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# Investigation into the Effect of Air Conditioning System on SI Engine Emission at different operating conditions

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ABSTRACT

*The world is interesting with air pollution currently. The sources of air pollution are more than one; the most main source considers the means of transportation, especially automobiles. Vehicles emit pollutants emission into air, such as carbon monoxide and carbon dioxide, hydrocarbons and nitrogen oxides. This research studies the influence of the air conditioning system on the engine performance, especially the emission of pollutants from the engine. Air conditioning system is a significant one of the loads that affect the engine performance characteristics, which increases the fuel consumption and thus increase the emission of pollutants into the surrounding environment. The study examines the influence of the different operating conditions on the air conditioning system and consequently on the performance characteristics of the engine and its emission of pollutants. The results of the research show the significant impact of the thermodynamic conditions of the vehicle carbine to enhance the performance characteristics of the vehicle engine and thereby reducing the emission of pollutants into the surrounding environment.*

## 1. Introduction

Recently the world has interested with the pollution emitted by transportation sector because of its severe harm on human health and surround environment. Most of developed countries have reported regulations and restrictions on automakers to reduce exhaust pollutants emissions of vehicles [1]. For example, European Union (EU) has enacted strict laws on the standard limits of pollutants, therefore automobiles manufacturers and research centers work to reduce emission of engine passing through various ways [2]. Therefore, the scientific and research centers shall consider all the means and methods by which to decrease and restrict the emission of pollutants. These solutions improve and increase the external characteristics and the performance of vehicle engine to enhance fuel economic and thus reduce the pollutants resulting from combustion. There are various methods such as the use of alternative fuels (ethanol, natural gas, hydrogen, fuel cells, electric batteries, etc.). The effect of air-conditioning system load on the engine performance such as emissions pollutants and fuel economic of passenger vehicles is significant matter, since the great spread to use of these systems have reached a high level [3].

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The air conditioning (A/C) system power consumption of mid-size cars is estimated to be higher than 12 % of the total vehicle power during regular maneuver [4]. Also it can be considered that A/C system occupies the second order of energy consumption after traction electric motor in electric and hybrid electric vehicles [5]. Further, A/C loads are the most significant auxiliary loads present in conventional vehicles nowadays; its energy can be considered as output useful energy into rolling resistance, aerodynamic drag, accelerating resistance or driveline losses for a typical vehicle. For example U.S. alone consumes about 20 thousand tons of fuel a year for A/C systems of passenger and light-duty vehicles [6]. The A/C load of a 1200-kg sedan, under peak conditions, can consume amount of engine power up to 6 kW, which can discharge the vehicle's battery pack rapidly.

This work deals with the effect of the A/C system on the performance of the engine, especially the pollutants emission into surrounding environment. To determine the influence of the A/C system on the performance of the vehicle engine and exhaust emissions, a vehicle engine was equipped with a vehicle cabin that quite similar to reality shape of the vehicle. The cabin was completely isolated from the surrounding environment. The thermal loads such as electric heaters were installed inside the cabin at different location to simulate the realistic thermal loads of the driver and passengers. The experimental result was measured at laboratories of Faculty of Engineering at Minia University. Precise devices of measurements were applied to determine performance parameters of the A/C system and engine performance characteristics. The main objectives of this study are to generated between time, speed and temperature before and after A/C is run on the modeled engine. determine the influence of the vehicle A/C system on the engine performance such as fuel consumption and emission of pollutants [7]. Therefore, the engine was run at various heat loads in the vehicle's cabin as well as different engine speeds. The significant pollutants of emission were determined such as carbon monoxide CO, carbon dioxide CO2 and hydrocarbons HC. The experimental work results show the influence of the A/C system on the pollutants emission and fuel consumption of the vehicle engine.

## 1. Vehicle A/C system description

People or passengers while in vehicles may feel uncomfortable due to excessive heat or polluted air as shown in **Figure 1**. In view of this, the use of air conditioning has become very important in the modern vehicle manufacturing to sustain the thermal comfort of passengers while reasonably quiet and also aid in defogging of vehicle windows so as to increase the active safety factor [8]. According to Daly [9], a prominent firm named Packard became the first automobile manufacturer to proffer ways of installing the air-conditioning unit for cars in 1939. The development of automobile air conditioning system since many years ago has left serious concerns on the minds of the vehicle owners, operators, and maintenance personnel as to know how much the effect it can have on their vehicles. The Heating, Ventilation and Air Conditioning system (HVAC) is a vital accessory which helps people to stay comfortable in the vehicle irrespective of the ambient (outside) conditions. However, since the A/C is powered by the same belt which operates the alternator, water pump, power steering pump, and other accessories, it has become important to examine its effects on the engine. Air-conditioning system pulls energy from the engine during operation and this is noticed as the engine speed increases at idle when the compressor is running. Therefore, there is a need to investigate the popular question being raised on the effect of air-conditioning system on the internal combustion engines. The mode of working or the functions performed by the important components of automobile A/C systems are very much the same with the similar components in the conventional A/C systems that people use in their homes and offices as shown in **Figure 2**. The components such as an evaporator, compressor, condenser, thermal expansion valve and receiver which are common in the conventional A/C systems are also found virtually in all automobile A/C systems (**Figure 3**).

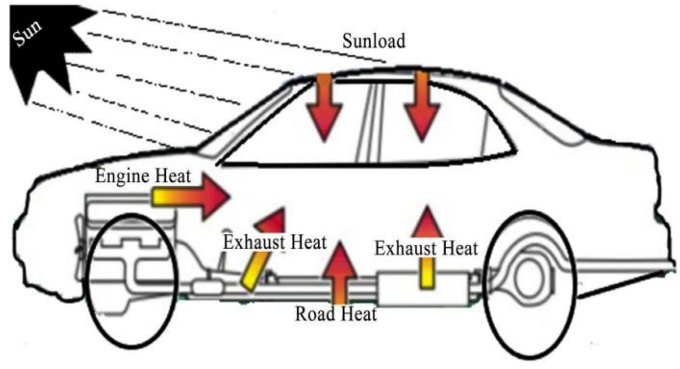


**Figure 1. Mode of heat sources in the vehicle [15].**

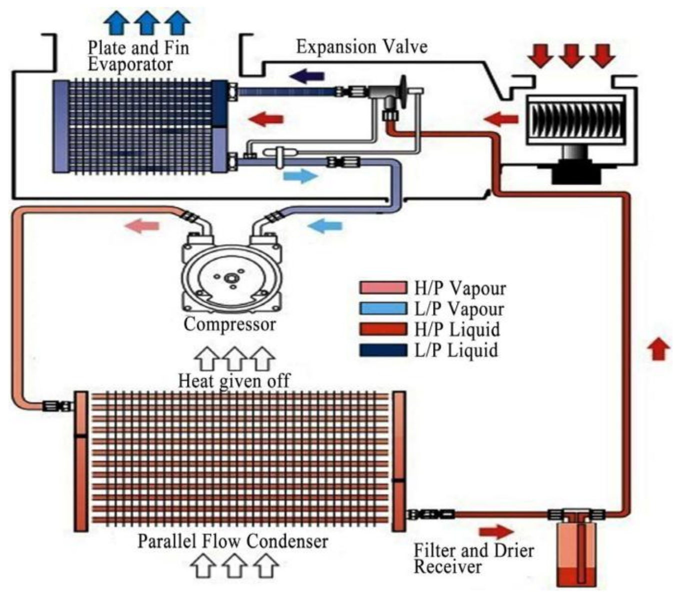


**Figure 2. Schematic arrangement of components of the automobile air conditioning system [15].**

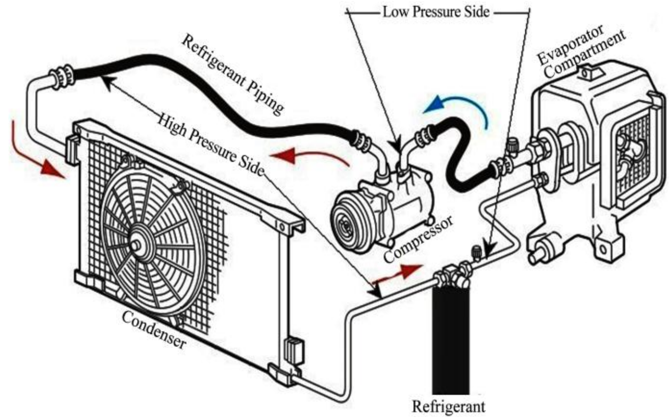

**Figure 3. Shapes of some of the components of automobile air conditioning system [15].**

Figure 3 shows the shapes of the common automobile A/C components. The diagram consists of the high pressure and low pressure sides which are similar to the A/C system used at homes, offices, halls and other A/C applications. The low pressure side consists of the suction piping to the inlet of the evaporator, the evaporating unit and the piping arrangement to the inlet of the compressor. The high pressure side consists of the piping arrangement from the exit of the compressor unit, the condenser unit and piping to the inlet of the throttle device. The mode of operation is in such a way that the refrigerant vapour at low temperature and pressure (in the evaporator) enters the "compressor" where it is compressed is entropically (constant entropy) and subsequently its temperature and pressure increase considerably. This vapour after leaving the compressor enters the ‘‘condenser" where it is condensed into high pressure liquid and is collected in a "receiver tank", from receiver tank it passes through the "expansion valve", here it is throttled down to a lower pressure and has a low temperature.

After finding its way through expansion "valve" it finally passes on to "evaporator" where it extracts heat from the surroundings or circulating fluid being refrigerated and vaporises to low pressure vapour [10]. Javotkova and Pavelek [11] described the alternate trends in the field of automobile air conditioning, the study was focused on the refrigerant, ventilation, and types of control system installed in the A/C system for internal combustion engines. An assessment was conducted about the most widely used contemporary refrigeration system working with the refrigerant R134a and a promising transcritical refrigeration system employing refrigerant CO2 as its working medium.

Meanwhile, the assessment did not reflect the effect of air-conditioning system on the internal combustion engines using any methods. Another study by Kiatsiriroat and Euakit [12], investigated and analyzed the coefficient of performance of an automotive air-conditioning system with R12/R124/R152a refrigerant mixture. Ratts and Brown [13] used experimental method to determine the automobile A/C system coefficient of performance, focusing on the interrelationships between the coefficient of performance, vehicle speed, and the compressor revolutions. Wang and Gu [14] performed an experimental analysis of an automotive air conditioning system with two-phase flow measurements. The obtained experimental results reveal there is a relationship in the coefficient of performance, evaporator cooling capacity, compressor power consumption, total mass flow rate, pressures, and temperatures in an automotive air conditioning system.

In another literature by Ariazone automotive training handbook [15], the theory of heat, pressure, temperature, and refrigerants were discussed in relation to internal combustion engines. The internal combustion engines, air-conditioning system components, and servicing methodology were also addressed but the real effects of the A/C on internal combustion engines were not discussed. In this study, the aim is to investigate statistically the effect of air conditioning systems

on internal combustion engines through the set of design objectives, formulate the research hypotheses to investigate the effect of A/C on the internal combustion engines using pair t-test at 5% significant level for the data obtained from time, speed and temperature variations before and after A/C is run on the modelled engine, and finally determine the model relationship through equation Hence, three variables such as time (in minutes), speed and temperature of the engine were considered and their respective effects were investigated while the engine was running at a static position. The static position was considered because of a drop of engine speed usually notice while the vehicle A/C is run at vehicle's static position.

## 2. Instrumentation setup and Experimental procedures

### 2.1 Instrumentation description

**Figure 4: Instrumentation setup of A/C system of vehicle**

An experimental set-up, to evaluate the performance of automotive A/C system is located in the laboratories of Faculty of Engineering, Minia University. The set-up of experimental work will be described and its accompanied measuring devices used to measure the effective main parameters. The components of the experimental set-up and measuring instrumentations are shown in **Figure 4**. The automotive A/C system used to decrease the heat from the passenger compartment to the condenser and then to surrounding environment through condenser [16]. The vehicle A/C system using conventional refrigerants with different quantities are tested in this study.

The performance of the A/C system under actual operating conditions using a specific type of refrigerant as the working fluid for the compressor is evaluated based on measuring the base temperature on Cabin of the vehicle.

The exhaust gas analyzer can measure up to five pollutants of emission. These pollutants emission are such as Carbon Monoxide (CO), Carbon Dioxide ($CO_2$), Hydrocarbons (HC), Oxides of Nitrogen (NOX) and Oxygen ($O_2$). It easy to work at any operating conditions and it is very simple to use it in the vehicle during the road test.
A type-k thermocouple connected to a digital thermometer, which measures the local surface temperature with an accuracy of ± 1℃. Thermocouples were located in inlet and outlet of each component of the vehicle A/C system. Thermocouple probe (type k), Model: Tp-01, Measure Range (-40 ℃ to 250℃) ; and digital laser photo tachometer, Hard shell ABS plastic digital non-contact with range 2.5 to 100,000 (RPM) for speed measurement. Calibrated in revolutions per minute (RPM) at the speed range of 600 to 4000 (RPM) and the accuracy of ±2% Output of ≤1 MW; Mirror length of L50 by W25 mm overall size of L130 by W65 mm and Scan diameter of 20 mm. Mirror length of L50 by W25 mm.

## 2.2 Experimental procedures

First, the vehicle Fiat Grande Punto vehicle with a 1.9 JTD engine was selected as a reference vehicle was prepared and the vehicle cabin was completely isolated to prevent heat exchange. The vehicle A/C system was charged with air and leaved for a period of time to make sure that there was no leakage in the vehicle A/C system. The calibration of the Thermocouple was done for accurate measuring of temperature. The Thermocouples are placed before and after each component of the cycle to measure the actual temperature. In the vehicle cabin; six thermocouples were installed in order to determine the average air temperature within the compartment. Pressure gauge installed in the vehicle A/C system in the low and high pressure lines.
To achieve practical experiments to determine consumption of fuel and exhaust emissions, measuring devices (exhaust gas analyzer) are connected with tail pipe of engine vehicle. At the beginning, the vehicle is run until it reaches to the optimum operating conditions. During the warm-up process of the vehicle the measuring devices were calibrated and ensure their safety before the start of practical experiments. Fuel consumption is measured using a balance with high accuracy and sensitivity. The fuel pump is immerged into a small tank and then placed on the surface of balance. The exhaust analyzer also records the different concentrations of the exhaust pollutants as well as the engine speed.

## 3. Results and discussion

This research is concerned to study the effect of the vehicle A/C system on the fuel consumption and the pollutants emission at different engine speed as well as different thermal load interior the vehicle cabin. The range of the engine speed of the vehicle during idling phase ranges from 1000 to 2500 rpm. Practical tests and measurements determine the behavior of the motor vehicle during idle speed, which like the vehicle during the waiting at traffic signs or in crowded places. In such cases, the influence of the A/C system will be significant on the engine performance. Therefore, it is essential to focus on the study of this case and determine the consumption of fuel as well as the exhaust emission of pollutants from the vehicle during the idling phase of vehicle engine.

**Figure 5** illustrates the relationship between engine speed and the exhaust system temperature. At engine speed raises the exhaust system temperature increases because of the more quantity of fuel burnt to give more power to overcome the increased load.
It can be determined that the outlet temperatures of exhaust during the operation of the air conditioning system are higher than in case of non-operation of the air conditioning system. This is because during the operation of the A/C system, the engine consumes excess fuel as a result of the thermal load in vehicle cabin, thereby increasing the engine's output capacity, followed by a significant increase in exhaust temperatures.

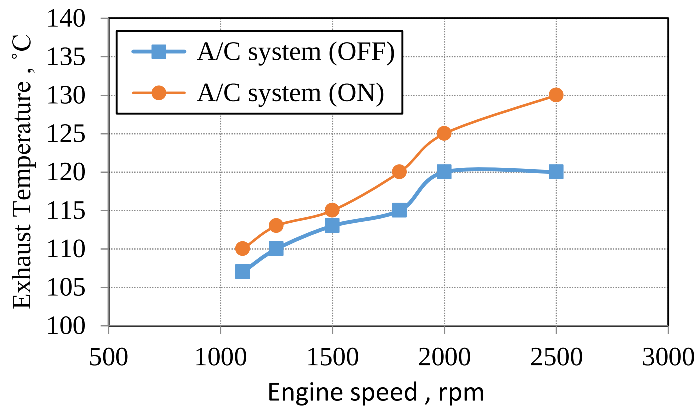


**Figure 5: Comparison of exhaust temperature at different engine speed**

**Figure 6** shows a relation between engine speed and the outlet cooling system temperature. It can be note that the temperature of cooling water during the operation of the A/C system is higher than in case of non-operation of the A/C system. This is due to the action that during maneuver of the A/C system, the engine consumes more fuel due, thus increasing the energy going to the cooling water of the engine. The difference of temperature for two cases increases with increase of engine speed.

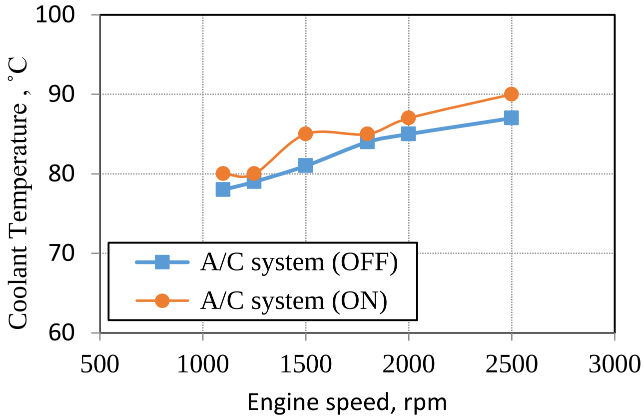


**Figure 6: Comparison of coolant temperature at different engine speed**

**Figure 7** shows a relation between engine speed and engine fuel consumption in case A/C is on. The fuel consumption is increased with the engine speed which the engine needs to burn more fuel at constant designated speed to generate the power that A/C needs. It is clear from the figure that consumption of fuel during the use of the A/C system is higher. The fuel consumption increases during the operation of the A/C system, which is due to raise the engine load, which requires to increase consumption of fuel and to add to the power producing from the engine.

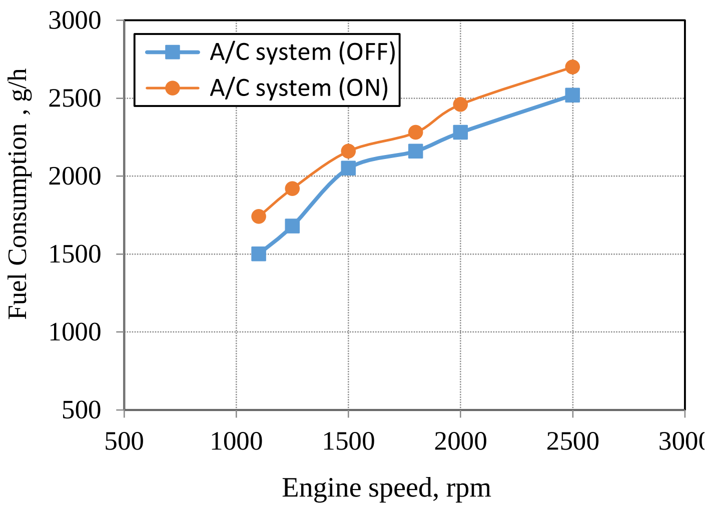


**Figure 7: Comparison of fuel consumption at different engine speed**

**Figure 8** shows the relationship between engine speed and HC emission of engine in case of A/C off and on. HC emission increases with engine speed because the amount of air and fuel increase which results in some of the fuel doesn't be burnt completely; this led to increase of HC pollutant. It is clear from the figure that hydrocarbon emission is high if the A/C system is used. This is due to increase fuel consumption and thus increased hydrocarbon emissions.

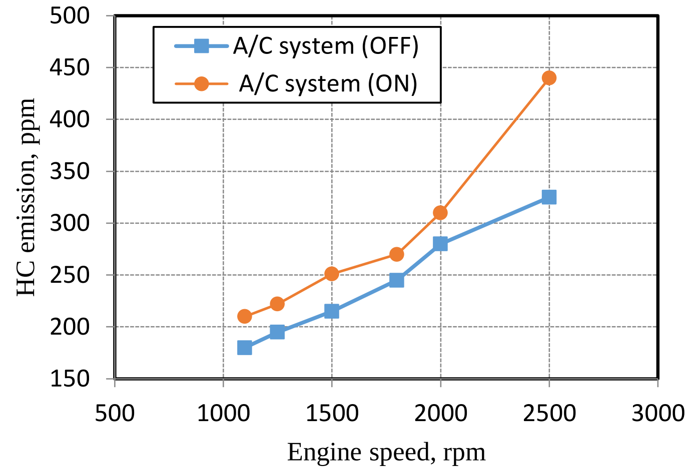


**Figure 7: Comparison of HC emission at different engine speed**

**Figure 8 and 9** show the relationship between the emission pollutants of both carbon dioxide and carbon monoxide during engine speeds for both cases of the A/C system. These figures indicate that the emission of pollutants increases with increasing speed. The amount of emission of pollutants CO and CO2 increase during the operation of the A/C system as a result of increased engine load and thus increased fuel consumption, which increases the emission of pollutants.

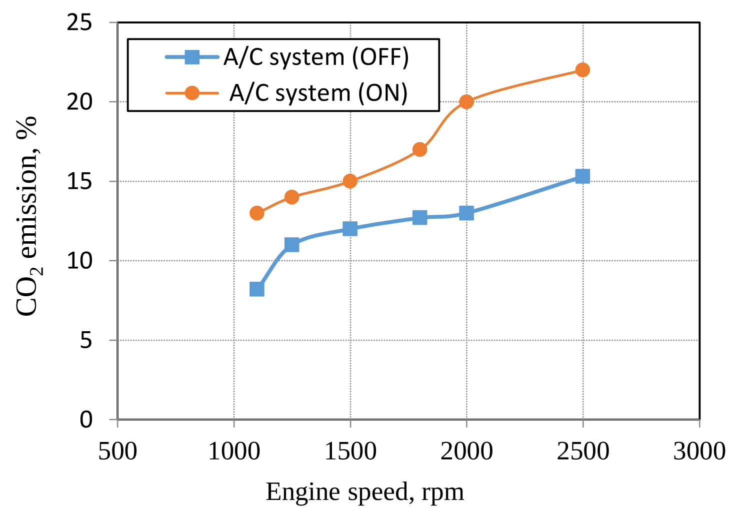


**Figure 8: Comparison of CO2 emission at different engine speed**

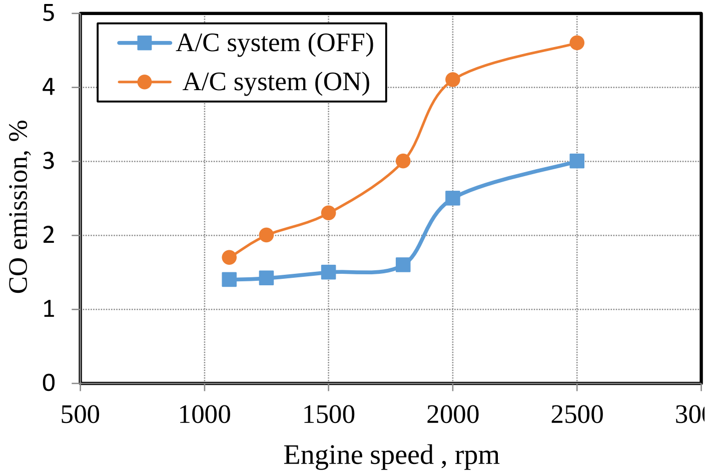


**Figure 9: Comparison of CO emission at different engine speed**

**Figure (10)** shows the relation between engine speed & NOx amount in the exhaust gas. The amount of NOx emission in that condition is more high as the overall temperature is high that lead to increase the NOx emission.

It is clear that the emission of NOx is higher in the case of use of the A/C system. As the engine load increases, the combustion temperature increases within the combustion chamber of engine and thus the nitrogen oxides will be appeared in the exhaust.

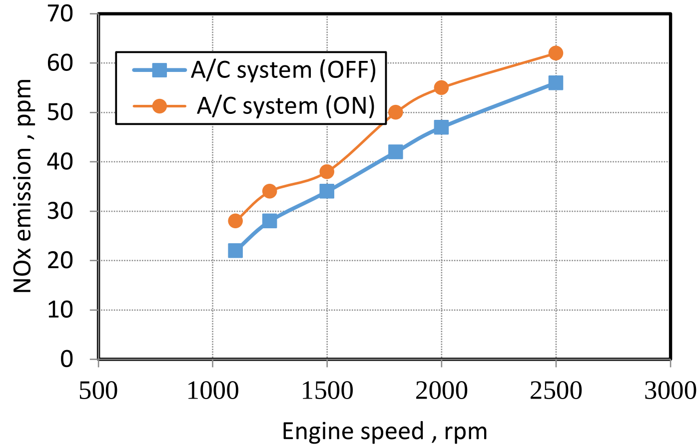


**Figure 10: Comparison of NOx emission at different engine speed**

Figures 11 and 12 show a comparison of all variables at 1100 speed drive. As previously mentioned, all variables are higher value in case of operation of A/C system. This is the speed when the vehicle is stopping and works the engine at idling during the traffic lights. These Figures are a summary of the research showing the influence of the applying of A/C system on the engine performance during the stop in the traffic lights. As vehicle stop for relatively long periods in cities due to traffic lights. This study gives great importance to the influence of the operation of A/C system on the pollutants emission and engine performance characteristics.

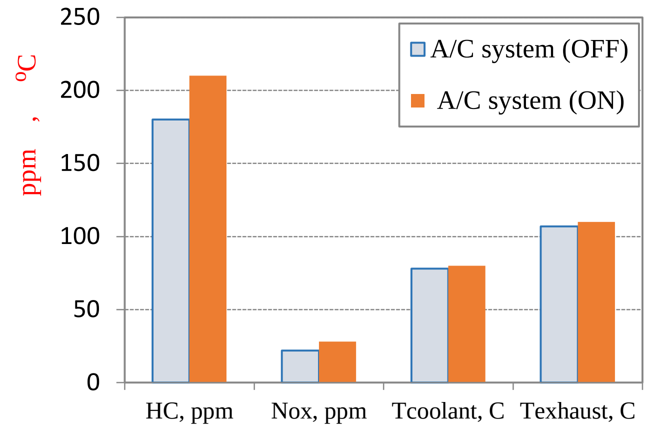


**Figure 11: Comparison between two cases of A/C at 1100 rpm**

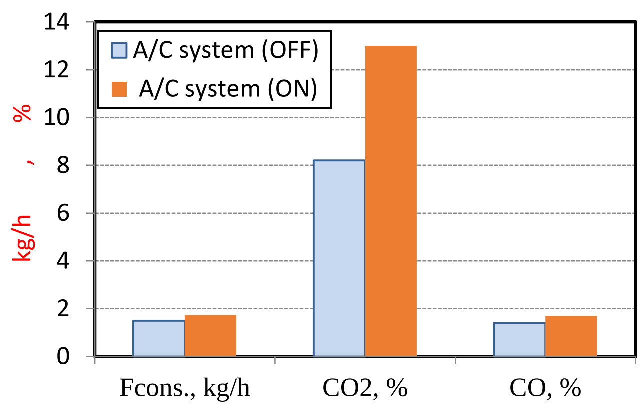


**Figure 12: Comparison between two cases of A/C at 1100 rpm**

## 4. Summary and Conclusions

- The air conditioning system is the single largest auxiliary load on a vehicle by nearly an order of magnitude. The air-conditioning systems used in automobiles decrease the consumption of fuel from traditional cars. Therefore, efforts to improve the performance of the air conditioning system have an important impact on improving the economy of fuel due to the increase in the number of vehicles produced by air conditioners and systems annually.

- Reduction in load of the air conditioning can have an important benefit due to the number of vehicles produced and equipped with air conditioning systems each year.
- Air conditioning systems also cause extra $CO_2$ emissions in and thus fuel consumptions that increase significantly with temperature & solar irradiation.
- Reducing A/C system load lead to decrease the amount of fuel consumed and as a result reduce the emission of harmful gases specially $CO_2$ emission.
- Vehicle manufacturers are seeking to find new research methodologies to reduce fuel consumption as a result of the use of the air conditioning system by developing means that can be applied in these systems to improve vehicle fuel economy and thus reduce emission of pollutants into the surrounding environment.

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