The influence of thermal regime on gasoline direct injection engine performance and emissions

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Abstract. This paper presents the experimental research regarding to the effects of a low thermal regime on fuel consumption and pollutant emissions from a gasoline direct injection (GDI) engine. During the experimental researches, the temperature of the coolant and oil used by the engine were modified 4 times (55, 65, 75 and 85 ºC), monitoring the effects over the fuel consumption and emissions (CO₂, CO and NOₓ). The variations in temperature of the coolant and oil have been achieved through AVL coolant and oil conditioning unit, integrated in the test bed. The obtained experimental results reveals the poor quality of exhaust gases and increases of fuel consumption for the gasoline direct injection engines that runs outside the optimal ranges for coolant and oil temperatures.

1. Introduction
The fuel consumption and pollutant emissions from internal combustion engines are still a major concern of researchers from the automotive engineering field. Also, the fuel consumption diminish will lead to the CO₂ low emissions.

According to the UE regulations, the amount of CO₂ will be limited since 2020 to 95 [g/km] for all new passenger vehicles.

One of the factors that influence the fuel consumption and quality of exhaust gases of an engine operating at a certain speed and load, it is the thermal regime. Generally, the engine thermal regime is characterized by an optimal coolant temperature that is around at 90 ºC. It is noticed that the engine is running cold when thermal regime is less than optimal.

It can be mentioned that since the cold start engine until reaching the thermal optimum, its performance is reduced. That is why cooling systems of internal combustion engines are designed to reduce the period in which the engines are running cold. The thermostat existence in the engine cooling systems shortens the time that coolant reaches the optimal temperature. A low value of the spark ignition engines can increase heat losses from the cylinder and also its mechanical losses. Also, the oil film on the cylinder can be diluted by the incompletely burned fuel, due to the contact between fuel and the cool cylinder walls. [1]

The thermal impact over the engine performance and durability depend inter alia on the engine type (spark ignition engine or compression ignition engine), fuel injection system (direct or indirect injection) and the type of air/fuel mixture (stratified or homogeneous).

This paper aims to highlight the link between thermal regime and a spark-ignition engine performances (economical and environmental) equipped with a direct injection system and homogeneous mixture.
2. Experimental research
The experimental researches were made at Transilvania University of Brasov, ICDT - Research & Development Institute. The spark ignition engine used for experimental researches is an AVL single cylinder research engine (figure 1), included in Series 540 Passenger Car Size engine family. This is a GDI (gasoline direct injection) single cylinder with homogeneous air/fuel mixture, with 475 cc cylinder capacity and an engine power 20 kW at 6000 rpm. The AVL research engine have two intake valves and two exhaust valves, and the piston is cooled with oil jet.

Figure 1. AVL Single Cylinder Research Engine (SCRE) and the AVL Test Bed.

During experimental research through AVL FI2RE software the fuel injection is divided into two periods, first and second direct injections. The engine load is controlled through manifold pressure. The injection parameters are controlled by set the number of injections (first, second or third direct injection). The fuel mixture can be adjusted by varying the amount of fuel injected per cycle (injection period, in μs). The ignition time is also set in crank angle degrees before top dead center (TDC). [2]

The engine is operated on a AVL Single Cylinder Engine Test Bed. This stand includes a temperature control equipment for oil and cooling water. With this equipment it was been possible that the coolant and oil temperatures to be changed independently of the operating time of the engine. The temperatures control was accomplished by the water to water heat exchangers. Research methodology is shown schematically in table 1.

As seen, keeping the operating parameters of the engine to a certain value, the cooling liquid and oil temperature has been modified. During the experimental research the engine has been running at partial loads and speeds. These operating regimes are the most usual ones in the exploitation of internal combustion engines for automotive.

The temperature control equipment measures the temperature of the cooling liquid and oil on both sides, entry and exit of the engine. The measurements done during each thermal regime were done after values have stabilized and the value was minimal.
Table 1. Experimental research methodology.

| Engine operating regime | Engine thermal regime¹ | Measured parameters |
|-------------------------|------------------------|---------------------|
| n₁ and M₁               | T¹ coolant and oil     | Series 1: power, fuel consumption CO, CO₂, NOₓ etc. |
|                        | T² coolant and oil     | Series 2: power, fuel consumption CO, CO₂, NOₓ etc. |
|                        | ⋮                      | ⋮                   |
|                        | Tⁿ coolant and oil     | Series n: power, fuel consumption CO, CO₂, NOₓ etc. |
| nₙ and Mₙ               | T¹ coolant and oil     | Series 1: power, fuel consumption CO, CO₂, NOₓ etc. |
|                        | T² coolant and oil     | Series 2: power, fuel consumption CO, CO₂, NOₓ etc. |
|                        | ⋮                      | ⋮                   |
|                        | Tⁿ coolant and oil     | Series n: power, fuel consumption CO, CO₂, NOₓ etc. |

¹ Constant temperature of intake air and fuel.

During experimental research the focus was on fuel consumption and on pollutant emissions. The fuel consumption of the engine was measured with AVL Fuel Mass Flow Meter, and the pollutant emissions of the exhaust gases with GA-21 Gas Analyzer. With this exhaust gases analyzer CO, NO and NO₂ emissions are directly measured and expressed in [ppm]. CO₂ concentration is expressed in percentage % and is calculated with equation (1), on the basis of direct measurements of the O₂ concentration and the maximum volume of CO₂ characteristic for the given fuel. Also the NOₓ value is calculated as a sum formed by NO and NO₂, as in equation (2). [3]

\[
\text{CO}_2 = \text{CO}_{2\max} \cdot \left(1 - \frac{\text{O}_2}{20,95} \%\right) \\
\text{NO}_x = \text{NO} + \text{NO}_2
\]

In order to follow only the influence of the coolant and oil temperature, the intake air and fuel temperature were maintained constant.

Below are several experimental results obtained with this equipment mentioned.

3. Experimental results and discussions

During experimental research the engine (and dynamometer) was operated at the speeds: 1500 [rpm] and 2500 [rpm]. At this speed (n), torque (M) developed by the engine wearies between 20 [Nm] and 25 [Nm]. As we already said before, when the engine is operated at these speeds and torques, the thermal regime was modified 4 times (328, 338, 348 and 358 K). The experimental results obtained in these operating conditions are shown below. In figure 2 are presented the fuel consumption values for studied engine, at different thermal regimes.

Figure 2 (a) and (b) reveals that economical performances of the gasoline direct injection engine are most adequate at high thermal regimes, closer to the optimal value of 363 [K]. It can be noticed that the trend of specific fuel consumption decrease is obvious at all operating regimes of the engine. We can conclude that the engine economy is improving because the high temperature regimes for coolant improves the quality of the cylinder combustion process.

Also with engine consumption performances are improved its ecological qualities. Therefore, one of the consequences of reducing fuel consumption is to reduce the emission of CO₂ from the exhaust gases (figure 3). The quality of the cylinder combustion process can be seen through the emission of CO concentration. It can be seen that the incomplete burned fuel quantity is reduced with increasing the coolant and oil temperature. The concentration of CO emission is minimal at the thermal regimes over 348 [K].
An undesirable effect of increasing the engine thermal regime is that of increasing the concentration of NOx. The concentration of this pollutant emissions depend to the temperature of the air-fuel mixture that burns in the combustion chamber first. Reduction of NOx emission for GDI engines can be achieved if are used stratified air-fuel mixtures in a cylinder. This solution allows to form a rich mixture around the spark plug and a poor mixture near the combustion chamber walls. Due to the low oxygen quantity in the mixture around the spark plug, the emission of NOx has a lower value. [4]

In figure 4 are presented the pollutant emissions of NOx resulted, according to the equation (2). By modifying the thermal engine, from 328 [K] to 358 [K], NO emission varied by 760 [ppm]. The concentration of NO2 vary with 63 [ppm], the maximum being below 120 [ppm]. In this case we can say that the change has an impact on the thermal emission of NOx due to significant variation of NO emission.
some of the factors that influence exhaust gas temperature are: the amount of fuel burned inside the cylinder, intake air temperature and heat transfer to the engine parts.[5] Intake air temperature in experimental research remained quasi-constant, but by increasing coolant and oil temperatures was the transferred heat to the engine parts was reduced, so that the gas temperature in the cylinder has increased. In addition, a lower amount of fuel burned with the increase in the thermal regime, which leads to a reduction of the gases temperature in the cylinder.

4. Comparison between the engine performance
If it transform temperature values in [°C], results that during experimental research coolant and oil temperatures varied by 18%, 36% and 54%, between 55 [°C] and 85 [°C]. The percentage changes in fuel consumption and polluting emissions revealed in figure 3, due to change in the thermal engine are shown figure 5.

Figure 4. Nitrogen oxide, nitrogen dioxide and exhaust gases temperature evolution in function of engine thermal regime changes.

Figure 5. Economical and ecological performances variation in function of engine thermal regime.
It can be seen that the concentration of CO and also the combustion process quality is strongly influenced by the thermal value. Engine fuel consumption is significantly improved by high thermal regimes. This is partly by observing the evolution of CO₂ emissions, whose minimum value is obtained in the coolant and oil temperature range 75-85 [°C].

5. Conclusions
AVL Single Cylinder Engine Test Bed infrastructure facilitated the development of experimental research regarded to the fuel consumption and emissions of CO, CO₂ and NOₓ in function of the single cylinder research engine thermal regimes.

The researchers effort to identify solutions to considerably reduce the duration of cold GDI engine functioning is justified if is related to the engine thermal regime, that affects its economical and ecological performances. In this respect experimental research presented in the paper is revealed a significant reduction in fuel consumption and CO emissions. CO₂ emissions concentration also show a downward trend in thermal regimes over 75 [°C]. Because of the way that NOₓ emission are formed, its concentration increased with the coolant and oil temperatures. The increase in NOₓ emissions with thermal regime has been facilitated by the fact that the investigated experimentally engine operates with homogeneous mixtures.

6. References
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