A SI Engine Indicated Characteristics Determination for Gasoline and Methane Operation

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Abstract. The present paper presents a study whose objective is to determine the indicated parameters of an spark-ignition engine and external mixture formation when running on methane and gasoline. The experiments were carried out using optimum adjusting parameters for engine operation on methane and gasoline fuels. The parameters measured and determined are: indicated specific fuel consumption, indicated mean effective pressure, indicated power, indicated efficiency, friction mean effective pressure and etc. over the entire engine speed range. An analysis of the obtained results is made, comparing the obtained indicated parameters at the operation of internal combustion engines with alternative fuel - methane and traditional fuel - gasoline.

1. Introduction
With the increasingly stringent environmental standards for exhaust gas set by European legislation, the use of alternative fuel sources is growing [1,3,4,5]. One option to reduce CO₂ emissions is by using alternative fuels. These alternative fuels for Spark-Ignition engines can be: LPG (liquid petroleum gas), CNG (compressed natural gas), different types of alcohols and biogas [7,8].

Methane alternative fuels, i.e. methane is of growing interest as they produce the lowest exhaust gas emissions when burnt in the engine. The disadvantages of these fuel systems are the additional large weight of the fuel tank and the lower power output upon engine retrofitting. Nevertheless, the fuel has a low cost and better environmental performance.

The indicator specific fuel consumption \( g_i \) gives an evaluation of the engine operating cycle economy. Indicated mean effective pressure (IMEP) \( p_i \) is the average pressure produced in the combustion chamber during the operating cycle. It is an expression of the theoretical, frictionless power known as indicated power \( N_i \). In addition to completely disregarding power lost to friction, indicated power gives no indication as to how much actual power is delivered to the propeller shaft for doing useful work. However, it is related to actual pressures that occur in the cylinder and can be used as a measure of these pressures.
Previous research has shown that when using methane as a SI engine fuel, CO₂ emissions are reduced by up to 20%, HC emissions are decreased by about two times and CO₂ emissions are reduced by an average of up to six times [10].

The greatest potential is associated with the use of methane to fuel engines. The CNG consists of about 95% methane and 5% other gases, which makes this gas a usable fuel for internal combustion engines. In addition, the exhaust gases produced when operating on this fuel have lower harmful emissions and the price of natural gas is times lower than that of gasoline [9].

There are several reasons for using methane as an alternative ICE fuel. Among these are the lower noise levels of the combustion process, the reduced exhaust emissions even with cold start, the significantly lower CO₂ emissions (about 30%), the high octane rating of methane, which makes it a suitable choice for supercharged gasoline engines as well. As compared to gasoline, methane fuels have the following disadvantages: lower density, extra energy required for their compression, gas losses during production and transportation. The majority of all gas engines are forced-ignition and intake-manifold fuel injection. Compared to gasoline, methane accounts for a significant portion of the fresh charge.

The aim of this research is to study and determine the indicated parameters of Spark-Ignition Engine when running on methane and to compare these results with the parameters of an engine running on traditional fuel - gasoline.

2. Experimental study procedures

2.1. Engine Details
The study was carried out on a gasoline engine in the laboratory of the Department of Transport Engineering and Technologies, Technical University of Varna. The experiments performed provide figures of wide-open throttle speed characteristics, with fuel-air ratio of α = 0.9 for gasoline and α = 1.05 for methane (these are the optimum AFR values for both types of fuel) and optimum electric spark ignition timing for each type of fuel. The characteristics were taken at crankshaft speeds of 1500 min⁻¹, 2000 min⁻¹, 3000 min⁻¹, 3500 min⁻¹, 4500 min⁻¹, and 5500 min⁻¹, with wide-open throttle.

The engine parameters are shown in Table 1.

| №  | Parameter                      | Value  |
|----|-------------------------------|--------|
| 1  | Volume [dm³]                  | 1.275  |
| 2  | Cylinder diameter [mm]        | 70.61  |
| 3  | Stroke [mm]                   | 81.28  |
| 4  | Compression ratio             | 9.75   |
| 5  | Nominal power/ crankshaft speed [kW/ min⁻¹] | 46/5500 |
| 6  | Nominal torque/ crankshaft speed [Nm/ min⁻¹] | 95/3000 |

2.2. Results
Table 2 indicates the principal parameters of the fuels used in the experiment.

| Parameter                      | Methane | Gasoline A95 |
|--------------------------------|---------|--------------|
| Lower heating value Hₜ [kJ/ kg] | 45 670  | 44 000       |
| Density [kg/m³], 20°C; 760 mm Hg | 0.748   | 720          |
The graphs shown in Figures 1 to 7 show the experimental results. Fig. 1 illustrate the variation of Indicated specific fuel consumption over the entire engine speed range with optimum control parameters when engine is running on gasoline and methane.

When the engine operates on methane, the minimum value of Indicated specific fuel consumption is 190 g/kWh at 3500 min⁻¹, with gasoline, the minimum value of Indicated specific fuel consumption is 254 g/kWh at the same crankshaft rotation. In terms of comparison between the two types of fuel, the Indicated specific fuel consumption marks an average decrease of approximately 33 % when the engine works on methane.

Figure 2 show the variation of Indicated mean effective pressure. When engine work on methane, the values of IMEP are lower because of air-fuel mixtures is lean and have higher heat losses for heating a larger cyclic quantity of air.

| Property                                      | Gasoline | Methane |
|-----------------------------------------------|----------|---------|
| Molecular mass [kg/mol]                       | 16.77    | 107     |
| Combustion rate [sm/s]                        | 33       | 43      |
| Combustion air required for complete combustion of 1 kg of fuel [kg] | 16.20 | 14.7 |
| Octane number - MM                            | 130      | 95      |
| Flash point [°C]                              | 540      | 744     |
| Mass composition H/ C [%]                     | 25/ 75   | 14.5/ 85.5 |

Figure 1. Variation of ISFC.
Fig. 2 show the variations of IMEP. The higher values are obtained at gasoline fuel, because of the indicated diagram have bigger area and the effective parameters are better.

Figure 3. Variation of Indicated power.

Fig. 3 show the variations of Indicated power. The higher values are obtained at gasoline fuel, because of the indicated diagram have bigger area and the effective parameters are better.

Figure 4 show the variation of friction power. At both fuels the friction power is almost equal, because of the mechanical losses in the engine do not change.
The variation of Friction mean effective pressure is shown on figure 5. The lower values are for gasoline, because of lower heat losses at burning process.

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**Figure 4.** Variation of Friction power.

**Figure 5.** Variation of Friction mean effective pressure.
Figure 6 and 7 shows the variation respectively of Mechanical efficiency and Indicated efficiency. The indicated efficiency at methane fuel is around 20% better than gasoline fuel. This shows that the combustion process when engine work with methane is more perfectly.

Figure 6. Variation of Mechanical efficiency.

Figure 7. Variation of Indicated efficiency.
3. Conclusion
The analysis of the experiment results provides the basis for drawing the following conclusions:

- The indicated efficiency at methane fuel is around 20% better than gasoline fuel because of that the combustion process when engine work with methane is more perfectly;
- Indicated specific fuel consumption marks an average decrease of approximately 33% when the engine works on methane.
- When engine work on methane, the values of IMEP are lower because of air-fuel mixtures is lean and have higher heat losses for heating a larger cyclic quantity of air.
- The higher values of indicated power are obtained at gasoline fuel, because of the indicated diagram have bigger area and the effective parameters are better.

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