A SI engine performance parameters determination for gasoline and methane operation

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Abstract. The present paper presents a study whose objective is to determine the performance parameters of an external mixture formation and spark-ignition engine when running on methane fuel. The experiments were carried out using optimum adjusting parameters for engine operation on methane and gasoline fuels. The parameters measured and determined are: brake specific fuel consumption, mean effective pressure, brake power, thermal efficiency, volumetric efficiency and etc. over the entire engine speed range. An analysis of the obtained results is made, comparing the obtained effective 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 [1-2]. One option to reduce CO₂ emissions is by using alternative fuels [3-5]. These alternative fuels for Spark-Ignition engines can be: LPG (liquid petroleum gas), CNG (compressed natural gas), different types of alcohols and biogas [6-7].

Methane alternative fuels, i.e. methane or biogas are 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 [8].

The use of biogas to fuel internal combustion engines is inappropriate due to the fact that biogas contains about 60% methane and about 35% carbon dioxide, which as a ballast gas does not participate in the combustion process but significantly reduces the calorific value of the fuel. Using biogas as fuel for engines is only feasible provided that upon obtaining it is subsequently purified to biomethane (upgraded biogas, biomethane) [9-11].

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 [12-13].

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 [14-15].
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 CO\textsubscript{2} 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 effective parameters of Spark-Ignition engine when running on methane and to compare these parameters with the parameters of an engine running on traditional fuel.

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 full throttle speed characteristics, with fuel-air ratio of \( \alpha = 0.9 \) for gasoline and \( \alpha = 1.05 \) 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 2000 min\(^{-1}\), 3000 min\(^{-1}\), 3500 min\(^{-1}\), 4500 min\(^{-1}\), and 5600 min\(^{-1}\), with 100% throttle valve opening.

The engine parameters are shown in Table 1.

| №  | Parameter                  | Value   |
|----|----------------------------|---------|
| 1  | Volume [dm\(^3\)]        | 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 \( H_u \) [kJ/ kg]          | 45 670  | 44 000       |
| Density [kg/m\(^3\)], 20°C; 760 mm Hg          | 0.748   | 720          |
| 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   |
When conducting the experiments, the following parameters were measured [2,6]: crankshaft speed, the force acting on the brake, fuel consumption, air consumption, etc. The parameters calculated are as follows:

*Brake Power*:

\[ N_e = \frac{3.14 \cdot n \cdot T}{30000} \text{ kW} \]  

(1) \n
n-cranks speed [min\(^{-1}\)], T-torque [Nm];

*Torque*:

\[ T = 0.974 \cdot 9.81 \cdot F \text{ Nm} \]  

(2) \n
F-measured brake force [kg];

*Brake specific fuel consumption*:

\[ g_e = \frac{1000 \cdot G_h}{N_e} \text{ g/kW.h} \]  

(3) \n
G\(_h\)-fuel consumption per hour [kg/h];

*Mean effective pressure*:

\[ p_e = \frac{120 \cdot N_e}{V_h \cdot n} \text{ MPa} \]  

(4) \n
V\(_h\)-displacement volume of engine [dm\(^3\)];

*Effective efficiency*:

\[ \eta_e = \frac{3.6 \cdot N_e}{G_h \cdot H_u} \]  

(5) \n
H\(_u\)-lower heating value [kJ/ kg];

*Volumetric efficiency*:

\[ \eta_v = \frac{120000 \cdot G_{air}}{\rho_{air} \cdot V_h \cdot n} \]  

(6) \n
G\(_{air}\)-air consumption per one hour [kg/s], \(\rho_{air}\)-density of air [kg/m\(^3\)];

The graphs shown in Figures 1 to 7 show the experimental results. Fig. 1 and Fig. 2 illustrate respectively the variation of Brake power and Torque over the entire engine speed range with optimum control parameters when engine is running on gasoline and methane.

![Figure 1. Variation of Brake Power.](Image)
When the engine operates on methane, the brake power varies from 13.8 kW at 1500 min\(^{-1}\) to 33.2 kW at 5600 min\(^{-1}\). With gasoline, the brake power varies from 18.5 kW at 1500 min\(^{-1}\) to 41.4 kW at 5600 min\(^{-1}\). In terms of comparison between the two types of fuel, the brake power marks an average decrease of approximately 22% when the engine works on methane. For both fuels, the maximum value of Torque is at 3000 min\(^{-1}\).

![Figure 2. Variation of Torque.](image)

Fig. 3 to Fig. 7 show the variations of brake specific fuel consumption, mean effective pressure, quantity fuel per cycle, effective efficiency and volumetric efficiency over the entire engine speed range for both fuels.

![Figure 3. Variation of Brake specific fuel consumption.](image)

When the engine runs on methane, the brake specific fuel consumption varies from 248 g/kWh at 1500 min\(^{-1}\) to 277 g/kWh at 5600 min\(^{-1}\). With gasoline, the brake specific fuel consumption varies from
318g/kWh at 1500min$^{-1}$ to 386g/kWh at 5600min$^{-1}$. The minimum values of the brake specific fuel consumption are at 2500 min$^{-1}$.

![Figure 4. Variation of Mean effective pressure.](image)

The Mean effective pressure varies from 0.87MPa at 1500min$^{-1}$ to 0.56 at 5600min$^{-1}$, when the engine works on methane and from 1.16MPa at 1500min$^{-1}$ to 0.7 at 5600min$^{-1}$, when engine operates on gasoline. The greater mean effective pressure values are recorded when the engine runs on gasoline and as a result from the more complete combustion of the fuel.

![Figure 5. Variation of Quantity fuel per cycle.](image)

The average difference of Quantity fuel per cycle for both fuels is around 41%, and the greater values are taken for gasoline operation.

Figure 6 shows the variation of Effective efficiency of the engine working on both fuels. With methane, the coefficient of effective efficiency varies from 31% at 1500min$^{-1}$ to 24% at 5600min$^{-1}$. When the engine works on gasoline, the coefficient varies from 30% at 1500min$^{-1}$ to 23% at 5600min$^{-1}$.
1. With methane, the effective fuel efficiency is higher by about 5% due to the higher calorific value of methane.

![Figure 6. Variation of Effective efficiency.](image1)

The last figure shows the variation of the engine volumetric efficiency for both fuels. With methane, the volumetric efficiency varies from 0.73 at 1500min\(^{-1}\) to 0.61 at 5600min\(^{-1}\). When the engine works on gasoline, the volumetric efficiency varies from 0.86 at 1500min\(^{-1}\) to 0.7 at 5600min\(^{-1}\). The lower values for alternative fuel are due to the fact that methane occupies a larger volume in fuel-air mixture. The lower values at high crankshaft speeds result from increased hydraulic resistances at higher crankshaft speeds.

![Figure 7. Variation of Volumetric efficiency.](image2)

The average difference of volumetric efficiency for both fuels is around 12%, the better indicators being associated with gasoline operation.
3. Conclusion
The analysis of the experiment results provides the basis for drawing the following conclusions:

- When the engine works on methane, the brake power is reduced by up to 22%.
- The mean effective pressure is improved by 22%, when the engine runs on gasoline as a result from the more complete combustion of the fuel.
- When operating on methane, the effective fuel efficiency is higher by around 5% due to the higher calorific value of methane.
- When the engine works on gasoline, the volumetric efficiency is 12% higher.
- Although the brake power is low when the engine runs on methane and the additional equipment for the methane system is heavy, the price of this fuel is lower than gasoline and the exhaust emissions are lower, which justifies and enables the use of methane as alternative SI engine fuel.

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