International Journal of
I.C. Engines and Gas Turbines

ISSN: 2582-290X
Volume 9, Issue 2, 2023
DOI (Journal): 10.37628/IJICEGT

http://mechanical.journalspub.info/index.php?journal=JIEGT&page=index

Review IJICEGT

Improving Internal Combustion Engine Performance by Using Reduced Power Air Conditioning System

C. Armenta-Déu*

Abstract

The paper studies and analyzes the effects of adsorption air conditioning system instead of the classical compression unit on the vehicle internal combustion engine (ICE) performance. The adsorption system uses the residual heat from the ICE cooling circuit to create the necessary thermodynamic conditions to reduce the temperature in the vehicle cockpit. The proposed system has the advantage of no mobile parts for operating since it works on pressure difference base. The system improves the coefficient of performance (COP) of the internal combustion engine since it uses thermal energy released at the engine cooling to generate air conditioning. The simulation has proved the validity of the proposed system for current vehicle driving conditions. The system is suitable for low-power engines where conventional compression units do not fit because of the high power requirements of the air conditioning system. The new A/C system increases the coefficient of performance of the internal combustion engine up to 4% when replacing a classical adsorption air conditioning unit and up to 25% if the replaced A/C system is a compression one. The COP of the ICE increases linearly with refrigerant mass flow and decreases with engine power for a given flow mass. The proposed system is more effective in low power engines, but applies to power range up to 150 kW. The paper shows the influence of low power ancillary equipment on the internal combustion engine global efficiency.

Keywords: Internal combustion engine, vehicle air conditioning; coefficient of performance improvement; cooling heat recovering

INTRODUCTION

Vehicle air conditioning system uses the classical compression thermodynamic cycle to remove thermal energy from the cockpit. This configuration requires a considerable power and energy to compress the refrigerant fluid circulating through the air conditioning circuit, which reduces the scope of application to vehicles equipped with internal combustion engine above a certain threshold [1]. This situation derives from the high power requirements of the air conditioning system, which penalizes the coefficient of performance of the internal combustion engine, increasing the fuel consumption and reducing the driving range [2-5].

An interesting fact about air conditioning systems is that there is an alternative to the traditional compression system, which is called an adsorption system [6]. This system requires a heat power source to operate the thermodynamic cycle. In vehicles equipped with internal combustion engines, the heat power is generated by the released thermal energy at the engine cooling system [7, 8]. Currently, this energy is released to the environment, but by recovering this heat, we can not only improve the overall performance of the vehicle but also reduce thermal emissions to the atmosphere, which can help preserve the temperature and reduce the impact of global heating [9-11].

***Author for Correspondence**
C. Armenta-Déu
E-mail: cardeu@fis.ucm.es

Professor, Faculty of Physical Sciences, Complutense University of Madrid, Spain

Received Date: March 02, 2024
Accepted Date: March 07, 2024
Published Date: April 02, 2024

Citation: C. Armenta-Déu. Improving Internal Combustion Engine Performance by Using Reduced Power Air Conditioning System. International Journal of I.C. Engines and Gas Turbines. 2023; 9(2): 41–51p.

Internal combustion engine operation is enhanced [12] by using an adsorption air condition unit because it requires less energy, which permits the ICE to dedicate the saved power to propel the vehicle at a higher level or to save fuel to increase driving range [13, 14]. Indeed, since air conditioning takes the energy for operating from the ICE, the only power source in conventional cars, lowering the air conditioning requirements can be devoted to the propelling system [15]. This situation is interesting in low ICE operating regimes, where the ICE delivering power is limited, or in vehicles with a low-power ICE.

Recovering heat from ICE cooling circuit also benefits internal combustion engine thermal operation since it lowers the engine compartment temperature, making the ICE to operate at lower thermal level, which increases its efficiency [16, 17]. Previous work shows the feasibility of using adsorption cooling system powered by waste heat from ICE; others prove how the recovered heat available in the engine exhaust gas can be applied to generate air conditioning in vehicles with ICE [18].

THEORETICAL FOUNDATIONS

The vehicle cooling system operates under a thermodynamic cycle basis between high and low-temperature focus according to the classical diagram of Figure 1 [19].

The thermodynamic diagram corresponding to the air conditioning circuit is shown in Figure 2.

Using classical expression for the Coefficient of Performance (COP) of the air conditioning unit;

$$COP = \frac{\dot{Q}_{evap}}{\dot{W}_{comp}} \tag{1}$$

The evaporation heat depends on the thermal energy removal from the vehicle cockpit; considering a comfort temperature, T_{comf} and a current cockpit temperature T_{hot}:

$$\dot{Q}_{evap} = m_{air} c_{air} \frac{(T_{hot} - T_{comf})}{\Delta t} \tag{2}$$

m_{air} *and* c_{air} are the mass and specific heat of the air contained in the vehicle cockpit, and Δt is the cooling time.

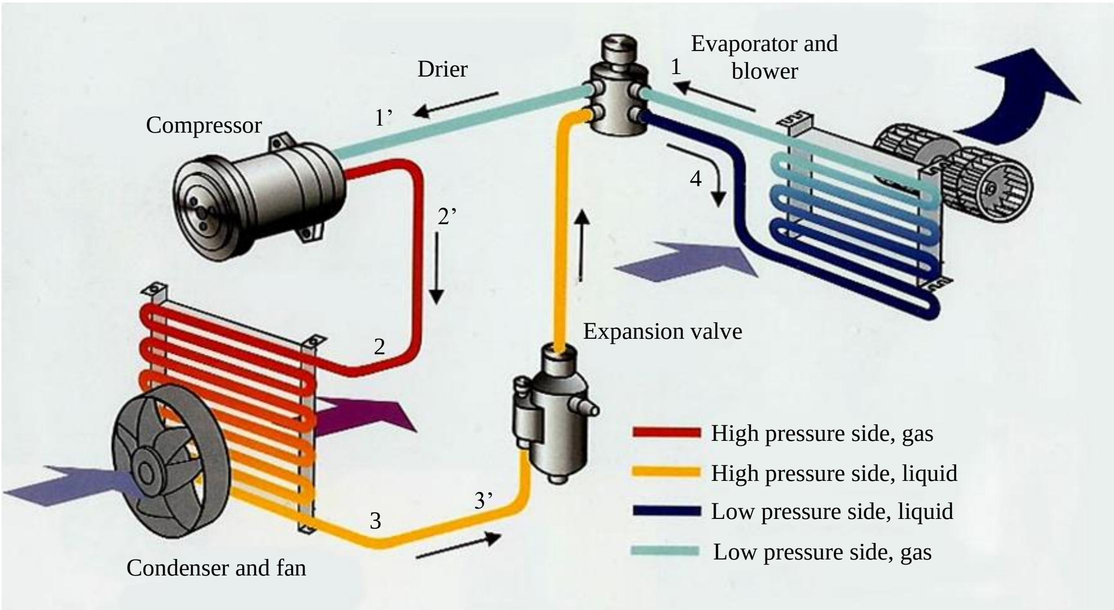

Figure 1. Schematic view of vehicle air conditioning unit (compression system).

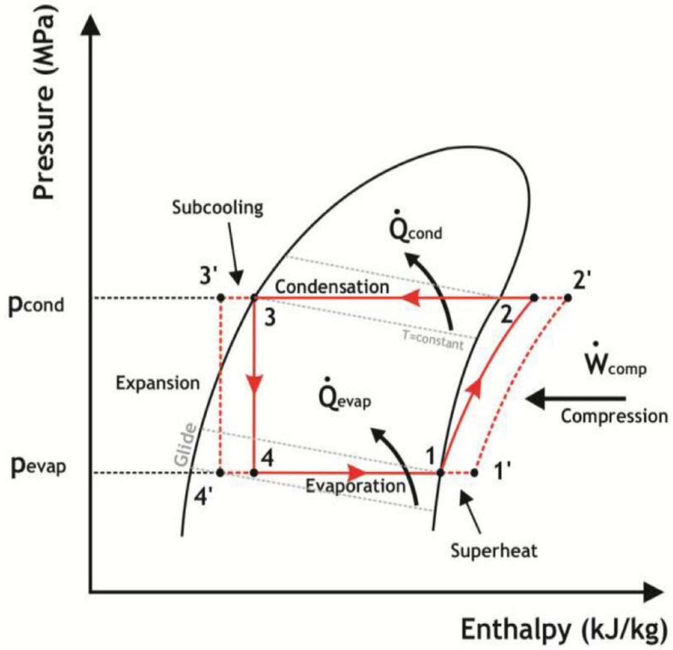

Figure 2. Mollier diagram of compression air conditioning system.

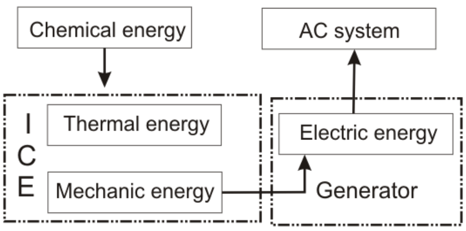

Figure 3. Schematic diagram of energy conversion.

The compression power is given by:

$$\dot{W}_{comp} = \frac{\dot{m}_{ref}}{\rho_{ref}}(p_{cond} - p_{evap}) \tag{3}$$

$\dot{m}_{ref}$ and ρ_{ref} are the mass flow and density of the refrigerant in the air conditioning circuit; p_{cond} and p_{evap} are the condensation and evaporation pressure.

Power for operating the air conditioning system comes from the internal combustion engine through an electric generator that converts mechanical force in electricity. The global conversion process follows the pattern described in the next diagram (Figure 3):

Conversion at the ICE and generator involves energy losses; therefore, the conversion efficiency applies to every process; mathematically:

$$\dot{W}_{comp} = \dot{W}_{ch}\eta_{ch-th}\eta_{th-mech}\eta_{gen}\eta_{tr} \tag{4}$$

Sub-indexes *ch*, *th*, *mech*, *gen* and *tr* account for chemical, thermal, mechanic, generator and transmission, respectively.

Adsorption air conditioning system uses a heat source to evaporate a refrigerant fluid from a liquid mixture as we can see in Figure 4. We notice the adsorption system replaces the mechanical compressor by a thermal one.

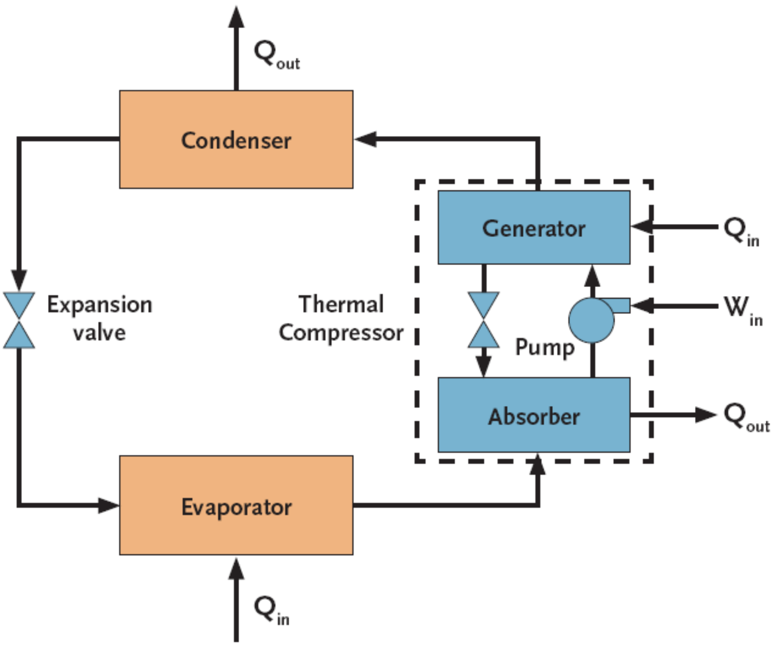

Figure 4. Layout of adsorption air conditioning system.

The coefficient of performance of an adsorption air conditioning system is:

$$COP = \frac{\dot{Q}_{in,evap}}{\dot{W}_{in}+\dot{Q}_{in,gen}} \tag{5}$$

$\dot{Q}_{in,gen}$ represents the heat injection to the generator to evaporate the refrigerant from the liquid mixture and $\dot{Q}_{in,evap}$ is the thermal energy extracted from the vehicle cockpit to maintain comfort temperature. $\dot{W}_{in}$ corresponds to the pump power to elevate liquid mixture pressure.

For an adsorption air conditioning system:

$$\dot{W}_{in} = \frac{\dot{m}_{ref}}{\rho_{ref}} \Delta p \tag{6}$$

$$\dot{Q}_{in,gen} = \dot{m}_{ref} L_{ref} \tag{7}$$

Δp is the pressure increase for the liquid mixture and L_{ref} is the latent heat of refrigerant.

Internal combustion engine operates under variable thermal efficiency within the range of 38% to 50% [20-23] depending on the fuel type, gasoline or diesel. Nevertheless, if we include mechanic conversion, the ICE engine efficiency reduces to 20%-40% for gasoline engine [24-26] and up to 45% for diesel engines [27]; however, the most current average diesel efficiency operates in the range from 25% to 35% for medium and low power engines [28].

In global terms, we have:

$$\eta^{ICE} Q_f \frac{m_f}{t_{op}} = \dot{W}_{mech} \tag{8}$$

η^{ICE} is the ICE global efficiency, m_f and Q_f are the fuel mass and combustion heat, and t_{op} is the operation time.

When the air conditioning system operates, a fraction of the energy generated by the ICE derives to the A/C unit to supply power for working according to diagram of Figure 3. In such a case, we have:

$$\eta_{eff}^{ICE} Q_f \frac{m_f}{t_{op}} = \dot{W}_{mech} - \dot{W}_{A/C} \tag{9}$$

η_{eff}^{ICE} is the ICE effective efficiency for driving and air conditioning operation.

Comparing equations 8 and 9:

$$\frac{\eta_{eff}^{ICE}}{\eta^{ICE}} = 1 - \frac{\dot{W}_{A/C}}{\dot{W}_{mech}} \tag{10}$$

Equation 10 shows how the ICE efficiency reduces when using the air conditioning system.

Combining equations 3, 6, 7 and 8 and comparing compression and adsorption air conditioning systems, we obtain:

$$\frac{\eta_{eff}^{ICE}\big|_{comp}}{\eta_{eff}^{ICE}\big|_{ads}} = \frac{\dot{W}_{mech} - \dot{m}_{ref}\frac{(p_{cond} - p_{evap})}{\rho_{ref,comp}}}{\dot{W}_{mech} - \dot{m}_{ref}\left(\frac{\Delta p + \rho_{ref,ads} L_{ref,ads}}{\rho_{ref,ads}}\right)} \tag{11}$$

$\frac{(p_{cond} - p_{evap})}{\rho_{ref,comp}}$and $\frac{\Delta p + \rho_{ref,ads} L_{ref,ads}}{\rho_{ref,ads}}$ are important factors in determining the effective ICE efficiency ratio for compression to adsorption air conditioning system use, as per the given expression. Comparing both terms, we have:

$$\frac{(p_{cond} - p_{evap})}{\rho_{ref,comp}} > \frac{\Delta p + \rho_{ref,ads} L_{ref,ads}}{\rho_{ref,ads}} \rightarrow \eta_{eff}^{ICE}\big|_{comp} < \eta_{eff}^{ICE}\big|_{ads}$$

$$\frac{(p_{cond} - p_{evap})}{\rho_{ref,comp}} < \frac{\Delta p + \rho_{ref,ads} L_{ref,ads}}{\rho_{ref,ads}} \rightarrow \eta_{eff}^{ICE}\big|_{comp} > \eta_{eff}^{ICE}\big|_{ads} \tag{12}$$

In present days, the most commonly used refrigerant fluid for vehicles' air conditioning systems is tetrafluoromethane, also known as norfluorane (INN), R-134a, or Freon 134a [29], whose properties may be consulted in literature [30].

Retrieving data from literature for the R-134a and the LiBr/H_2O and applying to equation 10, it results:

$$\frac{(p_{cond} - p_{evap})}{\rho_{ref,comp}} = 36.9\ ;\ \frac{\Delta p + \rho_{ref,ads} L_{ref,ads}}{\rho_{ref,ads}} = 2201 \tag{13}$$

Therefore, ICE efficiency is higher when working with a compression air conditioning system. This statement, however, changes if the thermal energy required for evaporating the refrigerant in the adsorption air conditioning unit comes from the engine cooling circuit residual heat; in such a case, equation 9 should be expressed as:

$$\frac{\eta_{eff}^{ICE}\big|_{comp}}{\eta_{eff}^{ICE}\big|_{ads}} = \frac{\dot{W}_{mech} - \dot{m}_{ref}\frac{(p_{cond} - p_{evap})}{\rho_{ref,comp}}}{\dot{W}_{mech} - \dot{m}_{ref}\frac{\Delta p}{\rho_{ref,ads}}} \tag{14}$$

And the equation 12 modifies consequently in:

$$\frac{(p_{cond}-p_{evap})}{\rho_{ref,comp}} > \frac{\Delta p}{\rho_{ref,ads}} \rightarrow \eta_{eff}^{ICE}\Big|_{comp} < \eta_{eff}^{ICE}\Big|_{ads}$$

$$\frac{(p_{cond}-p_{evap})}{\rho_{ref,comp}} < \frac{\Delta p}{\rho_{ref,ads}} \rightarrow \eta_{eff}^{ICE}\Big|_{comp} > \eta_{eff}^{ICE}\Big|_{ads} \quad (15)$$

Now, applying data from literature for R-134a and LiBr/H_2O dissolution:

$$\frac{(p_{cond}-p_{evap})}{\rho_{ref,comp}} = 36.9\ ;\ \frac{\Delta p}{\rho_{ref,ads}} = 0.007 \quad (16)$$

Which results in the conclusion that ICE efficiency is higher working with an adsorption air conditioning system if heat is supplied by the residual heat from the engine cooling fluid.

SYSTEM DESIGN

In this work, we propose a new air conditioning design which uses the residual thermal energy from engine cooling system. Although the idea of using the recovered heat from ICE cooling system to power the adsorption air conditioning unit is not new [10, 31-33], we propose a novel design focused to lower the energy consumption to operate the air conditioning system to the minimum possible; therefore, we reduce the energy requirements from the ICE, thus improving the effective internal combustion engine efficiency. To this goal, the following diagram applies (Figure 5).

The great advantage of the new design is the absence of mobile parts since it does not require a mechanic compressor nor a fluid pump because it operates on pressure difference basis. The only power requirement comes from the outdoor and cockpit air fan.

Current operating conditions are listed in Table 1.

SIMULATION

Working with the new design, we eliminate the heat energy dependence on external source, the ICE; therefore, equation 5 transforms in:

$$COP = \frac{\dot{Q}_{in,evap}}{\dot{W}_{in}} \quad (17)$$

And the ICE effective efficiency ratio is:

$$\frac{\eta_{eff,i}^{ICE}}{\eta_{eff,o}^{ICE}}\Bigg|_{ads} = 1 + \frac{\left(\frac{\dot{m}_{ref}}{\rho_{ref}}\Delta p + \dot{m}_{ref}L_{ref}\right)}{\dot{W}_{mech} - \left(\frac{\dot{m}_{ref}}{\rho_{ref}}\Delta p + \dot{m}_{ref}L_{ref}\right)} \quad (18)$$

Table 1. Operating conditions for the vehicle adsorption air conditioning prototype (**).

	Temperature (ºC)	Pressure (kPa)	Flow (kg/h)
Condenser	40	$2.4p_o$	$3.4m_o$
Evaporator	15	p_o	m_o
Boiler	80	6.67po	(*)
Vapor injector	126	$3.2p_o$	$2.4m_o$

(*) Set up by ICE cooling system design
(**) Because the design is under patent pending process, technical data are not available at this time

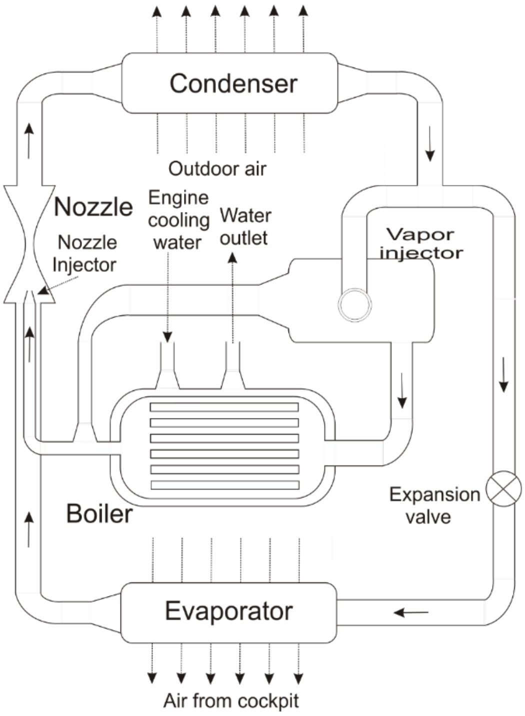

Figure 5. Layout of the adsorption air conditioning prototype.

Sub-indexes *i* and *o* account for the conventional and new design adsorption air conditioning system. Applying the condition of thermal energy supply by the engine cooling fluid:

$$\left.\frac{\eta_{eff,i}^{ICE}}{\eta_{eff,o}^{ICE}}\right|_{ads} = 1 + \frac{\left(\frac{\dot{m}_{ref}}{\rho_{ref}}\Delta p\right)}{\dot{W}_{mech} - \left(\frac{\dot{m}_{ref}}{\rho_{ref}}\Delta p\right)} \tag{19}$$

Simulation runs for a refrigerant mass flow from 1 kg/s to 5 kg/s to fit the different vehicle brand and model. The results of the simulation are shown in Figure 6.

We notice the ICE effective efficiency improvement reduces with the engine output power. These results are consistent with the expected values for an adsorption air conditioning system since the required power for the A/C unit does not depend on the engine power.

We observe that efficiency improvement depends linearly on the refrigerant mass flow independently on the engine power. The simulation results show that the new air conditioning design improves the ICE performance with the A/C power requirements increase. Indeed, when the user moves the A/C selector to a higher air conditioning flow, the system reacts, generating a higher global performance of the internal combustion engine.

Repeating the comparison for the compression air conditioning system (Figure 7).

We observe that ICE effective efficiency improvement follows the same linear dependence on mass flow for all the engine power with the only difference of higher values. The influence of the new air conditioning system on the ICE performance, when comparing to a conventional compression unit, is similar to the case of using a non-modified adsorption system; nevertheless, the increase of the ICE effective efficiency is higher in the former case.

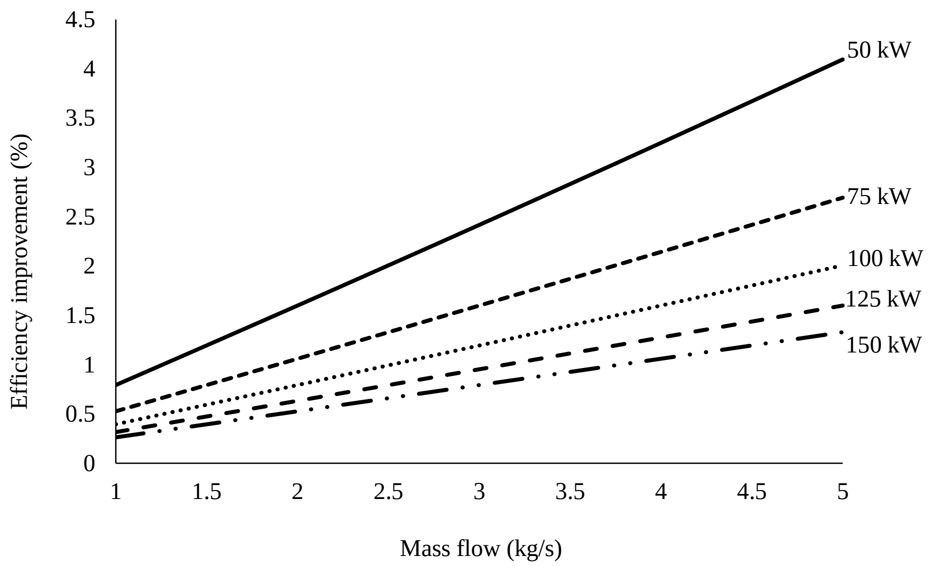

Figure 6. Improvement of the internal combustion engine's effective efficiency for various engine power by using a modified design of the adsorption air conditioning system.

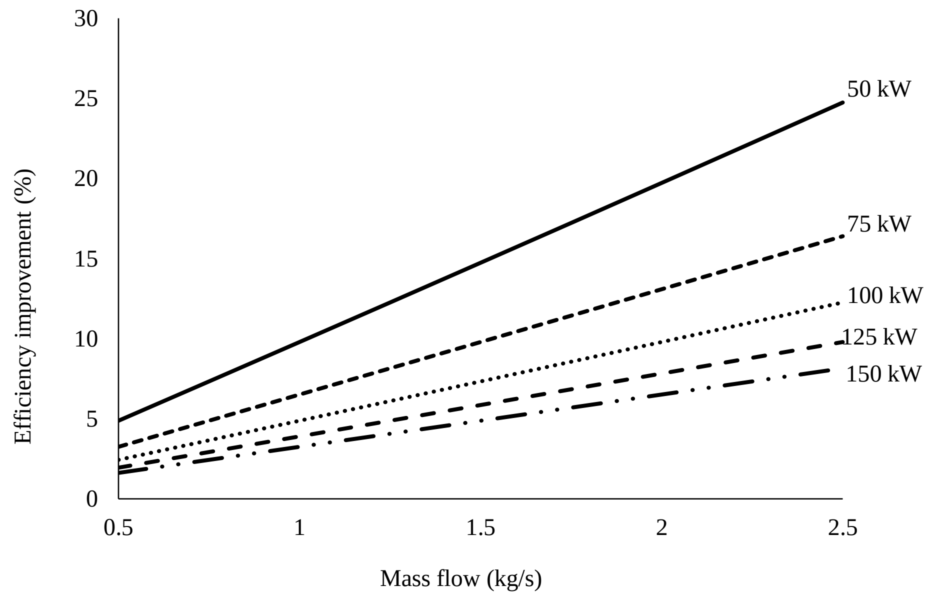

Figure 7. Improvement of the internal combustion engine's effective efficiency for various engine power comparing the use of a new adsorption and a conventional compression air conditioning system

We have compared the improvement in ICE performance when replacing a compression A/C system by an absorption one to validate the simulation process. Literature provides a current reduction in ICE performance for a compression A/C system between 2% and 25% depending on engine power and air conditioning demand [34-36]. If we compare these values with the lowest and highest results from the simulation for the compression A/C unit comparison, we observe a close agreement, within 96% accuracy. Figure 8 shows the comparison between predicted and simulated values of the ICE efficiency improvement for a compression air conditioning system use.

We appreciate the good matching between predicted values (solid lines) and simulated results (dashed lines) for the entire range of engine power, proving the validity of the proposed methodology (Figure 8).

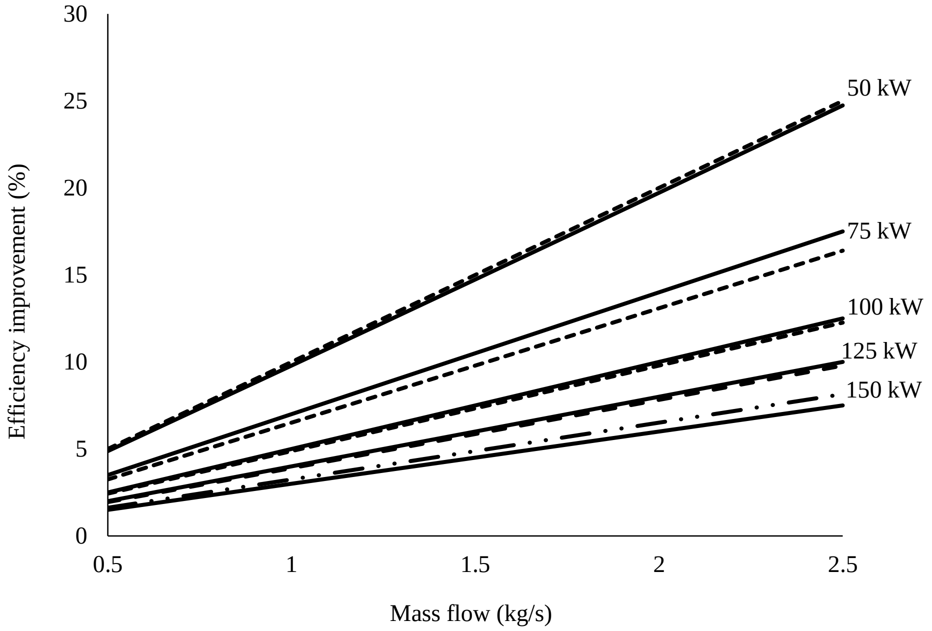

Figure 8. Comparison between predicted and simulated values of the ICE efficiency improvement for a compression air conditioning system use.

CONCLUSIONS

A new adsorption air conditioning system has been applied to reduce energy consumption and improve internal combustion engine performance. The system lowers the power demand due to a new design, eliminating mobile parts and operating under pressure difference base. The engine effective performance increases up to 4% when replacing a classical adsorption air conditioning system by the new device; this increase raises up to 25% if the replaced system is a conventional compression air conditioning unit.

The engine global efficiency enhances linearly with refrigerant mass flow independently on the engine power. The engine efficiency lowers with the output power for a specific refrigerant mass flow. The lowering is more significant as the engine power increases. For high engine power the new air conditioning design barely improves the ICE efficiency compared to a classical adsorption air conditioning system; however, as the engine power decreases, the influence of the new A/C design on the ICE efficiency increases.

Simulations tests run for engine power from 50 kW to 150 kW; the simulation produces accurate results in predicting the ICE efficiency improvement. Simulation results and predicted data matches within 96% accuracy. The developed work proves the importance of having low energy consumption ancillary equipment, like an air conditioning system, to enhance the internal combustion engine performance.

REFERENCES

1. SEO, J. H., KIM, H. J., JUNG, K. J., KIM, D. W., YEOM, J. K., & LEE, M. Y. (2013). Review of conventional air conditioning system for internal combustion engines. International Journal of Air-Conditioning and Refrigeration, 21(02), 1330001.
2. Farrington, R., & Rugh, J. (2000). Impact of vehicle air-conditioning on fuel economy, tailpipe emissions, and electric vehicle range (No. NREL/CP-540-28960). National Renewable Energy Lab.(NREL), Golden, CO (United States).
3. Lee, J. T., Kwon, S., Lim, Y., Chon, M. S., & Kim, D. (2013). Effect of air-conditioning on driving range of electric vehicle for various driving modes (No. 2013-01-0040). SAE Technical Paper.

4. Lee, J., Kim, J., Park, J., & Bae, C. (2013). Effect of the air-conditioning system on the fuel economy in a gasoline engine vehicle. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 227(1), 66-77.
5. Jiang, L., Wang, R. Z., Li, J. B., Wang, L. W., & Roskilly, A. P. (2018). Performance analysis on a novel sorption air conditioner for electric vehicles. Energy Conversion and Management, 156, 515-524.
6. Mendes, A. D. C. A., Pujatti, F. J. P., & Cortez, M. F. B. (2022). Conceptual Design of an Adsorption Refrigeration System Applied to Vehicles. International Journal of Refrigeration, 135, 60-74.
7. Hamdy, M., Askalany, A. A., Harby, K., & Kora, N. (2015). An overview on adsorption cooling systems powered by waste heat from internal combustion engine. Renewable and Sustainable Energy Reviews, 51, 1223-1234.
8. Zadeh, P. G., & Chung, J. D. (2024). Exploring adsorption refrigeration for automobile air-conditioning: A comprehensive review. Applied Thermal Engineering, 122390.
9. Zhong, Y., Wert, K. L., & Fang, T. (2010). An adsorption air-conditioning system to reduce engine emissions and fuel consumption for heavy-duty vehicles.
10. Zhong, Y., Fang, T., & Wert, K. L. (2011). An adsorption air conditioning system to integrate with the recent development of emission control for heavy-duty vehicles. Energy, 36(7), 4125-4135.
11. Jadhao, J. S., & Thombare, D. G. (2013). Review on exhaust gas heat recovery for IC engine. International Journal of Engineering and Innovative Technology (IJEIT), 2(12).
12. Kato, Y. (2009). Thermal energy storage in vehicles for fuel efficiency improvement. Proc. Effstock, 14-17.
13. Vashisht, S., & Rakshit, D. (2021). Recent advances and sustainable solutions in automobile air conditioning systems. Journal of cleaner production, 329, 129754.
14. Lahlou, A., Ossart, F., Boudard, E., Roy, F., & Bakhouya, M. (2020). Optimal management of thermal comfort and driving range in electric vehicles. Energies, 13(17), 4471.
15. Wang, R. Z., & Oliveira, R. G. (2006). Adsorption refrigeration—an efficient way to make good use of waste heat and solar energy. Progress in energy and combustion science, 32(4), 424-458.
16. Aguiar, P., Miyauchi, E., & Baumgartner, L. (2013). Thermal Management Solutions to Reduce Fuel Consumption (No. 2013-36-0246). SAE Technical Paper.
17. Guzzella, L., & Onder, C. (2009). Introduction to modeling and control of internal combustion engine systems. Springer Science & Business Media.
18. Boatto, P., Boccaletti, C., Cerri, G., & Malvicino, C. (2000). Internal combustion engine waste heat potential for an automotive absorption system of air conditioning Part 2: The automotive absorption system. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 214(8), 983-989.
19.] How Does The A/C System Work In Our Vehicle. Custom Automotive Care (CAC) How Does The A/C System Work In Our Vehicle. - Custom Automotive Care (lincolncustomauto.com) [Accessed online: 28/02/2024]
20. Johnson, T., & Joshi, A. (2018). Review of vehicle engine efficiency and emissions. SAE International Journal of Engines, 11(6), 1307-1330.
21. Lee, B., Oh, H., Han, S., Woo, S., & Son, J. (2017). Development of high efficiency gasoline engine with thermal efficiency over 42% (No. 2017-01-2229). SAE Technical Paper.
22. Boretti, A.A. Energy recovery in passenger cars. J. Energy Resour. Technol. Trans. ASME **2012**, 134, 022203. [**Google Scholar**] [**CrossRef**]
23. Dahham RY, Wei H, Pan J. Improving Thermal Efficiency of Internal Combustion Engines: Recent Progress and Remaining Challenges. Energies. 2022; 15(17):6222. https://doi.org/10.3390/en15176222
24. "Toyota Gasoline Engine Achieves Thermal Efficiency of 38 Percent". 14 April 2014. [Accessed online: 29/02/2024]
25. "Geely DHE1.5 Engine Beats BYD Xiaoyun with Thermal Efficiency of 43.32%". 26 August 2022. [Accessed online: 29/02/2024]

26. https://www.epa.gov/sites/default/files/2018-10/documents/high-efficiency-ic-engine-sae-2018-04.pdf [Accessed online: 29/02/2024]
27. "Medium and Heavy Duty Diesel Vehicle Modeling Using a Fuel Consumption Methodology" (PDF). US EPA. 2004. Retrieved 2017-04-25. [Accessed online: 29/02/2024]
28. Wan Mansor, Wan Nurdiyana & Yahaya, Noor & Abdullah, Samsuri & Ghazali, Nurul Adyani & Ismail, Marzuki & Vaughn, J. & Olsen, D.B.. (2018). Engine performance, combustion and emissions evaluations of a diesel natural gas dual fuel engine. ARPN Journal of Engineering and Applied Sciences. 13. 9213-9221.
29. "Refrigerant Transition & Environmental Impacts". U.S. Environmental Protection Agency. 6 August 2015. Retrieved 1 October 2020.
30. Freon™134a. Refrigerant (R-134a). Thermodynamic Properties (SI Units). freon-134a-si-thermodynamic-properties.pdf
31. Peyman Gholamali Zadeh, Jae Dong Chung, Exploring adsorption refrigeration for automobile air-conditioning: A comprehensive review, Applied Thermal Engineering, Volume 241, 2024, 122390, ISSN 1359-4311, https://doi.org/10.1016/j.applthermaleng.2024.122390.
32. Maeda, S., Thu, K., Maruyama, T., & Miyazaki, T. (2018). Critical review on the developments and future aspects of adsorption heat pumps for automobile air conditioning. Applied Sciences, 8(11), 2061.
33. Christy, T. C., Fusco, D., & Toossi, R. (2001). Adsorption air-conditioning for containerships and vehicles. METRANS Transportation Center.
34. Mogro, A. E., & Huertas, J. I. (2021). Assessment of the effect of using air conditioning on the vehicle's real fuel consumption. International Journal on Interactive Design and Manufacturing (IJIDeM), 15(2-3), 271-285.
35. Huff, S., West, B., & Thomas, J. (2013). Effects of air conditioner use on real-world fuel economy (No. 2013-01-0551). SAE Technical Paper.
36. Johnson, V. H. (2002). Fuel used for vehicle air conditioning: a state-by-state thermal comfort-based approach (No. 2002-01-1957). SAE Technical Paper.