Estimation of exhaust gas temperature for a biogas engine

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ABSTRACT

This article examines the effects of charge, engine speed, ignition timing, and air-fuel ratio on the temperature of exhaust gases when using biogas as fuel. The effects of varying engine operating conditions on exhaust gas temperature are analyzed. The article discusses whether increasing engine charge and engine speed leads to higher exhaust gas temperatures, and whether adjusting ignition timing and air-fuel ratio has a more complex effect on temperature. Detailed analyses are presented to conclude that optimal ignition timing and air-fuel ratio can lead to reduced exhaust gas temperatures and improved engine efficiency when using biogas as fuel.

INTRODUCTION

Research is constantly being conducted worldwide on alternatives that can impact the performance and emissions of internal combustion engines. The use of biogas represents an option that brings a series of benefits, such as reducing environmental impacts, mitigating the greenhouse effect, and utilizing organic waste that could have inadequate disposal. Biogas reduces the dependence on fossil fuels, which are more harmful to the atmospheric air quality in urban areas.

In order to ensure driver safety and the longevity of the internal combustion engine, as well as compliance with legal emission standards, electronic engine management is performed. This management is usually developed from a model of the engine capable of responding in real-time, so that this model can be employed in a hardware-in-the-loop to test the responsiveness of the electronic control unit (ECU). Using a dynamometer, experiments are conducted to obtain an appropriate model of the parameter that is intended to be estimated.

One of the parameters that most influences emissions in the exhaust system is the temperature of the exhaust gases. Many levels of various pollutants are closely related to this temperature value. Therefore, it is important to model the exhaust gas temperature, so that prediction and control of emissions can be enabled. Experimental analyses can be carried out to conclude which variables have the most impact on the exhaust gas temperature, in order to create a precise model that is capable of responding in real-time.

The present research aims to model the exhaust gas temperature, in order to enable emission control based on this parameter. The sections of the article are as follows. Section 1 will detail the methodology employed, so that the repeatability of the research is possible. Section 2 will explain the modeling of the exhaust gas temperature. Section 3 will show the experiments carried out and the results obtained. The article concludes with acknowledgments and the conclusion.

METHODOLOGY

The process begins with a literature review, in order to become acquainted with models of exhaust gas temperature and the main parameters that affect it. Next, a laboratory planning is carried out in order to collect data that can support analyses of the models. The collected data is then processed by software to present the experimental results.

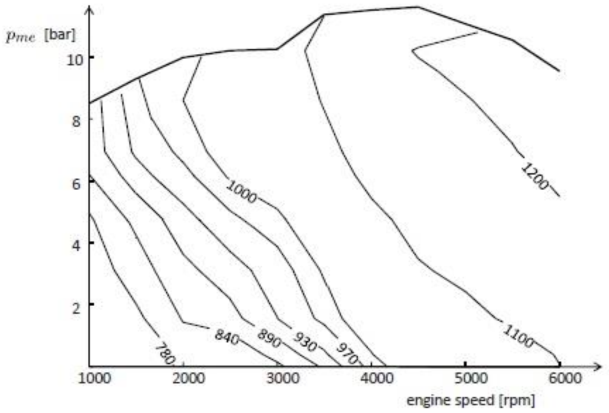
MODELING

An important variable for modeling is the exhaust gas temperature, as it allows us to know the enthalpy of these gases. We recommend that the researcher install a temperature sensor in the exhaust manifold. Pay attention to the choice of the sensor, as the walls of the exhaust manifold can reach levels as high as 900K [1] and the exhaust gases levels as high as 1200K [2].

Transient modeling of changes in exhaust gas temperature will not be carried out, as this transient is negligible, since with a variation in the operating point, the change in exhaust manifold temperature is practically immediate [3]. However, the researcher should be aware of the sensor delays they are using.

Firstly, we suggest the collection of a base map of exhaust gas temperature for λ≈1, optimal recirculation rate, and optimal ignition angle, in order to obtain a result as shown in Figure 1. The mean effective pressure and engine speed should be varied and the exhaust gas temperature obtained for each ordered pair of these values.

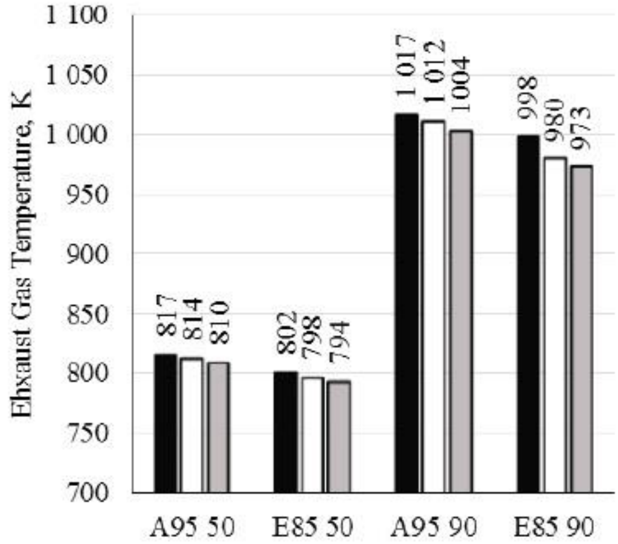
Figure 1.: Exhaust gas temperature as a function of mean effective pressure and engine speed.



Source: [2]

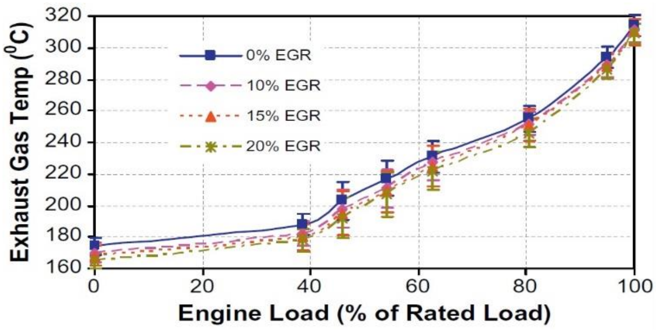
Next, we will present studies that researched the influence of excursions in the optimal ignition angle and the optimal recirculation rate on the temperature of exhaust gases. In figure 2, two fuel blends (E85 and A95=E5) were tested at different engine speeds, and the exhaust gas temperature was measured as the ignition angle was varied. In figure 3, in a diesel engine, the exhaust gas temperature was raised for different recirculation rates. Note that, in both cases, the changes in temperature are indifferent to the objective of this chapter, since such temperature changes result in small and negligible enthalpy changes. Only for large excursions of the ignition angle do we have significant changes in temperature [4]. If the reader wishes, they can consult [5], which is another study that showed variations in exhaust temperature according to excursions in the ignition angle for cold start. In this study, the temperature variations are also negligible.

Figure 2.: Exhaust gas temperature as a function of fuel composition and engine speed. The number next to the fuel composition is the engine speed in $km \cdot h^{-1}$. A95 is the common gasoline in the Republic of Latvia, with 5% addition of anhydrous ethanol. The black columns correspond to an ignition angle of 31 to 31.5 APMS, the white columns correspond to 33 to 34 APMS, and the gray columns correspond to 36 to 37 APMS.



Source: [6]

Figure 3.: Exhaust gas temperature as a function of relative load for different recirculation rates.



Source: [7]

From the exhaust gas temperature map, we can estimate the enthalpy of the exhaust gases. Firstly, we need to know the composition of the exhaust gases, which can be determined by knowing the fuel mixture and the air/fuel ratio used in the combustion process.

Once the composition is known, we can determine the exhaust gas temperature at the operating point from the exhaust gas temperature map. With the temperature known, we can estimate the enthalpy of the exhaust gases using thermodynamic tables that relate the enthalpy of each gaseous chemical compound to the temperature at which it is found.

EXPERIMENTAL STRUCTURE

In this experiment, the engine was used coupled to a bench dynamometer to adjust the engine speed. The intake pressure, injection timing and ignition angle are controlled using the INCA software, and the data were recorded in Matlab software. A programmable ECU was used, which communicates with the INCA software. The engine used is the EA 111 VHT 1.6 liter, modified to work with indirect gas injection.

Table 1: Instrumentation used.

Pre-catalytic lambda sensor	LSU4.9
Passive bench dynamometer	Schenck Type D 360 1E hydraulic
Active bench dynamometer	Antriebstechnik INDY 33/4P
Lambda measurement analyzer	ETAS LA4
Analog input reader	ETAS ES650
Gasoline FLEX ECU	BOSCH MED17ETAS-2.41
Calibration and acquisition software	INCA v7.1
Engine	EA 111 VHT 1.6 liter

Figure 4: EA 111 VHT 1.6 liter engine coupled to the Schenck Type D 360 1E hydraulic Passive bench dynamometer.

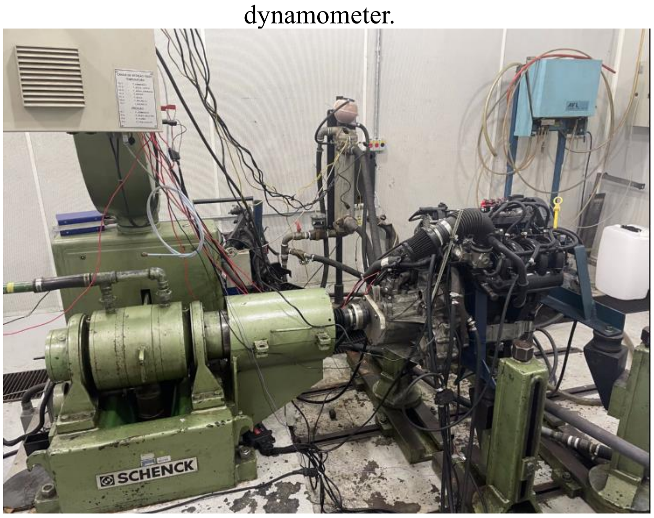


Figure 5: Programmable ECU connected to a data acquisition board.

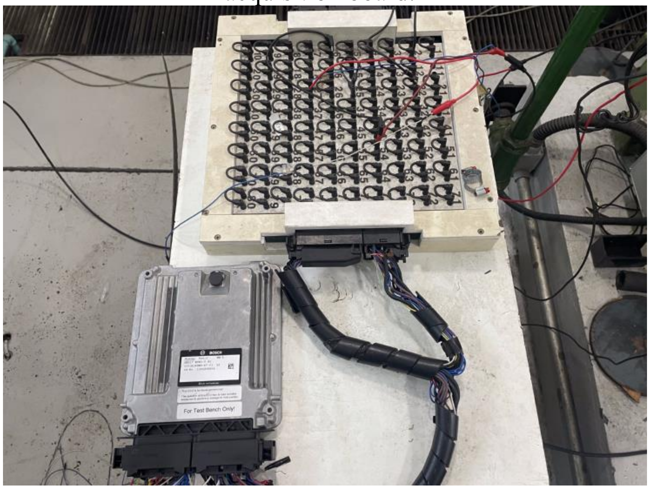
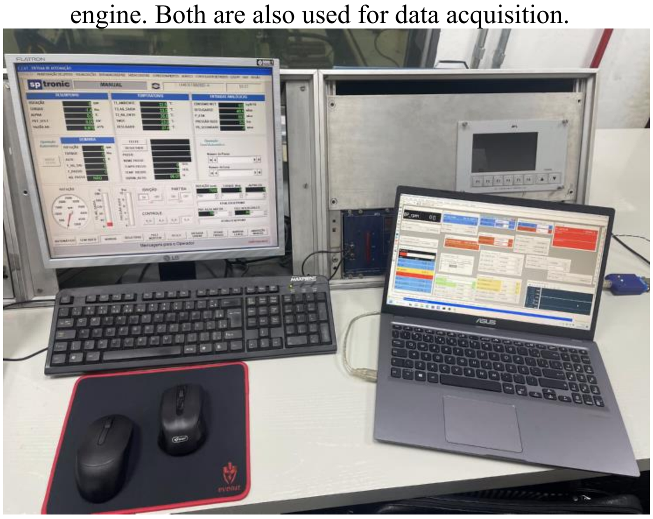


Figure 6: E_CAT software used to control the dynamometer, and INCA software used to control the engine. Both are also used for data acquisition.



RESULTS

Firstly, by maintaining the stoichiometric ratio and ignition timing as mapped in the ECU, a curve of the exhaust gas temperature is obtained, as shown in Figure 1, taking into account that the indicated mean effective pressure and effective torque are proportional. This curve can be used as a basis for modeling the exhaust gas temperature. Indeed, there is a clear tendency for the temperature to increase as torque and speed increase. This is due to the higher demand for fuel and oxygen needed to generate more power, resulting in a greater release of heat and, consequently, higher exhaust gas temperatures. An alternative solution is to map the exhaust gas temperature as a function of the intake pressure and engine speed. Both curves have a similar shape and are possible solutions for modeling the exhaust gas temperature.

Figure 7: Exhaust gas temperature as function of engine effective torque and engine speed.

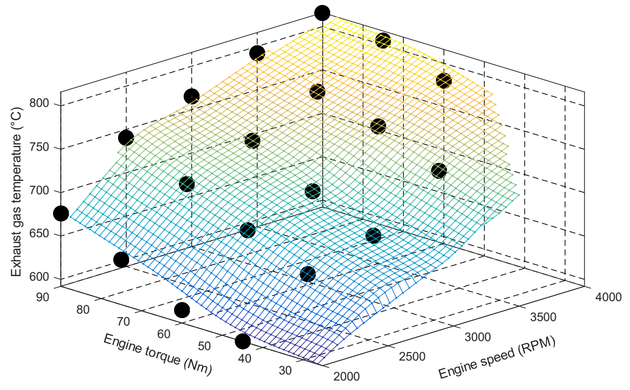
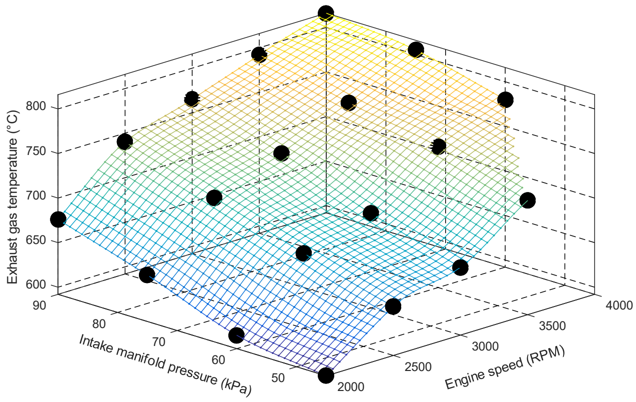


Figure 8: Exhaust gas temperature as function of intake manifold pressure and engine speed.



To explore the modeling of exhaust gas temperature, the impact of varying the air-fuel ratio and ignition timing was studied to understand the magnitude of their effect on exhaust gas temperature. Two types of tests were conducted. In the first test, the ignition timing was varied while keeping the effective torque constant (the throttle valve opening was manipulated to change the intake pressure and maintain constant torque). It was observed that there is a significant variation in temperature, indicating that a correction factor is necessary to account for the variation in exhaust gas temperature in the model as the ignition timing changes. According to the experiments, lower ignition angles result in a shorter time interval for heat transfer between the gases and the engine, leading to higher temperatures. In the second experiment, the intake pressure was kept constant, and the same result was observed.

Figure 9: Exhaust gas temperature as function of ignition angle, for constant engine speed and constant effective torque.

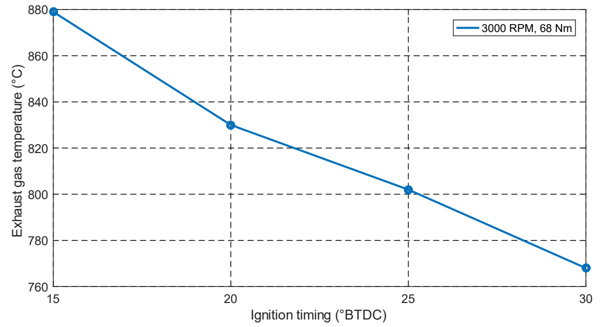
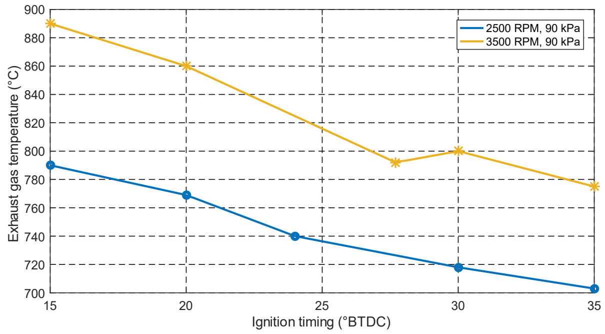
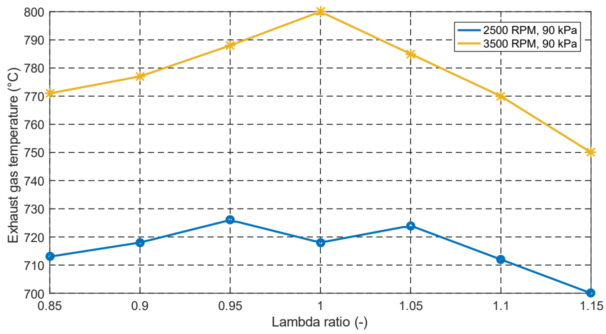


Figure 10: Exhaust gas temperature as function of ignition angle, for constant engine speed and constant intake manifold pressure.



Finally, the air-fuel ratio was varied to investigate its impact on the exhaust gas temperature. It can be concluded that the impact of changes in the air-fuel ratio is not as significant as the impact of changes in the ignition timing. Therefore, a possibility to simplify the exhaust gas temperature model is to disregard the influence of variations in the air-fuel ratio.

Figure 11: Exhaust gas temperature as function of lambda ratio, for constant engine speed and constant intake manifold pressure.



CONCLUSION

In conclusion, this article examined the modeling of exhaust gas temperature in relation to engine torque and engine speed, as well as in relation to intake manifold pressure and engine speed. It was found that varying the ignition timing has a significant impact on exhaust gas temperature, while varying the air-fuel ratio does not have a significant impact.

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