Influence of intake air temperature on internal combustion engine operation

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Abstract. This paper presents three methods for reduce thermal losses in the intake system with improvement of airflow and thermal protection. In the experiment are involved two patented devices conceived by the author and one PhD theme device: 1- Dynamic device for air transfer, 2-Integrated thermal deflector, and, 3-Advanced thermal protection. The tests were carried on different vehicle running in real traffic and in the Internal Combustion Engines Laboratory, within the specialization "Road vehicle" belonging to the Faculty of Engineering Hunedoara, component of Politehnica University of Timișoara. The results have been processed and compared with the ones obtained without these devices.

1. Air temperature influence on fuel consumption and exhaust emissions

Recent studies show significant differences in fuel consumption and exhaust emissions depending on the temperature of the intake air. It is well accepted that the combustion and emissions characteristics are highly rely on the oxygen availability and fuel properties. The excess of oxygen resulted in very lean mixture that lead to the instable combustion and misfire. In fact, lean mixture tends to promote a longer ignition delay and a slower burning rate resulted in longer combustion duration. This condition creates longer time for heat transfer from combustion to the end gas that lead to the knocking phenomenon. However, the engine operates with deficiency of oxygen resulted in rich mixture that leads to the higher unburned gaseous fuel due to shorter ignition delay and faster burning rate.

Therefore, it is vital to make sure the charged air entered into the combustion chamber was sufficient of oxygen in order to promote complete combustion. The previous researches also showed that the air intake temperature has a significant role to increase the combustion efficiency, stability and reduced exhaust emissions [1-3].

Based on previous study, fuel economy can be improved through several strategies such as introduce electronic devices into the gasoline engine. In general, lower fuel consumption and less emission can be achieve by having complete combustion in the combustion chamber. The increased oxygen availability in the combustion chamber can promotes complete combustion and oxidation of both CO and HC emissions. Controlled air intake temperature is one of the possible methods to promote higher combustion efficiency and improved combustion stability. Air intake temperature is important to ensure higher amount of fuel involves in the combustion process. Besides that, air intake temperature will also control the exhaust emissions and combustion process [1].
Brake Specific Fuel Consumption (BSFC):
Figure 1.a shows the result of BSFC when the engine operating at 1500 rpm until 3000 rpm with a variation of air intake temperatures (20°C, 25°C and 30°C). In all engine test conditions the BSFC decreases as the engine speed increases due to air turbulent effects resulted in an improved fuel mixture and complete combustion. At higher engine speed, a larger portion of gaseous fuel to be involved in the oxidation process that leads to higher reaction activity resulted in lower BSFC. The results also show that the BSFC decreases as the air intake temperature decreases [1].

The ignition delay period is reduced with lower air intake temperature due to higher oxygen availability. This allows combustion occurs at the end of compression stroke and early of expansion stroke which convert larger fraction of the fuel energy to the useful work. The results show that the effect of air intake temperature is dominant at higher engine speed compared with lower engine speed. This is due to higher injected fuel at higher engine speed that requires more oxygen to complete the combustion.

The highest value of brake specific fuel consumption was 380 g/kW.hr at higher air intake temperature 30°C, which was 4 % higher than the lowest air intake temperature 20°C at the same engine speed of 1500 rpm. But, when the engine speed increase up to 3000 rpm, the value of BSFC reduce about 22 % from 380 g/kW.hr to 298 g/kW.hr. The higher air intake temperature resulted in lower oxygen concentration will lead to a small negative effect on the combustion rate and BSFC [1].

Carbon Monoxide (CO) Emission:
Figure 1.b illustrates the carbon monoxide emissions of the engine operating at different engine speed and constant engine load. In fact, CO emissions are greatly influenced by fuel–air mixing and the air-fuel ratio. It is observed that the concentrations of carbon monoxide keep increase directly proportional due to increase of engine speed. The engine speed was set-up from 1500 rpm to 3000 rpm. The result shows that 341 ppm of CO emissions was produced when the engine operates with 20°C of air intake temperature at 3000 rpm of engine speed. The value was 6 % lower than the engine operates at 30°C of air intake temperature [1]. The behaviour of CO emission is consistent with the quality of the combustion process and poor oxidation of mixture. The higher air intake temperature tends to reduce oxygen availability resulted in an unstable combustion where partial burn and misfire may take place.

It also was found that, the emissions of CO decreased with the decrease of air intake temperature regardless of engine speed. The possible reason is due to higher oxygen availability at lower temperature resulted in complete fuel mixing process and complete combustion [1].

Unburned Hydrocarbons (UHCs) Emission:
Figure 1.c shows the UHCs emissions trend for a gasoline engine operating with different engine speeds and constant engine load at variation of air intake temperatures. Ideally, the fuel should be
evaporated and mix with air before initiates the combustion process. The mixing process is highly dependent on the fuel droplet size, heat and oxygen availability. The trend of UHCs emissions was similar to that observed in previous results of CO emissions. The UHCs emission level was increased with the increase of the engine speed is due to high amount of fuel involved during the combustion process. However, the UHCs emissions decreased with the decrease of air intake temperature. This is due to high combustion temperature caused by pre-mixed burning and high rate of oxidation of UHCs at lower air intake temperature. The lower air intake temperature is also possible to ignite combustion at rich region mixture [4]. The higher UHCs emissions are produced by the engine operating at 30°C of air intake temperature is due to poor mixing process and incomplete combustion. The behaviour of UHCs emission is consistent with the amount of unburned gaseous fuel in the exhaust gas. This value is 128 ppm which is 10 % higher than the engine operates with 20°C of air intake temperature at the same engine test condition. The UHCs emissions at high engine speed 3000 rpm was higher about 85 % than at lower engine speed 1500 rpm for all variation of air intake temperature because of influence by the reducing of oxygen concentration that supplied to combustion chamber and high amount of injected fuel.

UHCs emissions are generally produced due to incomplete combustion of a carbon containing fuel. Lower excess oxygen concentration results in rich air–fuel mixtures at different locations inside the combustion chamber [5]. This heterogeneous mixture does not combust completely and results in higher UHCs emissions. In addition, the longer ignition delay due to the oxygen deficiency caused by increased air intake temperature will lead to poor UHCs oxidation process. In conclusion we can say that the fuel consumption is improved with the decrease of air intake temperature regardless of engine speed. Also, carbon monoxide and unburned hydrocarbons were decreased with the decrease of air intake temperature, again regardless of engine speed. So, based on the studies presented before, the lower air intake temperatures resulted in lowest fuel consumption and reduced exhaust emissions regardless of engine speed. This conclusion leads us to the solution presented in next session of the article.

2. Presentation of the methods and devices
A cold air intake (CAI) is an assembly of parts used to bring relatively cool air into a car's internal-combustion engine. Most vehicles manufactured from the mid-1970s until the mid-1990s have thermostatic air intake systems that regulate the temperature of the air entering the engine's intake tract, providing warm air when the engine is cold and cold air when the engine is warm to maximize performance, efficiency, and fuel economy. With the advent of advanced emission controls and more advanced fuel injection methods modern vehicles do not have a thermostatic air intake system and the factory installed air intake draws unregulated cold air. Aftermarket cold air intake systems are marketed with claims of increased engine efficiency and performance. The putative principle behind a cold air intake is that cooler air has a higher density, thus containing more oxygen per volume unit than warmer air [6].

2.1. Dynamic Device for Air Transfer (DDAT) pat. No. RO2009 00028
Dynamic device for air transfer (Figure 2) refers to a device designed to collect and transfer air from outside the engine compartment on the air filter, to make a laminar, concentrated flow of air and lowering its temperature for increase the volumetric efficiency of internal combustion engine. The Dynamic Air Transfer Device consists of: external collection diffusers (one or several), connection joints and external axial collector (one or two passages). We can say that the advantages of this device are: the air transfer to the filter has a concentrated laminar flow; the low air temperature allows a more efficient internal cooling of the ICE; a slight effect of overfeeding is created, which is proportional to the speed of the car; an increased volumetric efficiency; a higher burning yield of the combustion mix lower levels of polluting emissions; dynamic admission; makes possible to shorten the distance between the filter and admission gallery.
Pressure variation measurements (Figure 3) have been carried out at different speeds both in the area where the air is transferred from the DDAT to the filter and the area where the air is absorbed by the filter (left and right side) without the DDAT. The measurements were performed with the digital manometer TESTO 510 (0-100hPa). A significantly higher air collection and transfer effect is observed with DDAT than in the case of the simple absorption performed by the super-absorbing filter [7], [8].

2.2. Integrated thermal deflector pat. no. RO201000026

The integrated thermal deflector (Figure 4) it’s designed to protect the air filter area from the thermal radiations generated by the cooling radiator and combustion engine. The integrated deflector has the form of a separating wall between air filter area and rest of engine compartment.
The usage of the integrated thermal deflector has the following advantages: the air flow generated by cooling radiator (i.e. thermal radiations) is deflected outside the air filter area; the temperature of the air filter is maintained at an optimum level (i.e. their over-heating is avoided). Temperature variation measurements (Figure 5) have been carried out at different speeds both in the area of the air filter and outside the area of the air filter with the integrated thermal deflector mounted on the site [7].

![Figure 5. Intake air temperature values](image)

2.3. Advanced thermal protection
Because of the position in the engine compartment the intake (Figure 6) is highly exposed to thermal radiations from the cooling radiator, exhaust pipe and engine itself which is a disadvantage, the intake air is heated and the result is a lower density, thus containing less oxygen per volume unit than cold air.

![Figure 6. Intake temperature - Thermal imager](image)

One method of reducing thermal losses is to insulate the intake with a new kind of material. The principal scope is to resource and development a new insulates material from composite, natural and organic materials based from recycling materials.

Early comparative tests were carried out on sections (Figure 7) of intake with or without layers of insulation materials. The tests were performed with various layers (Figure 8) of insulation materials such as silicone, carbon fibre, cork and various mixtures.
Comparative tests (Figure 9) on sections from intake coated with an insulating layer revealed a significant improvement regarding thermal losses.

3. Conclusions

In conclusions, we can say that these methods can reduce thermal losses in the intake system by providing a higher pressure air flow while maintaining a low temperature along intake system, contributing to increasing the filling efficiency $\eta_V$ of the engine cylinders. Also improving the filling efficiency $\eta_V$ means a lower specific fuel consumption and lower exhausts pollutants.

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