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# SIMPLE 1-D MODEL PERFORMANCE COMPARISON OF A SINGLE CYLINDER ICE FUELED BY GASOLINE AND METHANE[6]

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***Abstract:***

*The paper presents a simple 1-D model of a single cylinder spark-ignited aspirated ICE created by means of the software product Ricardo WaveBuild. The geometrical parameters of the model are based on the geometry of a real spark-ignited engine-generator with 196 cm$^3$ engine displacement and 3.73 kW engine nominal power at 3000 min$^{-1}$. The generator has 2 kW nominal electrical power. Moreover, the model assumptions and software settings are described. The aim of the paper is to present, analyze and compare the engine performance over the full speed range of the engine for two different fuels – gasoline and methane. The obtained results reveal higher brake torque, brake power, thermal efficiency, but also brake specific fuel consumption for the case of gasoline fuel. These results confirm the already available results from older research cited in the literary review, and they also verify the model nominal power against the one supplied by the producer of the engine. One of the final goals of our study is to use the current model for constructing an experimental test-bench. The model and the bench would be used for simulating and testing the engine with different fuels, including with anode-off gasses from a solid oxide fuel cell stack.*

***Keywords:*** *ICE, gasoline, methane, performance, 1-D, model, Ricardo WaveBuild*

## INTRODUCTION

Much of the research on contemporary internal combustion engines is focused on making them more ecological by testing and adopting alternative fuels, such as alcohol-based fuels (Iliev, 2021), hydrogen (Juknelevičius et al., 2019), methane (Aljamali et al., 2014; Dimitrov, 2022; Dimitrov et al., 2021), and others. Furthermore, there are attempts on applying an ICE in combined cogeneration plants coupled with a fuel cell stack, thus guaranteeing power generation with low environmental impact, high plant global efficiency, and good dynamic capabilities (Sapra, 2020). In cases when a solid oxide fuel cell (SOFC) stack is applied, the emitted anode-off gasses (AOG) from the stack can be further combusted in the ICE individually (bottoming cycle) or blended with additionally injected fuel (combined cycle). The AOG contains carbon oxide, carbon dioxide, water vapors, hydrogen and extremely low amounts of methane in the case when pure methane is reformed and used as fuel for the stack. When natural gas is fed to the stack, instead of pure methane, other hydrocarbons could also exist in the AOG. Due to the presence of carbon dioxide,

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which is an inert gas, and the pretense of hydrogen – a very low-density gas, the AOG are very diluted which may bring upon the need for additional fuel injection in the engine in order for it to operate well. Most commonly this additional fuel injection is of methane, so that both the engine and the stack could use the same fuel storage and delivery system.

The ICE, based on which the current model is built, is namely intended for integration in a SOFC-ICE combined cycle and thus for experimentally testing the combustion of various fuels, including gasoline, methane and the stack's AOG with and without additional fuel blending. However, an important part of a realizing such a system, is the modelling of the engine and the stack. Simulations are definitely easier and faster to accomplish than experimental tests, and they allow for the research of numerous different model layouts. Based on the results from the simulations the optimal experimental setup is determined, lowering tests' time and cost. Hence, the inspiration for this study, which examines the performance of the selected engine with two fuels – gasoline and methane. The results are used as basis for the preparation of the test bench, for the integration of the ICE in the combined cycle, and for the overall construction of the SOFC-ICE system. Additionally, the usage of methane in SI ICEs has shown lower brake effective pressure, lower brake power and lower brake torque in comparison to gasoline when applied at identical conditions. If the current model is correctly built, a similar trend would be verified in the generated results. The thermal efficiency could be either lower or higher in the case of methane, depending on the type of the fuel injection system and strategy, as well as on the intake system.

## EXPOSITION

### ICE data and model assumptions

The model consists of a single cylinder, two valves connected to it, two straight ducts connected to the valves and two ambient elements, representing the endless intake and exhaust environments - Figure 1. The necessary engine geometrical data for making the model complete and running is listed in Table 1, as already mentioned – according to a real engine from a gasoline engine-generator unit.

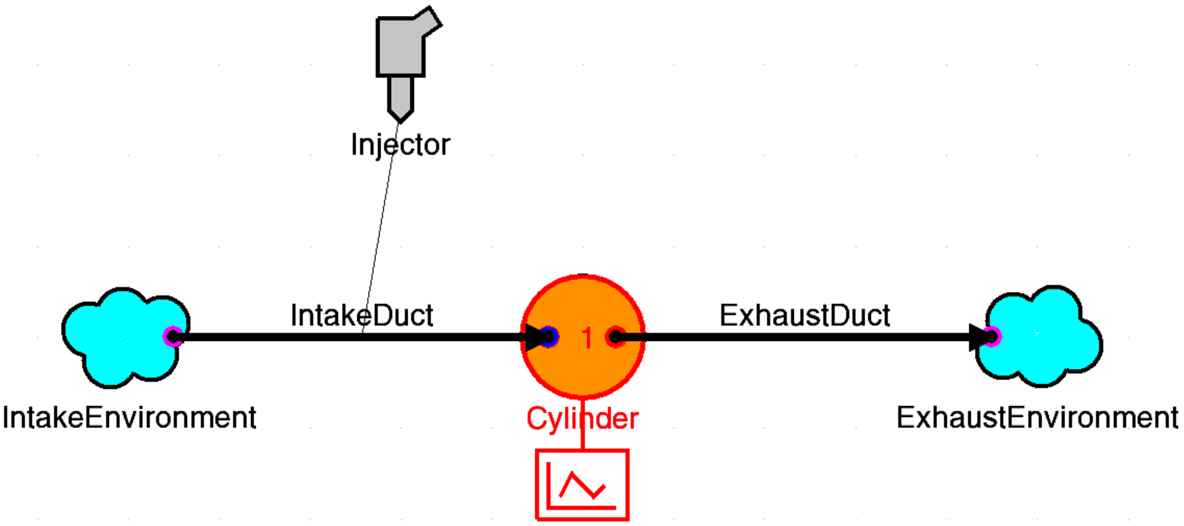


Fig. 1. Representation of the model in Ricardo WaveBuild.

The applied heat exchange strategy is based on the Woschni model, while the combustion strategy – on the SI Wiebe model - Figure 2. The lift profiles of the intake and exhaust valves are taken from the real engine and are presented in Figure 3. The used injector is from the proportional type, which injects fuel continuously into the intake duct and automatically maintains the set air/fuel ratio by adjusting the fuelling rate proportionally to the instantaneous air mass. The injector parameters are presented in Figure 4. The fuel/air ratio is set to 0.068 for gasoline and 0.059 for methane, since those are the stochiometric values. The injector is situated in the beginning of the intake duct for both cases.

Table 1. ICE geometrical data.

| Displacement, $cm^3$ | Piston bore/stroke, mm | Clearance height, mm | Compression ratio, - |
|---|---|---|---|
| 196 | 68/54 | 0.1 | 8.5 |
| **Engine type** | **Number of valves, -** | **Nominal power, kW** | **Intake/exhaust valve ref. diameter, mm** |
| Spark-ignited, aspirated | 2 | 3.73 at 3000 $min^{-1}$<br>5 hp at 3000 $min^{-1}$ | 22.6/21.5 |
| **Intake/exhaust valve lash, mm** | **Intake/exhaust duct diameter, mm** | **Intake and exhaust ducts length, mm** | **Weight, kg** |
| 0.15/0.2 | 24.5/26 | 100 | 17.5 |

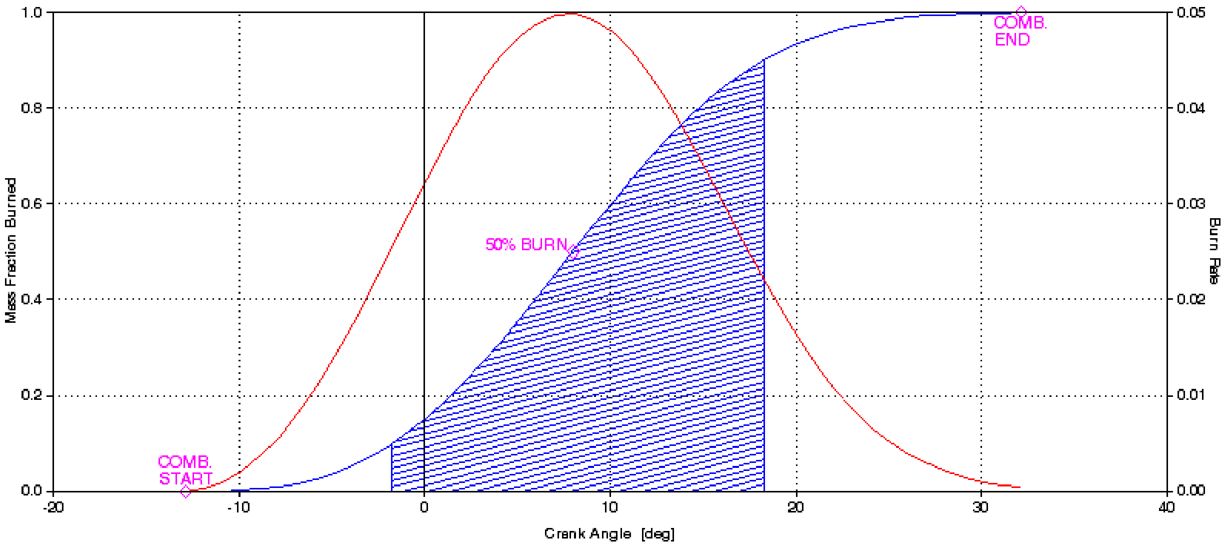


Fig. 2. SI Wiebe combustion model used in the simulation.

The parameters of the chosen gasoline and methane fuels are presented in Figure 5 and Figure 6 – they are taken from the pre-set data available in Ricardo. When simulating methane, the whole fuel amount is vaporized, thus the fuel/air mixture is set as a real gas in the program's settings, else it would not run the simulation. Thus, in order to define the model likewise with gasoline, its fuel/air mixture is also set to the setting for real gas.

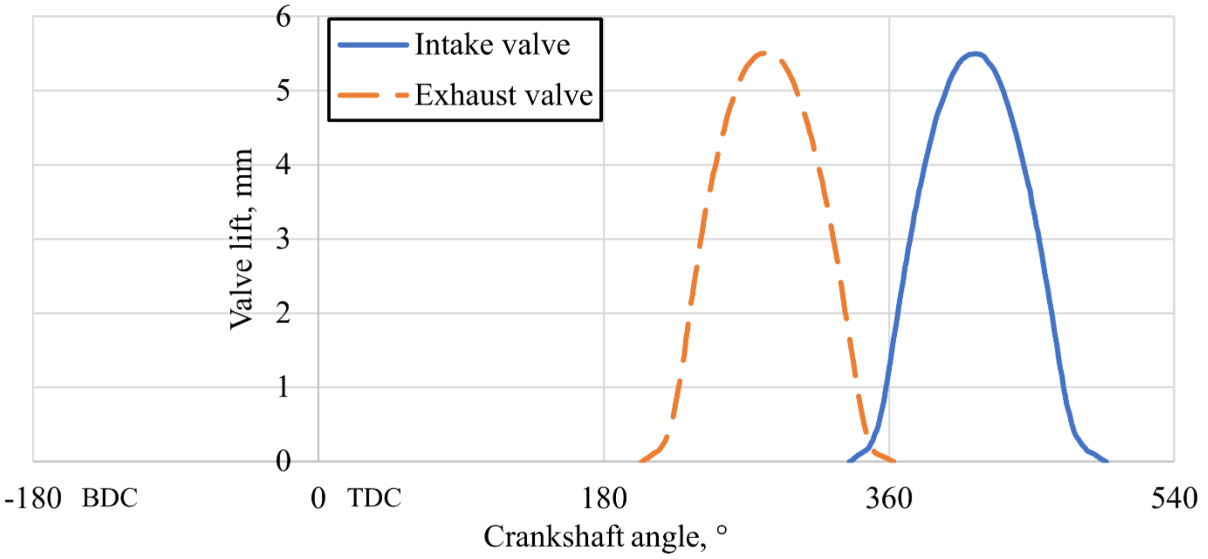
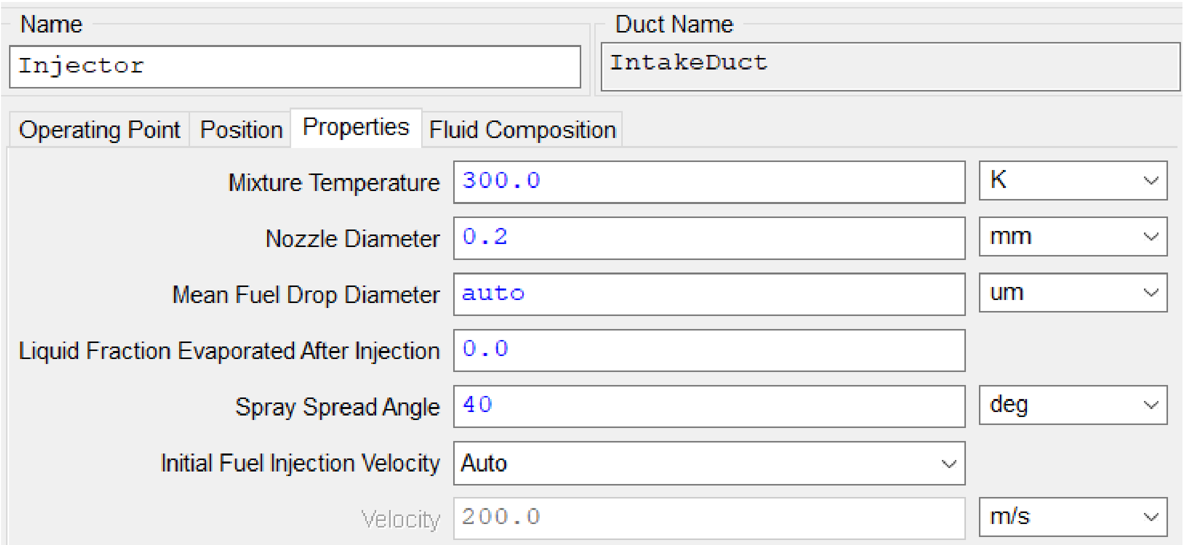
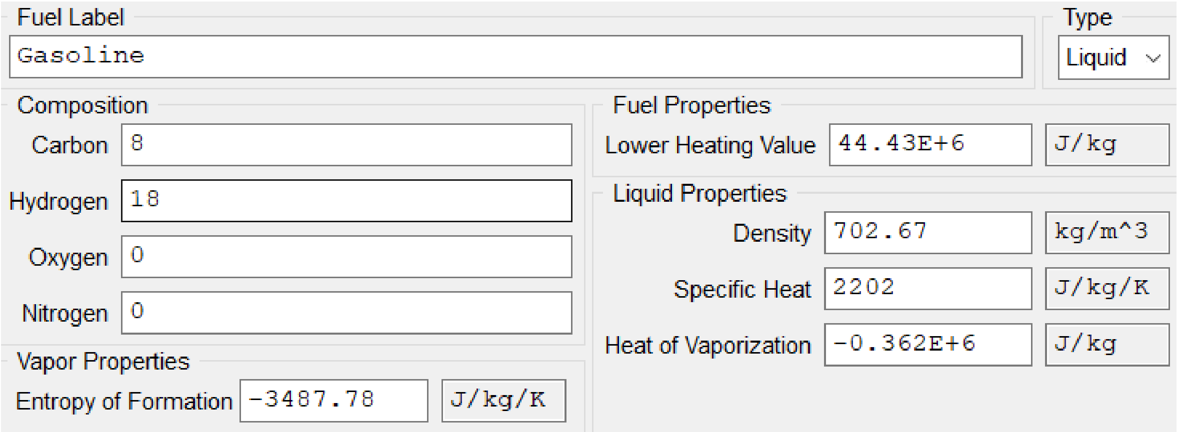


Fig. 3. Intake and exhaust valve lift profiles (BDC = bottom death center, TDC = top death center).



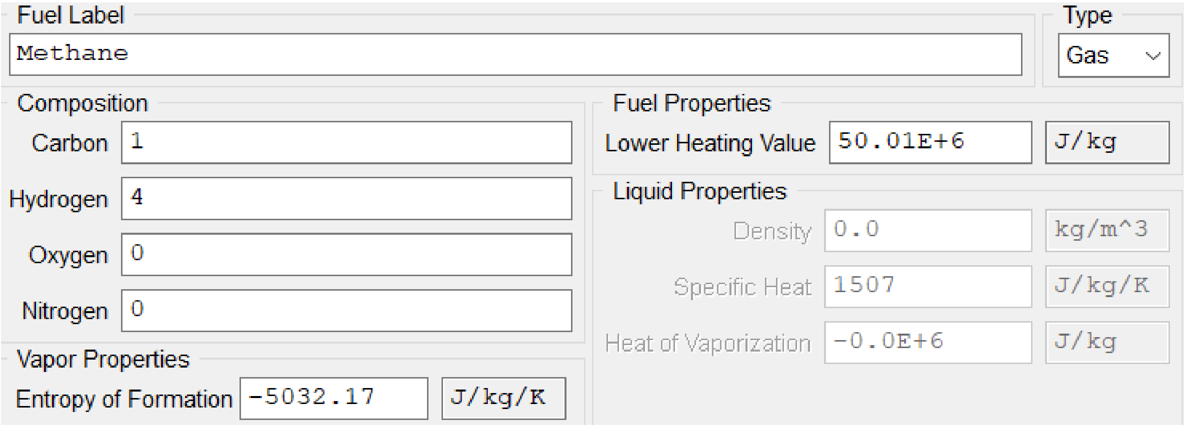
| | | |
|---|---|---|
| Name | Injector | |
| Duct Name | IntakeDuct | |
| Mixture Temperature | 300.0 | K |
| Nozzle Diameter | 0.2 | mm |
| Mean Fuel Drop Diameter | auto | um |
| Liquid Fraction Evaporated After Injection | 0.0 | |
| Spray Spread Angle | 40 | deg |
| Initial Fuel Injection Velocity | Auto | |
| Velocity | 200.0 | m/s |

Fig. 4. Injector parameters.



| | | |
|---|---|---|
| Fuel Label | Gasoline | |
| Type | Liquid | |
| **Composition** | | |
| Carbon | 8 | |
| Hydrogen | 18 | |
| Oxygen | 0 | |
| Nitrogen | 0 | |
| **Vapor Properties** | | |
| Entropy of Formation | -3487.78 | J/kg/K |
| **Fuel Properties** | | |
| Lower Heating Value | 44.43E+6 | J/kg |
| **Liquid Properties** | | |
| Density | 702.67 | kg/m^3 |
| Specific Heat | 2202 | J/kg/K |
| Heat of Vaporization | -0.362E+6 | J/kg |

Fig. 5. Gasoline fuel properties.



Fuel Label: Methane

Type: Gas

Composition

Carbon: 1

Hydrogen: 4

Oxygen: 0

Nitrogen: 0

Vapor Properties

Entropy of Formation: -5032.17 J/kg/K

Fuel Properties

Lower Heating Value: 50.01E+6 J/kg

Liquid Properties

Density: 0.0 kg/m^3

Specific Heat: 1507 J/kg/K

Heat of Vaporization: -0.0E+6 J/kg

Fig. 6. Methane fuel properties.

**Results and comparison**

The displacement of air by methane in the intake system leads to a lower amount of air mass flowing to the engine over the whole speed range in the case of methane fuel – Figure 7. This hence leads to a lower volumetric efficiency - Figure 8. The lower air mass flow also results in less injected fuel than the standard case (supposing that in the standard case the air mass flow is the same for both gasoline and methane), as the injector doses it proportionally on the flow in order to maintain constant fuel/air ratio.

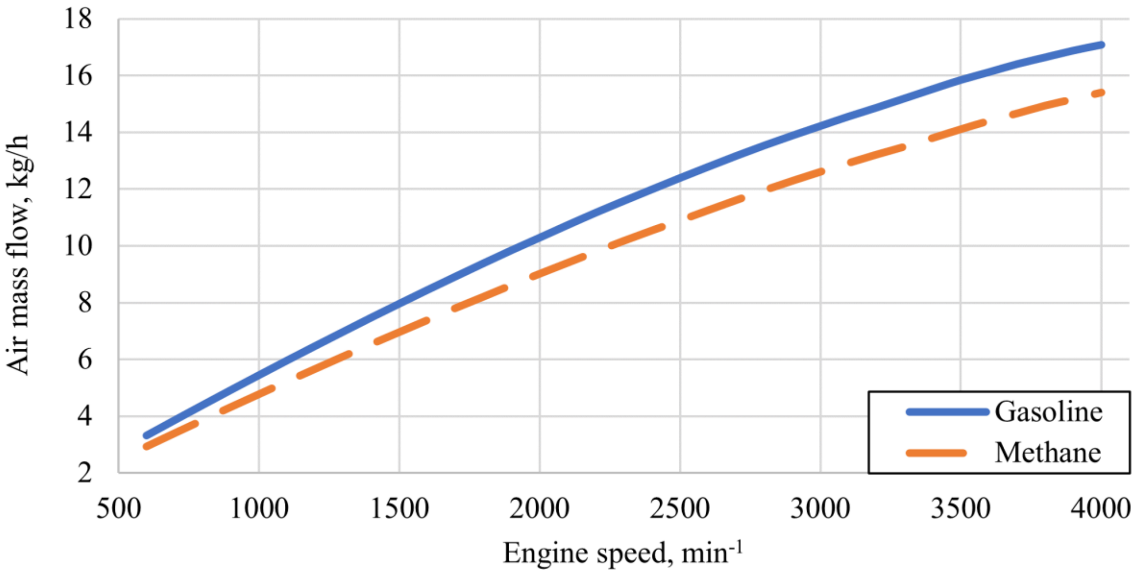


Fig. 7. Air mass flow vs engine speed.

The air mass flow at nominal speed is 14.23 kg/h for gasoline and 12.62 kg/h for methane.

The volumetric efficiency at nominal engine speed of 3000 min$^{-1}$ is 69.22% for gasoline and 61.38% for methane.

The indicator diagram at 3000 min$^{-1}$ of the engine with both fuels is presented in Figure 9. It is visible from it that the in-cylinder pressure with methane is lower which is namely due to the lower volumetric efficiency.

The highest in-cylinder pressure for the gasoline case is 47.93 bar at 15.18 ° crankshaft angle, while in the case of methane fuel – 43.72 bar at 14.21 ° crankshaft angle.

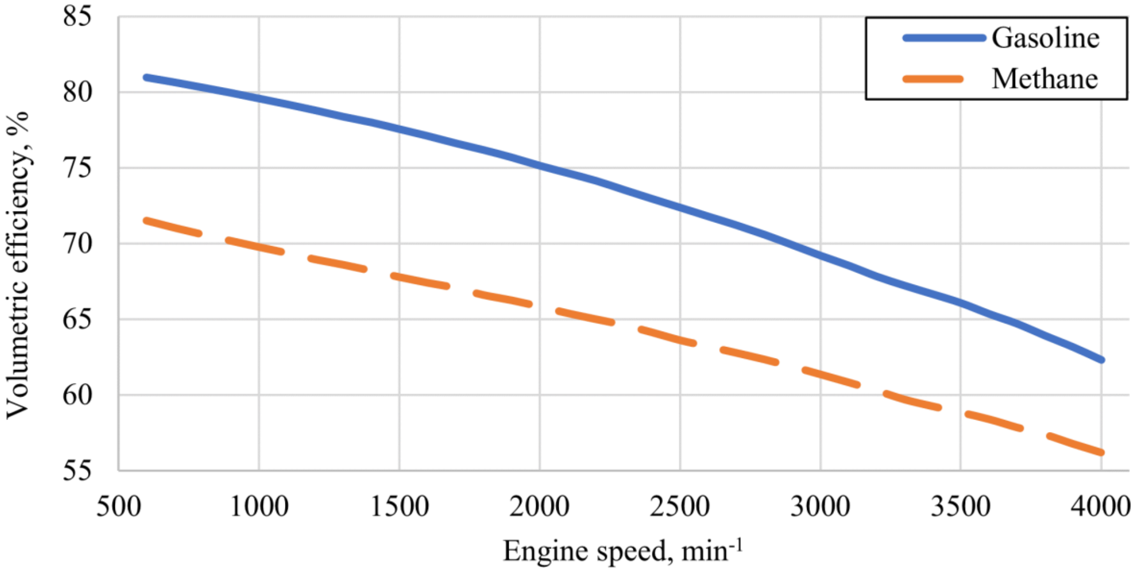


Fig. 8. Volumetric efficiency vs engine speed.

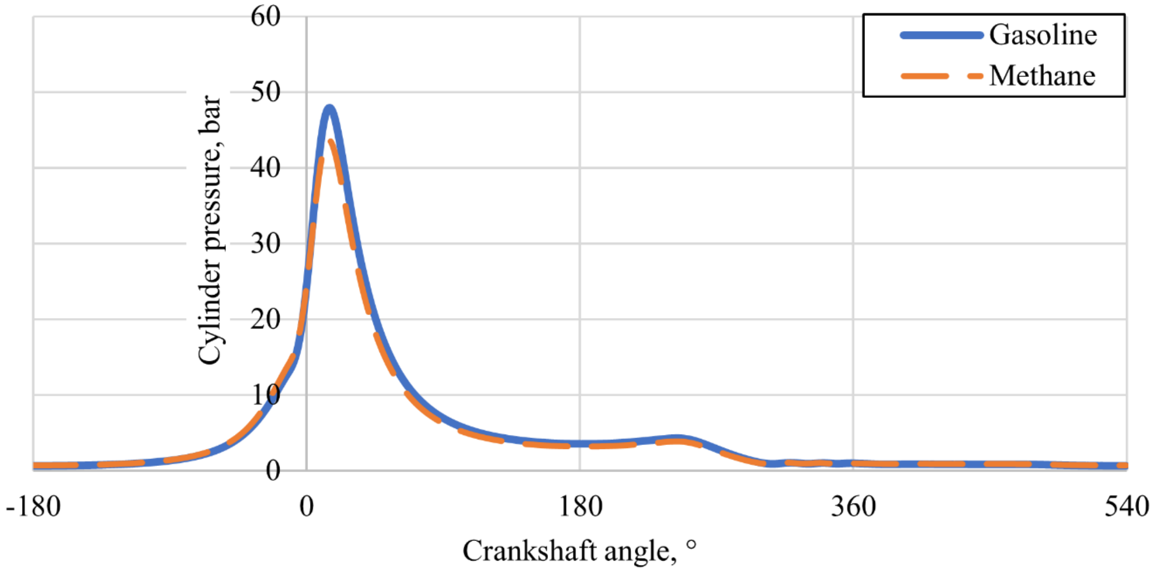


Fig. 9. Indicator diagram of the engine at nominal speed (3000 $\text{min}^{-1}$).

The lower in-cylinder pressure and lower volumetric efficiency lead to worse performance in regards to brake torque – Figure 10, brake power – Figure 11, and brake thermal efficiency – Figure 12, of methane compared to gasoline.

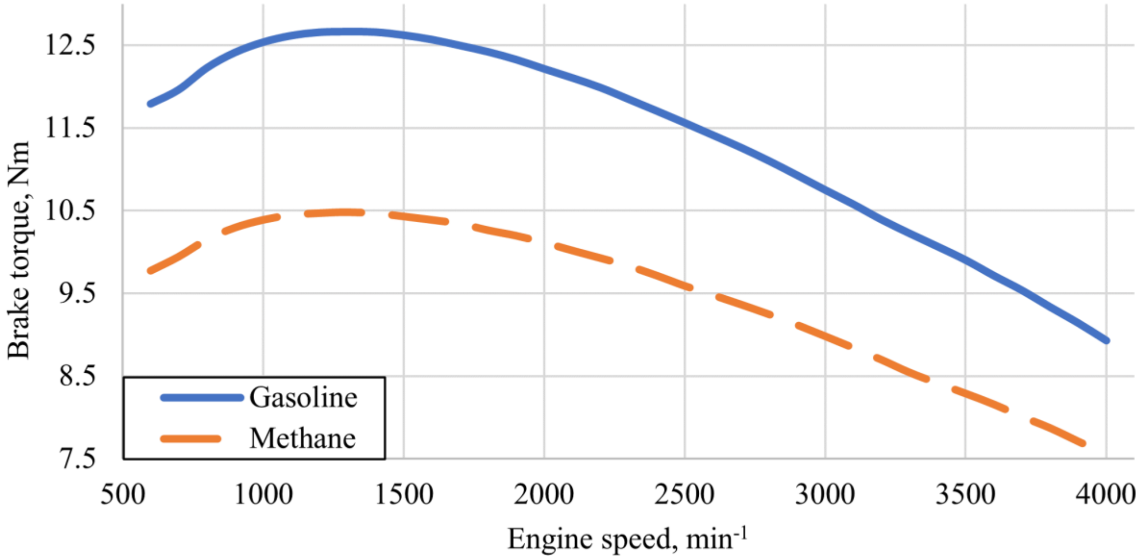


Fig. 10. Brake torque vs engine speed.

The highest brake torque values are achieved for both cases at 1300 min$^{-1}$ – 12.67 Nm for gasoline and 10.44 Nm for methane. At the nominal speed of 3000 min$^{-1}$ the values are 10.75 Nm and 8.98 Nm for gasoline and methane respectively.

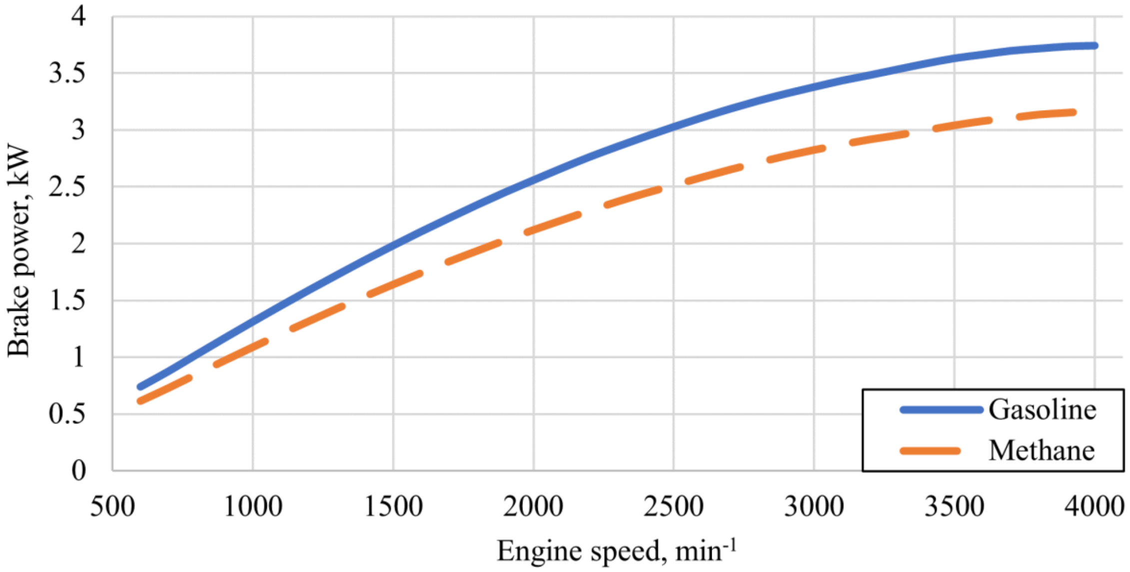


Fig. 11. Brake power vs engine speed.

According to the producer’s specification of the engine the maximum engine speed is 3500 min$^{-1}$. The results show 3.38 kW and 2.82 kW for the gasoline and methane case respectively at nominal speed, and 3.63 kW for gasoline and 3.04 kW for methane at maximum speed. The value for gasoline at nominal speed is very close to the value given by the producer – 3.73 kW, which verifies the accuracy of the model.

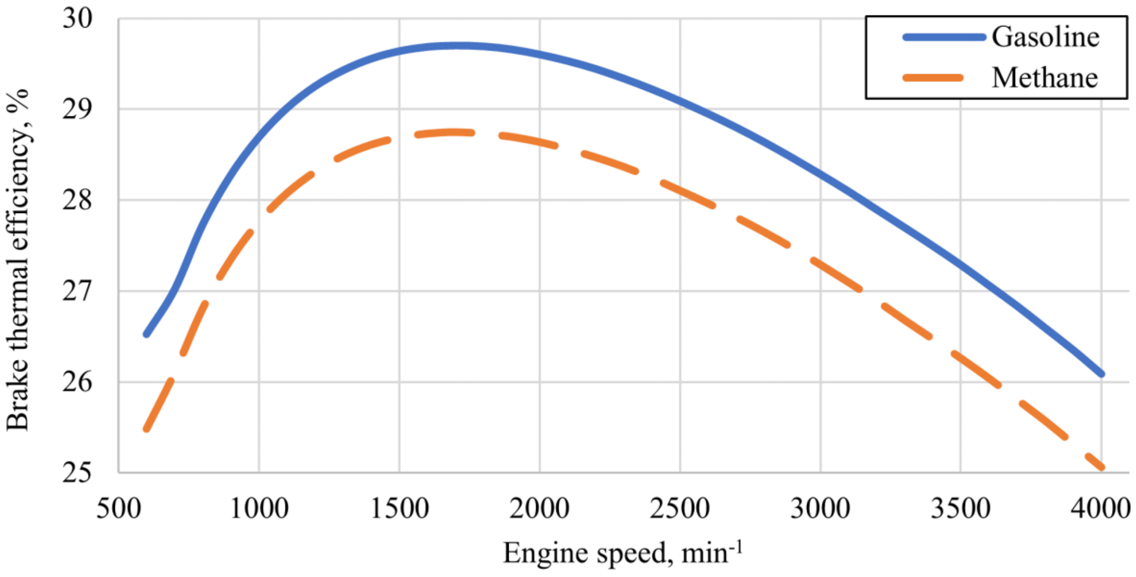


Fig. 12. Brake thermal efficiency vs engine speed.

The maximum brake thermal efficiency is achieved at 1700 min$^{-1}$ and is 29.7% for gasoline and 28.75% for methane. In the current case, the efficiency for methane fuel is lower over the whole engine speed range due to the lower volumetric efficiency. At nominal speed the values are 28.28% and 27.29% for gasoline and methane respectively.

Nonetheless, there are lower values for the brake specific fuel consumption (BSFC) in the case of methane – Figure 13. BSFC is measured by dividing a constant to the lower heating value of the fuel and to the brake thermal efficiency of the engine. Given the lower heating values for the fuel mixtures are different, the BSFC is definitely different compared to the thermal efficiency, as it is the case – methane has a higher calorific value than gasoline. If the two fuel mixtures have the same calorific values, BSFC would be higher for the engine with lower efficiency.

As BSFC is lower for methane, the harmful emissions of the engine would also be lower at the expense of power. The exact estimation of those emissions is going to be the aim of a future study. The obtained results from the model verify the already announced results from the short literary review and also verify that the accuracy of the model results comes close to the specification of the real engine given by the producer.

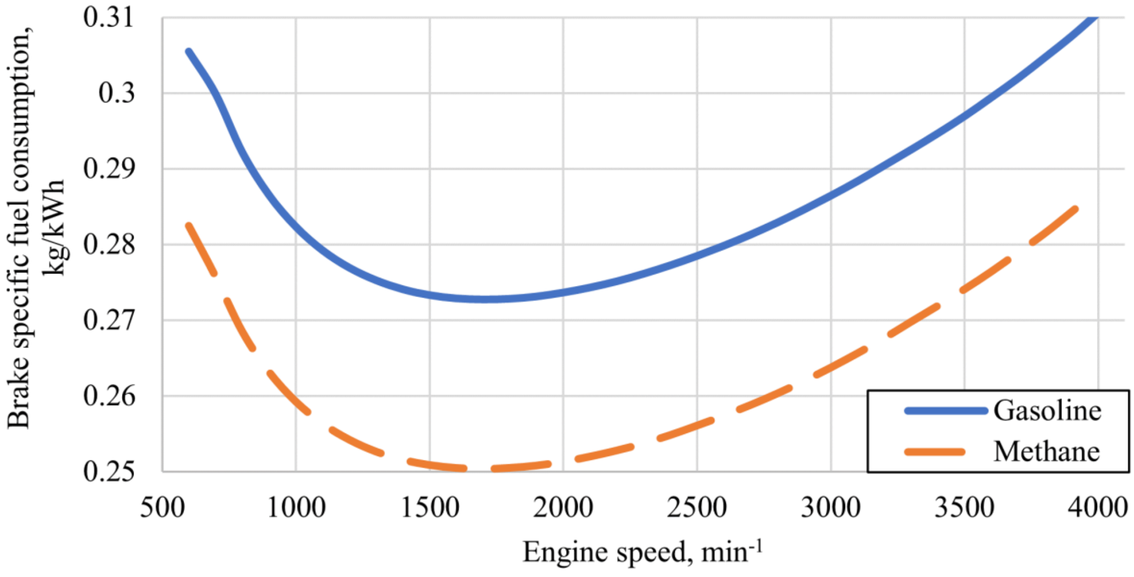


Fig. 13. Brake specific fuel consumption vs engine speed.

The lowest fuel consumption coincides with the highest efficiency, which is at 1700 min$^{-1}$. The obtained results show 0.2728 kg/kWh and 0.25014 kg/kWh for gasoline and methane correspondingly. At nominal speed the values are 0.2865 kg/kWh for gasoline and 0.2638 kg/kWh for methane.

## CONCLUSION

The obtained results from the model based on a real SI aspirated engine with 196 cm$^3$ volume from an engine-generator confirm with close accuracy the given information by the producer – 3.38 kW power at nominal speed, while 3.73 kW announced in the engine's specification. When comparing the engine performance with two different fuels – gasoline and methane, the results show higher in-cylinder pressure, higher brake torque, higher brake power, and higher thermal efficiency in the case of gasoline, which is due to the higher air mass flow and thus higher volumetric efficiency of the engine when running on gasoline. The future research would be focused on building an experimental setup based on the current model and on performing experiments with different fuels, including anode-off gasses from a solid oxide fuel cell stack. The results from the current model will be compared against the experimental ones.

## ACKNOWLEDGEMENTS

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