing advanced nozzles for uniform mist distribution, determining the ideal droplet size and flow rate, and assessing energy and water consumption for sustainable practices. Additionally, studies should investigate the long-term effects of mist application on condenser materials to ensure durability and prevent corrosion. The potential integration of mist systems with new refrigerants like R-1234yf and natural alternatives should also be explored to comply with environmental regulations. Beyond automotive applications, the use of mist systems in industrial HVAC units, refrigeration, and renewable energy cooling deserves attention, especially in regions with extreme climates. These research avenues could pave the way for efficient, sustainable, and versatile cooling solutions across various applications.

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