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Experimental Analysis of a New LPG Evaporator/Regulator for Vehicles

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Abstract

An LPG evaporator/regulator has been designed to be heated with air rather than engine coolant and tested experimentally in this study. It has been observed that when using the new system in engines converted to be able to use LPG fuel, both LPG can be conditioned to the required state of the engine, and the ambient air can be cooled down thanks to the utilization of the refrigerating effect of LPG. The experiments conducted have been showing the system is feasible with a highest efficiency and coefficient of performance value of 25% and 1.1, respectively.

1. INTRODUCTION

Vehicular alternative energy sources are gaining importance in recent years due to economy and environmental concerns. LPG is an alternative fuel for internal combustion engines to ensure fuel economy and reduce exhaust emissions thanks to its low price and low carbon ratio with regard to diesel and gasoline fuels [1-3]. In today's vehicle engines, sending LPG into the cylinders in gas phase mixing with air requires an evaporator/regulator heated by the engine coolant water (E/RW). It reduces the pressure and ensures the gasification of LPG that is in liquid phase under pressure in the tank. LPG entering the E/RW in liquid form attracts the latent heat of vaporization while it transforms to gaseous state. Withdrawal of its high latent heat of evaporation from the engine coolant leads to waste this heat. In the case of using an E/RA system heated by the air, the evaporation heat of LPG would be drawn from the air and cool down of the air would be provided. Thus, the E/RA system both would have performed the task of the E/RW system, and providing divert of cooled air into the cabin which decreases the air conditioning load of the vehicle, contributed to energy efficiency and environmental protection. On the other hand, because the engines operate with difficulty under the regime temperature, fuel consumption and exhaust emissions of vehicles increase at cold start of the engine. For this reason, fuel consumption and exhaust emission tests have been measured with the very initial operation of the engines in New European Driving Cycle (NEDC), which lasts 1180 s from beginning to its end [4] including its cold start. As this kind of legislative procedures motivate automotive industry [5,6], vehicle manufacturers focus on economy and emission concerns especially at cold start of the engine. As fears of global warming lead to changes in energy trends [7], and since LPG is a cheaper fuel and has less climate change triggering [8] harmful emissions when compared to gasoline, solution ways that establish the engines to be operated at cold start on LPG can be helpful to the problem specified above.

A limited references stands out when looking at studies related to LPG E/R in literature. In an experimental study, Masi [9] focuses on the benefits of the use of LPG fuel in spark ignition engines. Masi, in whose study it was observed that the inlet temperature of LPG to the E/R was about room temperature (20-30°C), reported in the results part of his work that flow rate of engine coolant entering to

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the E/R and the heat transfer surface of the E/R were more than enough for low and mid engine speeds. This excess flow rate and transfer surface caused overheating of the LPG and reduced volumetric efficiency of the engine. In case of high rpms, because overheating of gaseous LPG at the E/R outlet was lesser due to the increase of LPG flow rate, the engine showed an increase in volumetric efficiency according to the study. Masi and Gobbato [10] referred to two basic problems seen in spark ignition engines running on LPG in the work they done. In the study it was reported that these problems were decrease in volumetric efficiency and the performance of LPG E/R. According to the study, because it was difficult to design the E/R and calculate the theoretical performance of the E/R, it must be supported by experimental tests was announced by the authors also. Gumus and Ugurlu [11] designed the E/R using phase change materials (PCM) to store heat energy and tested it at the idle speed of the engine in their work to eliminate the disadvantages of cold start problem that occurs in the engines running on LPG. As a result, with the E/R given the capability of thermal energy storage, the engine was provided to the first movement using LPG instead of gasoline at cold start and thus the fuel economy was increased and the exhaust emissions were decreased. Price et al. [12] found that the engine coolant flow rate in the E/R connected to the heater line of the engine cooling system increases from 0.2 to 0.6 L/h depending on the engine speed from 2000 to 7000 rpm in their experimental study about the thermodynamic performance of an LPG E/R. The change of the LPG flow rate emerged as between 0.0003 and 0.0062 kg/s in the same situation. For they applied no insulation to the E/R in their study, they neglected the radiant heat loss from the E/R to the environment. Karabiyik et al. [13] experimentally investigated the impacts of LPG heated by the exhaust gases on fuel consumption and exhaust emissions in an air-cooled spark ignition engine in their study. They performed the experiments at half throttle and full throttle openings of the engine, and they used a suitable heat exchanger to heat the LPG by the heat of the exhaust of the engine. The authors stated that with the system they used in their work they raised the temperature of the LPG about 150°C and achieved 23% lower fuel consumption compared to the conventional LPG system heated by the engine coolant. Also, exhaust emissions emerged lower with the system mentioned in the work. On the other hand, in addition to above E/R studies there are also numerous works on the use of LPG as an alternative refrigerant in literature [14]. LPG is used as a refrigerant without any change in refrigerators, ACs and similar cooling devices at various sizes was examined generally in these studies. Referring to the results obtained from these studies, improvement of COP, reduction of the refrigerant amount used and energy saving in the cooling machines draw attention by the result of the use of LPG. Therefore LPG can be used as a refrigerant; even it has a higher cooling effect than the other refrigerants are understood from the studies. The higher cooling effect of LPG is largely based on its higher latent heat of vaporization. Properties of LPG constituting propane, butane, isobutane and some other refrigerants are given in Table 1. Upon analyzing the table, it is clearly understood that LPG is a good substitute for common refrigerant gases.

Table 1. *Comparison of some refrigerants [14]*

Refrigerant	R11	R12	R22	R134a	R290	R600	R600a
Common name	Trichlorofluoromethane	Dichlorodifluoromethane	Chlorodifluoromethane	1,1,1,2-Tetrafluoroethane	Propane	Butane	Isobutane
Chemical formula	CCl_3F	CCl_2F_2	$CHClF_2$	F_3CCH_2F	C_3H_8	C_4H_{10}	C_4H_{10}
Refrigerant class	CFC	CFC	HCFC	HFC	HC	HC	HC
Molecular mass (g/mol)	137.37	120.91	86.47	102.03	44.1	58.13	58.13
Density (kg/L)	1.47 (21.1°C)	1.34 (30°C)	1.21 (21.1°C)	<1.22	0.500 (20°C)	0.579 (20°C)	0.564
Vapor density (air=1)	4.8	4.2	3	3.5	1.6	2	2
Boiling point (°C)	23.8	-29.8	-40.8	-26.1	-42.1	-0.4	-11.7
Critical point (°C)	198	111.8	96.2	101.08	96.67	152	135
Critical pressure (bar)	44.1	41.1	49.9	40.6	42.5	38	36.5
ODP	1	1	0.07	0	0	0	0

GWP (100 years)	3400	8500	1700	1300	3	3	3
Latent heat of vaporization at 1 atm (kj/kg)	227.3	165.24	-	216.87	427.8	385.2	364.25
Life in the atmosphere (years)	-	130	15	16	<1	<1	<1
Explosion limits (in air % by volume)	Not explosive	Not explosive	-	Not explosive	2.3 - 7.3	1.6 - 6.5	1.8 - 8.4

This study focuses on the operation of an internal combustion, spark ignition, water-cooled and LPG powered engine with an LPG conversion system that has an air heated E/R instead of a traditional E/R heated by the engine coolant. With designed and experimentally tested E/R system, running the engine with LPG and cooling of the ambient air during engine operation have been provided. Thermal behavior of the E/R system has been investigated on the test engine at idle, quarter and half gas throttle operating conditions.

2. MATERIALS AND METHODS

2.1. Characteristics of the Test Engine

A spark-ignition and water cooled engine was used to easily adapt to the LPG conversion. The LPG regulator regulates the pressure of LPG for all engine speeds. General characteristics of the test engine are given in Table 2.

Table 2. *General characteristics of the test engine*

Brand and model	Lombardini LGW 523 MPI
Operation	4 Stroke, spark ignition
Fuel injection system	Electronically controlled multi-point sequential injection
Cooling system	Water-cooled
The number and arrangement of cylinders	2, In line
Number of valves and camshaft position	4, Overhead camshaft
Cylinder diameter and length	72 X 62 mm
Total engine displacement	0.505 L
Compression ratio	10.7:1
Maximum engine speed	5500 rpm
Maximum engine power	15 kW (20.4 HP)
Maximum engine torque	34 Nm @ 2150 rpm

2.2. Characteristics of the E/RA System

The E/R has two main functions: reducing the pressure of LPG from the tank to the engine for combustion, and covering the heat of evaporating LPG. These two tasks are met by an E/RW that has a monolithic structure in conventional systems. Both the LPG and the engine coolant enter the E/RW and exit circulating in different channels without interfering with each other. The reduction process of LPG pressure is performed by a regulator in E/RW. As shown in Figure 1 the E/RW system performs the tasks of reducing the pressure of LPG from 1 to 2, while evaporating it between 2 and 3. Meanwhile the engine coolant is cooled between a-b due to the heat given to the E/RW. In this study, an E/RA containing only a regulator part of an E/RW to reduce the LPG pressure and an AC evaporator in order to meet the heat drawn by the evaporating of LPG has been designed. The E/RW was selected as suitable for the engine. The engine coolant connections of the E/RW used in the E/RA were cut so that it can only make the pressure regulation of LPG. The air conditioning evaporator used in the E/RA was selected in a feature that it may evaporate more amounts of LPG than the test engine would consume. The air blown onto the regulator and the evaporator can draw the latent and sensible heats of LPG. As shown in Figure 2 the E/RA system has performed reducing the pressure of LPG from 1 to 2, while evaporating the LPG between 2 and 3. In the meantime, the air has been cooled down between a-b due to the heat taken by the E/RA. On the other hand, since the engine coolant heats up to about 80°C in the E/RW, but the air of the test environment is about 24°C in the E/RA, the point that the 2-3 line reaches would be farther in the E/RW than in the E/RA. The evaporator used in the E/R system and some important features of the evaporator are given in Figure 3 and Table 3, respectively.

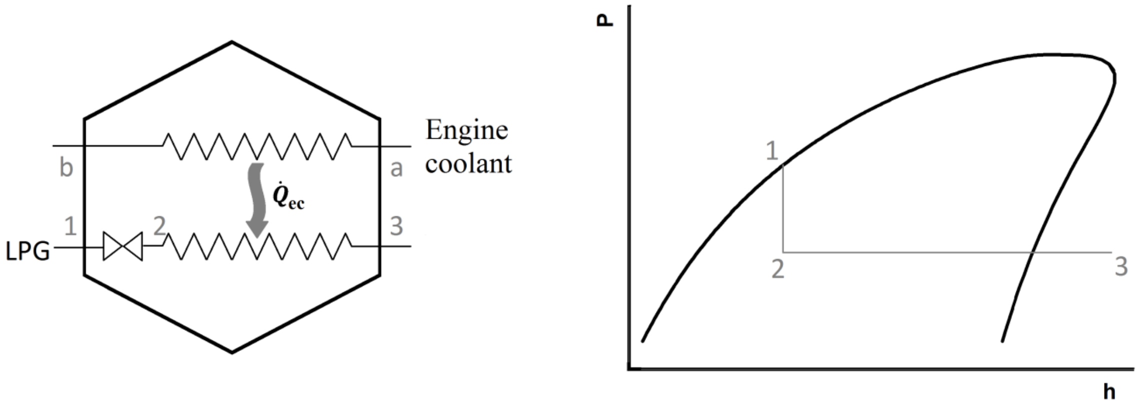

Figure 1 The processes taking place in the E/RW system

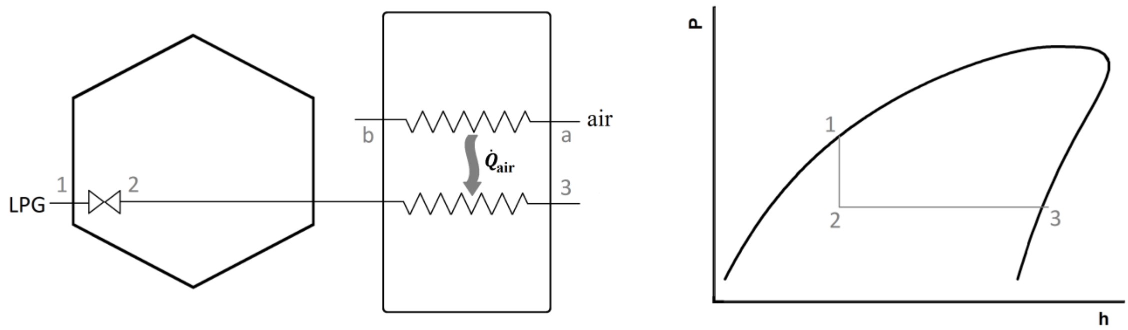

Figure 2. *The processes taking place in the E/RA system*

Figure 3. *The evaporator used in the E/RA system*

Table 3. *Properties of the evaporator used in the E/RA system*

Manufacturer	Valeo
Type	Plate-fin
Dimension	245 X 240 X 60
Material	Aluminum
Weight	1.6 kg
Number of Channels	24 pieces
Channel width	3 mm
Fin shape	Wavy
Number of fin rows	23 pieces
Width of fin rows	7.3 mm
Main channel width	22 mm
Fin queue length	223 mm
Inlet tube inner diameter	8.4 mm
Inlet tube outer diameter	11.55 mm
Outlet tube inner diameter	11 mm
Outlet tube outer diameter	14.15 mm
Number of fins in each row	134 pieces
Fin thickness	0.13 mm
Distance between two fins	1,55 mm

After the regulator and the evaporator being connected to each other constituting the E/RA system and the fan placed in front of these two elements blowing air toward the evaporator fins through the regulator surface, these elements were sealed in airtight with an insulation material (0,033 W/mK) thickness of 20 mm and the outer surface of the insulation material was banded with a tape used in duct insulating. The inlet and outlet of the system were connected to the cooling test room (60x44x40 cm in size) made by extruded polystyrene thermal insulation boards (0,035 W/mK) with an insulating material used in pipe insulation (0,039 W/mK). The room, which was used for damping the air coming from the E/RA, was empty during the tests and near the test rig in a place that no heating/cooling source influences. While the LPG flow entering the E/RA in liquid form goes to the engine in gaseous form; in the meantime, the air blown by the fan to the evaporator and regulator couple is dried and cooled down by the latent heat of the LPG. It is thought by the authors that there is no need to establish any discharge mechanism for condensing moisture on the evaporator surface because the psychrometric calculations have been done according to the measured values of air at the inlet and outlet of the E/RA. Energy need of the supply air fan is met by the engine battery. A view of the E/RA system can be seen in Figure 4.

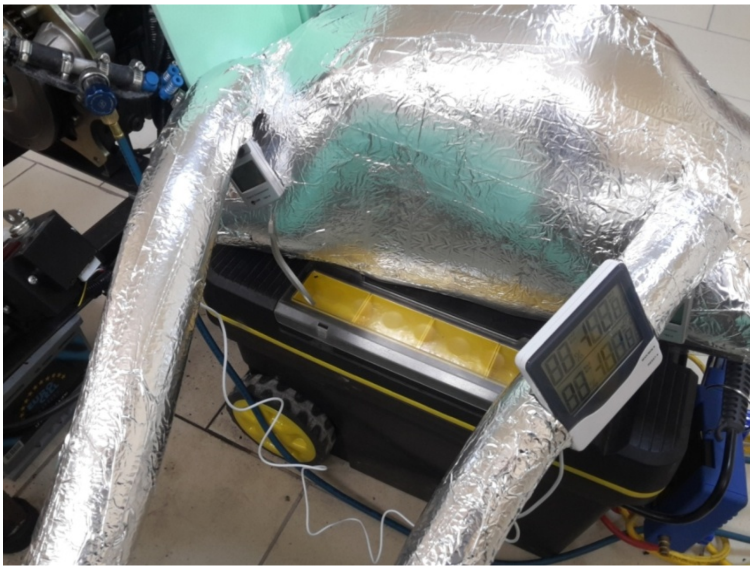

Figure 4. *A view of the E/RA system*

2.3. Measurement Instruments Used in the Experiments

Layout of the measuring devices used in the experiments on the test rig and some fundamental properties of these devices are given in Figure 5 and Table 4, respectively.

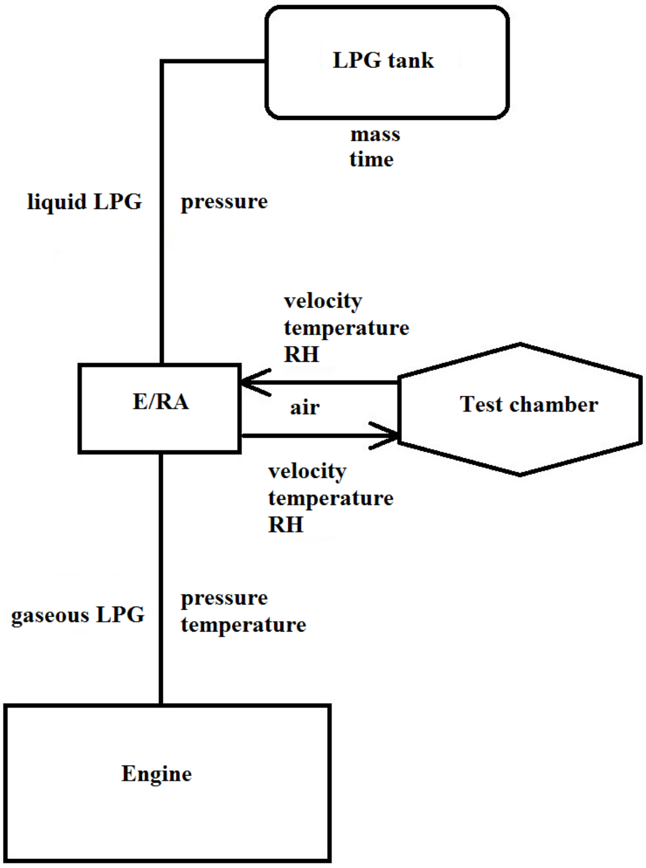

Figure 5. *Layout of the test apparatus on the rig*

Table 4. *Features of the test apparatus used in the experiments*

Value	Brand - model	Range	Accuracy	Tolerance
Weight	YCS-B	0-30 kg	1 g	± 5 g
Engine speed	DT-2234C+	2.5-99,999 rpm	0.1 rpm	±(0.05%)+1 rpm
LPG pressure	Mastercool	0-52 Bar	0.07 Bar	±0.07 Bar
Temperature	UNI-T UT325	-200-1372°C	0.1°C	±(0.2%) + 0.6 ºC
Flow	Gentek Gnt604	0.6-6 m3/h	0.1 L/s	±0.5%
Air velocity	Tecman TM816	0-30 m/s	0.1 m/s	±5%
Air temperature	TFA 30.5013	-10-60°C	0.1°C	±0.8°C
Air humidity	TFA 30.5013	10-99% RH	1% RH	±3.5% RH

2.4. Execution of the Tests and Calculations

Experiments were performed at room temperature about 24°C, to be repeated three times with the cases that the engine operated at idle (1000 rpm), quarter (1800 rpm), and half throttle (2400 rpm) openings under no load conditions. The period of the longest experiment that reached to the regime state, which was about 1900 s, was considered in the determination of the test period for all circumstances. Before executing all the experiments the test equipments were waited to return their initial conditions. Indicators of the measuring instruments were recorded with a camera capable of shooting in high quality during the experiments. After these records were transferred to a computer, the calculations were made for each 10

seconds. The figures that show the experimental measurements were plotted for every 90 s so that the signs of the lines can be seen clearly.
Together with the operation of the engine LPG flow starts taking heat from the E/RA. Thus we need a comprehensive formula for the air, because the temperature and RH of it would decrease depending on time:

$$\dot{Q}_{air} = \dot{m}_{air}\left[\left(h_{i,air} - h_{o,air}\right) - (\omega_{i,air} - \omega_{o,air}) \times h_{f,w}\right] \quad (1)$$

where $\dot{Q}_{air}$ is the heat taken from the air (kJ/s), $\dot{m}_{air}$ is the mass flow rate of the air (kg/s) circulating through the E/RA system, $h_{i,air}$ and $h_{o,air}$ are the enthalpies of the air (kJ/kg)) at the inlet and outlet of the E/RA, $\omega_{i,air}$ and $\omega_{o,air}$ are the specific humidity values of the air (kg water/kg dry air) at the inlet and outlet of the E/RA, and $h_{f,w}$ is the enthalpy of the water (kJ/kg) condensing at the surface of the E/RA. These statements in Eq.(1) are calculated by the following average empirical formulas [15] depending on the air temperatures ($T_{i,air}$, $T_{o,air}$) and RHs ($\Phi_{i,air}$, $\Phi_{o,air}$) measured at the inlet and outlet of the E/RA:

$$\dot{m}_{air} = \frac{V_{air} \times A_{duct}}{v_{air}} \quad (2)$$

$$h_{i,air} = 5{,}4664 + (0{,}779894 \times T_{i,air}) + (0{,}01173 \times T_{i,air} \times \Phi_{i,air}) + (0{,}0000133 \times T_{i,air}^{3} \times \Phi_{i,air}) \quad (3)$$

$$h_{o,air} = 5{,}4664 + (0{,}779894 \times T_{o,air}) + (0{,}01173 \times T_{o,air} \times \Phi_{o,air}) + (0{,}0000133 \times T_{o,air}^{3} \times \Phi_{o,air}) \quad (4)$$

$$\omega_{i,air} = -0{,}00053 + (0{,}0000891 \times \Phi_{i,air}) - (0{,}0000067 \times \Phi_{i,air} \times T_{i,air}) + (0{,}00000043 \times \Phi_{i,air} \times T_{i,air}^{2}) \quad (5)$$

$$\omega_{o,air} = -0{,}00053 + (0{,}0000891 \times \Phi_{o,air}) - (0{,}0000067 \times \Phi_{o,air} \times T_{o,air}) + (0{,}00000043 \times \Phi_{o,air} \times T_{o,air}^{2}) \quad (6)$$

$$h_{f,w} = 104{,}83 - \left[\left(\frac{104{,}83 - 62{,}982}{10}\right) \times \left(25 - T_{o,air}\right)\right] \quad (7)$$

A program called EES benefiting from the pressure-temperature-enthalpy graphs of propane and butane that form LPG is used in the finding the enthalpy values of LPG that are used to calculate the heat LPG takes as in Eq.(8). According to this program enthalpy values are obtained for LPG based on the percentages of propane and butane in the LPG content. The $h_{i,LPG}$ value was determined according to the average pressure of the LPG tank that stays at room temperature throughout the experiments. It was accepted that the LPG is in the state of saturated liquid in the tank. The average tank pressures from the beginning to the end of the tests were kept at 500, 400, and 300 kPa for 1000, 1800, and 2400 rpm testing of the engine, respectively. The $h_{o,LPG}$ value was calculated with EES software depending on the pressure and temperature of LPG at the outlet of the E/RA for certain intervals and determined by interpolation according to the changing temperature during the experiment as in Eq.(9).

$$\dot{Q}_{LPG} = \dot{m}_{LPG}(h_{o,LPG} - h_{i,LPG}) \quad (8)$$

$$h_{o,LPG} = 603{,}65 + \left[\frac{(729{,}35 - 603{,}65)}{70} \times (T_{o,LPG} - 10)\right] \quad (9)$$

Efficiency for the E/RA is an extent that indicates how much of the heat drawn by the evaporating LPG and passed to the air. The equation that enables the calculation of the efficiency for E/RA per second throughout the experiment is as in the following:

$$\eta_{HB/R} = \frac{\dot{Q}_{air}}{\dot{Q}_{LPG}} \times 100 \tag{10}$$

COP of the E/RA is important because it indicates the cooling effect of the E/RA. Peltier effect thermoelectric coolers were inspired by the COP calculation of the E/RA. Unlike conventional coolers, there is no compressor in thermoelectric coolers. Similarly the E/RA system used in this work does not have any compressor, because the LPG in the tank has enough pressure. And if the pressure becomes insufficient, the tank is refilled with LPG in the fuel station. The operating costs of the engine that consumes LPG are not included in energy consumption of the E/RA. The only energy consumed by the E/RA system creating cooling effect is fan power required to circulate the air. The energy amount of the fan which draws from the battery is 24W for the air velocity of 2.3 m/s. The general formula required for calculating the COP for the E/RA is as follows:

$$COP_{R,HB/R} = \frac{\dot{Q}_{air}}{P_{fan}} \tag{11}$$

3. EXPERIMENTAL RESULTS AND DISCUSSION

Air temperature and RH values at the inlet and outlet of the E/RA with LPG outlet temperatures are shown in Figures 6-8 for the states that the engine runs at different speeds and the air velocity is 2.3 m/s. The E/RA outlet temperature, which is about 24°C initially, decreases to about 22-21-19°C respectively for 1000-1800-2400 rpms of the engine. When looking at the RH, at the end of the experiment it decreases to 39-29-22% for 1000-1800-2400 rpms of the engine, respectively, while it is about 57% at start. Decrease of the RH with time arises from both the decrease of the temperature and the E/RA taking an amount of humidity on it while it is cooling down. After about 1000 s for all rpms of the engine, decrease of the outlet temperature stops; even it rises a bit, showing the lowest point the E/RA can arrive at 2.3 m/s, because its efficiency decreases. LPG outlet temperature values are similar to the air outlet temperatures throughout the experiment. The LPG outlet temperature directly affects the air temperature at the outlet of the E/RA.

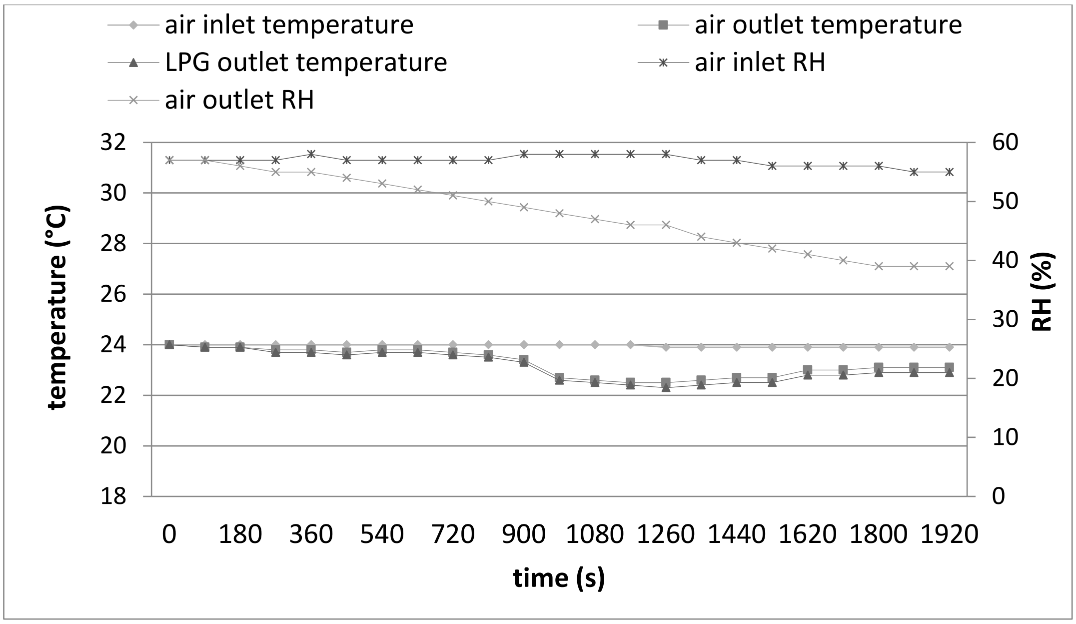

Figure 6. *Temperature and RH variations (1000 rpm)*

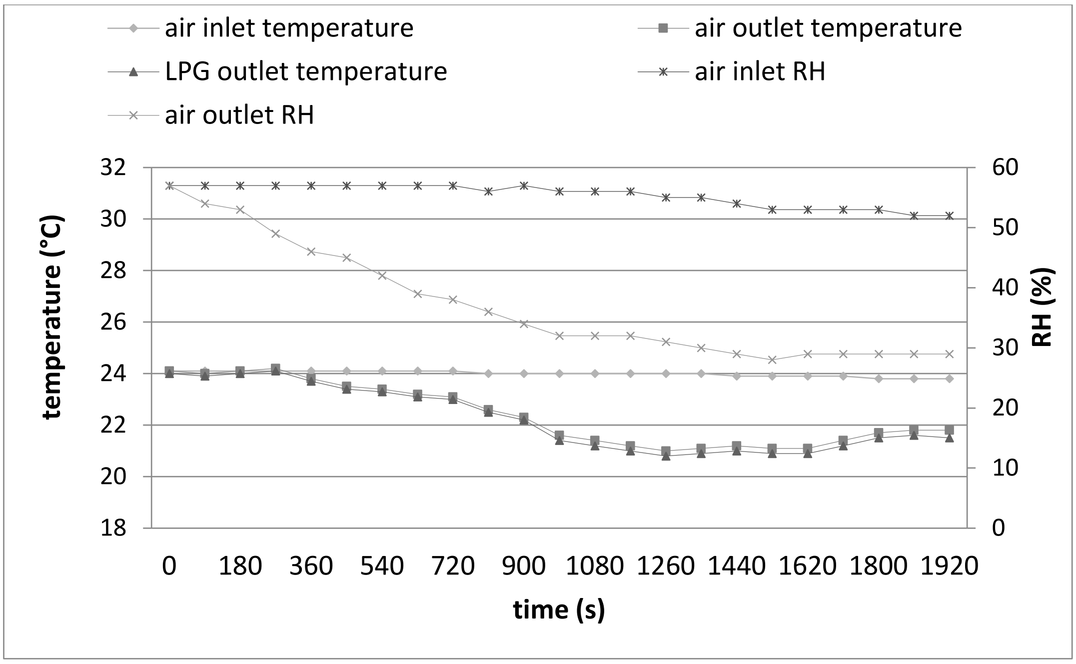

Figure 7. *Temperature and RH variations (1800 rpm)*

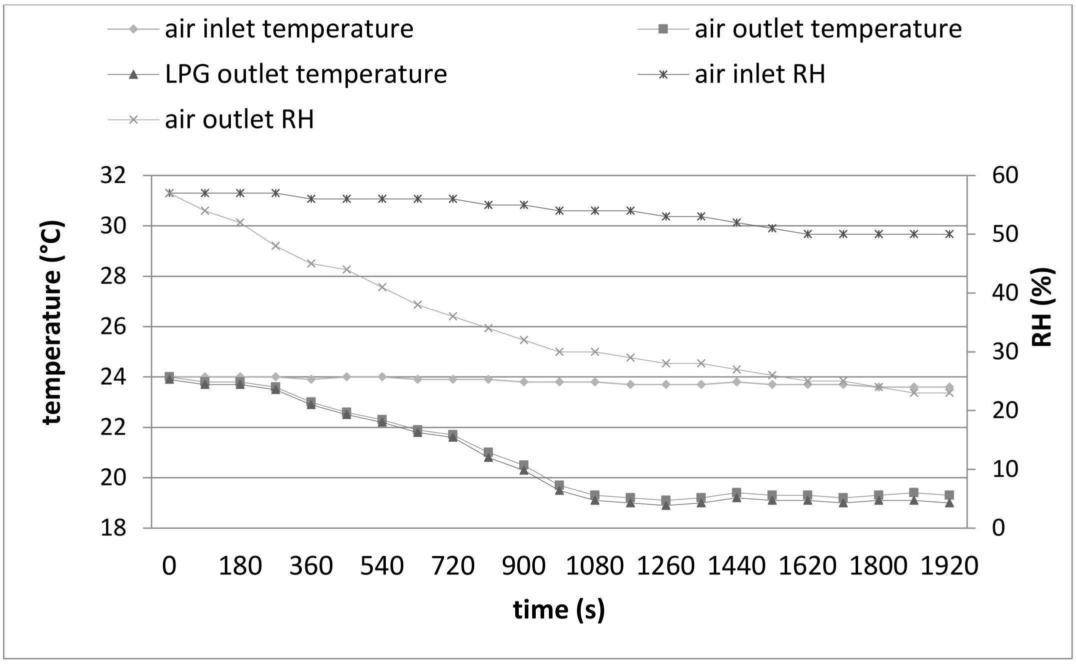

Figure 8. *Temperature and RH variations (2400 rpm)*

Variations of heat withdrawn from the air and the LPG draws in the E/RA at 2.3 m/s air velocity and 1000-1800-2400 rpms of the engine are seen in Figure 9. Heats withdrawn from the air reach to the values of about 12-22-22 W for 1000-1800-2400 rpms of the engine, respectively. As to heat values the LPG draws, they are about 70-110-170 W. The heat LPG draws is higher than the heat drawn from air shows cooling effect of LPG is not fully utilized by the E/RA.

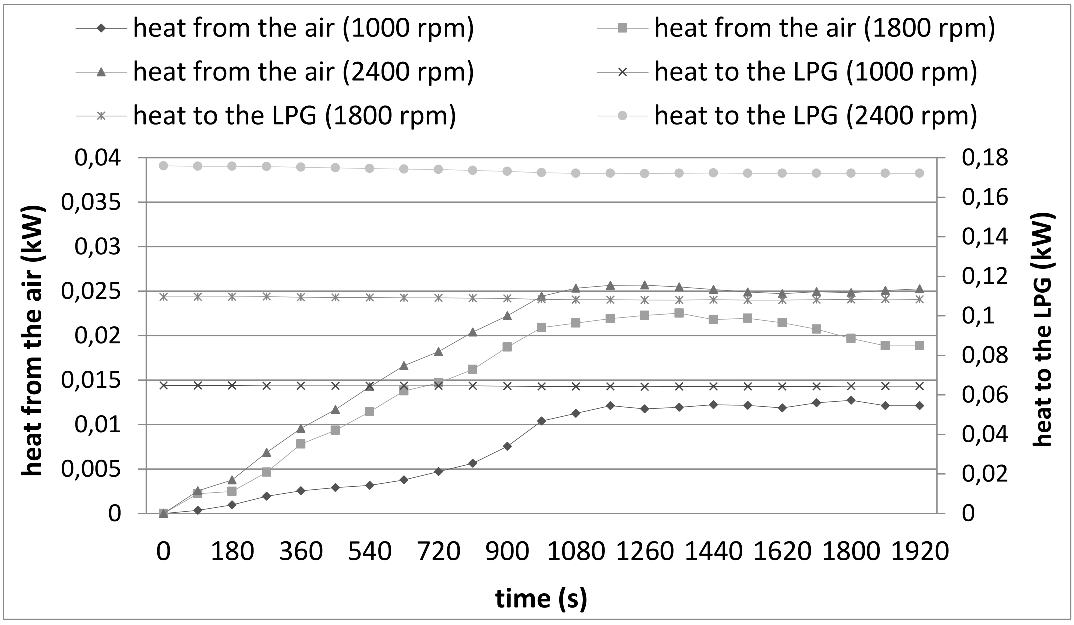

Figure 9. *E/RA (2.3 m/s) heat variations*

Efficiency values of the E/RA during the experiments for 2.3 m/s air velocity and 1000-1800-2400 rpms of the engine are seen in Figure 10. These values are 18-20-15%, respectively. The engine speed that the E/RA unit works at the highest efficiency is 1800 rpm. The efficiency at the 1800 rpm of the engine follows a more stable way but it yields the lowest efficiency value overall. Increase of the LPG flow reduces efficiency of the E/RA.

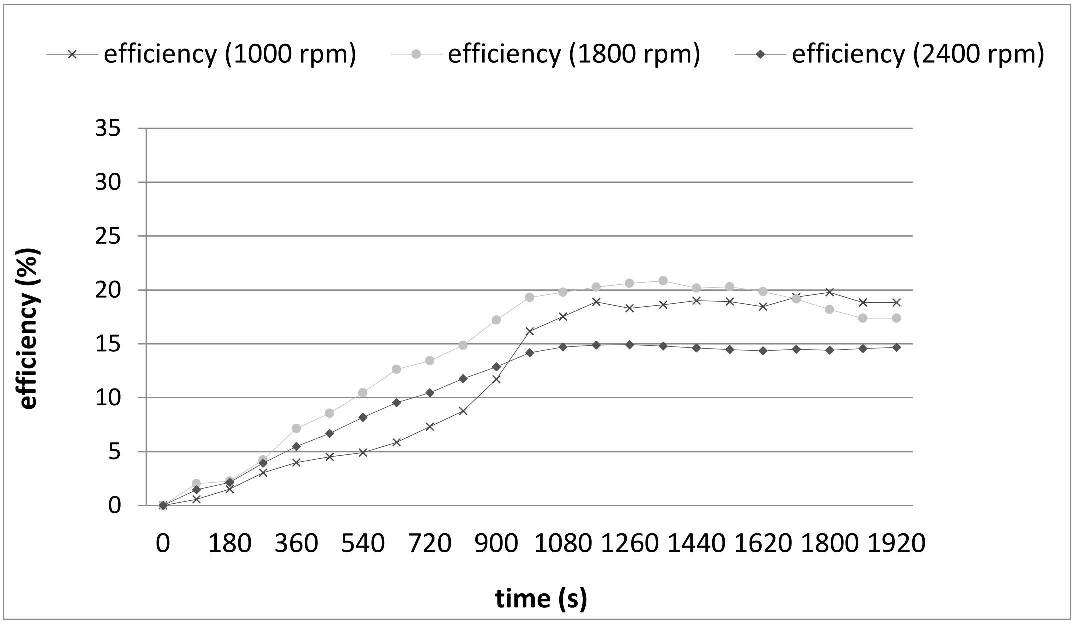

Figure 10. *Efficiency variations*

Time dependant variations of COP values of the E/RA for different engine speeds at 2.3 m/s air velocity are shown in Figure 11. The COP values reaches to the values of 0.5-0.9-1.1 for 1000-1800-2400 rpms of the engine, respectively. The COP values are low when compared to conventional coolers that have a compressor. As to the Peltier effect thermoelectric coolers, the experimental COP values of the E/RA are similar. To increase the COP of the E/RA increasing the cooling of the air and/or decreasing the fan power consumption are required.

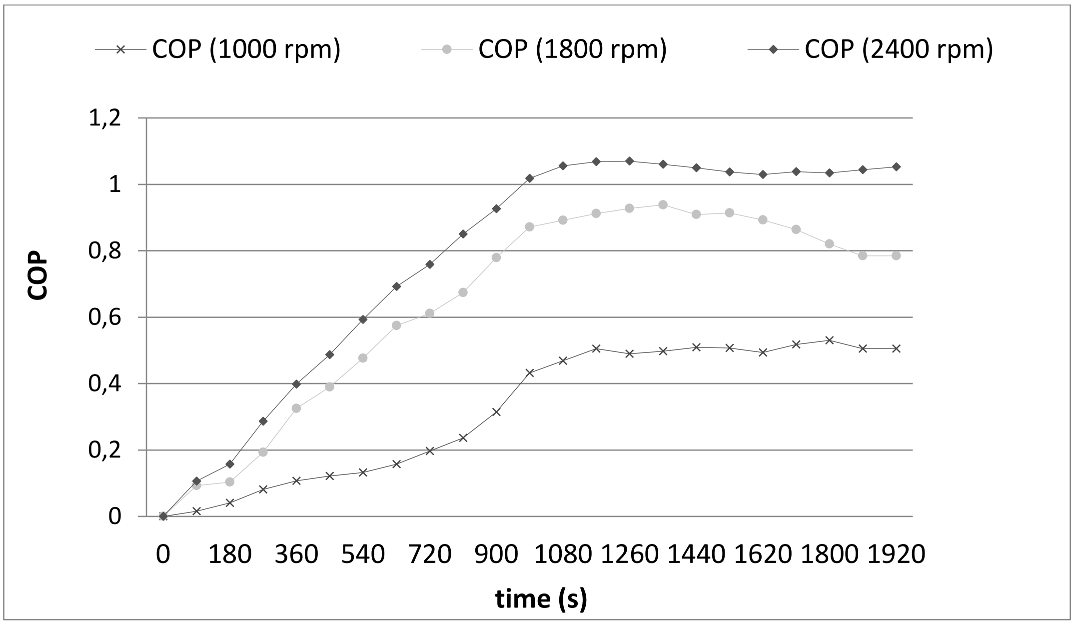

Figure 11. *COP variations*

4. CONCLUSIONS

This study has focused on an LPG conversion system E/R heated by the air instead of the cooling water of the engine. The system has been tried on an internal combustion, spark ignition, and water cooled engine operated with LPG fuel. Air temperature and RH values of the air outlet of the E/RA for 1000-1800-2400 rpms of the engine respectively saw the minimum values of; 23°C, 21°C, and 19°C temperatures and 39%, 28%, and 23% RHs at 2.3 m/s air velocity. The system had the highest efficiency values of 20%, 21%, 25%, and COP values of 0.5, 0.9, 1.1 at 2.3 m/s air velocity, respectively for 1000-1800-2400 rpms of the engine. Enhancing the efficiency values of the E/RA will enable benefiting more from the cooling effect of LPG. The COP values obtained from the experiments are low comparing that of the air conditioning systems that have a compressor, and high that of the Peltier effect thermoelectric cooler can be said.

Experiments and calculations have been shown the E/RA system is thermodynamically feasible. With improvements, the E/RA system can reduce the load on the air conditioning system of millions of cars that use LPG as fuel by the energy wasted already, and thus be able to decrease harmful exhaust emissions and fuel consumption at a significant proportion. To increase the efficiency of the E/RA system it would be useful to maintain the works on the following issues:

- Testing the E/RA at different air velocities,
- Testing of E/Rs with a lower / higher heat transfer capacity,
- Testing different types of E/Rs,
- Circulating the air and LPG in different geometries of the E/R body with a better design,
- Applying a better insulation to the E/R,
- Designing the system as the heat production of the air fan will be out of the air channel so that not to increase the temperature of it,
- Performing vehicle analysis with the E/RA system and determining vehicular, seasonal, mechanical etc. options for the E/RA.

ACKNOWLEDGEMENTS

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automotive workshop of Kırklareli University Luleburgaz Vocational College, and the experiments were conducted therein.

Nomenclature

A_{duct}	E/RA sectional area of the inlet-outlet channels (m2)
CCl2F2	Dichlorodifluoromethane
CCl3F	Trichlorofluoromethane
CFC	Chlorofluorocarbon
CHClF2	Chlorodifluoromethane
$COP_{R,HB/R}$	Coefficient of performance factor indicating the cooling effect of the E/RA
$\eta_{HB/R}$	Efficiency of the E/RA
F3CCH2F	1,1,1,2-Tetrafluoroethane
$\Phi_{i,air}$	Air relative humidity at the inlet of the E/RA (%)
$\Phi_{o,air}$	Air relative humidity at the outlet of the E/RA (%)
$h_{i,air}$	Enthalpy of air at the inlet of the E/RA (kJ/kg)
$h_{i,LPG}$	Enthalpy of LPG at the inlet of the E/RA (kJ/kg)
$h_{f,w}$	Enthalpy of water (kJ/kg)
$h_{o,air}$	Enthalpy of air at the outlet of the E/RA (kJ/kg)
$h_{o,LPG}$	Enthalpy of LPG at the outlet of the E/RA (kJ/kg)
HCFC	Hydro chlorofluorocarbons
HFC	Hydro fluorocarbon
$\dot{m}_{air}$	Mass flow rate of the air enters to the E/RA (kg/s)
$\dot{m}_{LPG}$	Mass flow rate of LPG (kg/s)
$\omega_{i,air}$	Specific humidity of air at the inlet of the E/RA (kg water/kg dry air)
$\omega_{o,air}$	Specific humidity of air at the outlet of the E/RA (kg water/kg dry air)
$\dot{Q}_{air}$	Heat withdrawn from the air (kJ/s)
$\dot{Q}_{LPG}$	Heat LPG draws (kJ/s)
P_{fan}	Energy the E/RA fan consumes (kW)
R11	Trichlorofluoromethane
R12	Dichlorodifluoromethane
R134a	1,1,1,2-Tetrafluoroethane
R22	Chlorodifluoromethane
R290	Propane
R600	Butane
R600a	Isobutane
$T_{i,air}$	Dry bulb temperature of the air at the inlet of the E/RA (°C)
$T_{o,air}$	Dry bulb temperature of the air at the outlet of the E/RA (°C)
v_{air}	Average specific volume of the air at the inlet and outlet of the E/RA (m3/kg)
V_{air}	Average velocity of the air at the inlet and outlet of the E/RA (m/s)

Abbreviations

AC	Air Conditioner
E/R	Evaporator Regulator
EES	Engineering Equation Solver
GWP	Global warming potential
E/RA	Evaporator Regulator with Air
LPG	Liquefied petroleum gas
ODP	Ozone depletion potential
RH	Relative humidity
E/RW	Evaporator Regulator with Water
TUBAP	Trakya University Scientific Research Projects

COP	Coefficient of Performance
PCM	Phase Change Materials

CONFLICT OF INTEREST

No conflict of interest was declared by the authors

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