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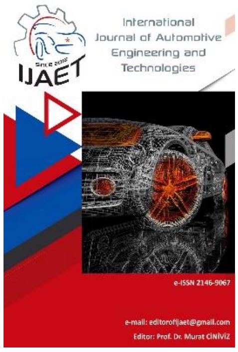

Original Research Article

Examining the effect of adding natural gas to an engine using a gasoline-methanol mixture as fuel on engine performance and emissions

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ABSTRACT

The power produced by the combustion of fossil fuels in internal combustion engines is transferred to the powertrain, and this generated power causes carbon dioxide (CO_2) and particulate matter emissions. Systems that do not cause CO_2 and other harmful emissions or cause less emissions are a strong alternative. In this context, methanol and natural gas are added to the engine to reduce emissions. In this study, engine performance and emissions were examined using three fuel mixtures. A two-cylinder gasoline engine was run using M20 fuel and natural gas was added at different rates from the engine manifold. The engine was operated at a constant 3000 rpm and using 6 different fuels (gasoline, M20, M20+50 g natural gas, M20+100 g natural gas, M20+150 g natural gas, M20+200 g natural gas), at different torque values (5, 10, 15 and 20 Nm) engine performance and emission values were compared. When fuel consumption is compared to gasoline fuel, the overall cycle average is 6% higher in M20, 3% higher in M20+50 and M20+100, 1% higher in M20+150 and 6% higher in M20+200, and emissions are reduced compared to gasoline in other fuels.

Keywords: Gasoline, methanol, natural gas, emission, engine performance.

1. Introduction

Fuel cell vehicles [1] or battery-using vehicles [2, 3, 4] are attracting increasing attention, considering the carbon dioxide (CO_2) and particulate matter emissions produced in the transfer of power produced as a result of the combustion of fossil fuels to the powertrain. Fuel cells are a potentially powerful technology because they do not cause CO_2 and other harmful emissions [5]. Similarly, these zero-emission systems have been widely used in urban vehicle applications [6, 7]. However, the use of internal combustion engine technology for heavy-duty vehicles with high levels of power requirements and long-distance transportation is likely to continue for many years [8]. Among these internal combustion engines (diesel, gasoline, natural gas and alcohol engines), natural gas spark ignition (SI) engines have been more widely used, especially in heavy-duty vehicle applications [9].

In natural gas SI engines, two combustion modes are used for combustion technology: stoichiometric and lean-burn combustion [10]. Extremely low emissions can be achieved in stoichiometric combustion through simple three-way catalyst equipment. Lean-burn combustion can achieve higher thermal efficiency but must be equipped with a high-cost after-treatment to meet the EURO VI emission regulation [11]. Due to increasingly stringent emission regulations, most natural gas SI engines operate in stoichiometric mode rather than lean-burn combustion mode but have low thermal efficiency and need precise air-fuel ratio control strategies [12]. Methane, the main component of natural gas, has a low laminar flame speed, resulting in incomplete combustion and high emissions of unburned hydrocarbons [13, 14].

Using natural gas together with liquid fuels with high flame spread rates may be a promising approach to improve the combustion characteristics of a natural gas SI engine. Methanol is considered the best alternative fuel for IC engines due to its following advantages. First, methanol is a renewable fuel that can be synthesized from hydrogen and CO_2 captured from the atmosphere [15]. Second, the laminar flame speed of methanol is higher than all other hydrocarbon fuels [16]. Third, methanol has high latent heat evaporation. Therefore, volumetric efficiency can be significantly increased when methanol is injected into the intake manifold [17]. Fourth, the oxygen content of methanol is almost 50% by mass. Therefore, methanol as an additive can lead to complete combustion [18]. There are many studies in literature regarding the advantages of methanol and natural gas.

Akbıyık et al. [19] investigated the effect of boron addition to lubricating oil on engine performance and emissions when gasoline and natural gas were used as fuel in a spark ignition engine. Experimental results showed that the use of boron-added lubricating oil caused an average reduction of 2.4-8% in specific fuel consumption when gasoline and natural gas were used as fuel in the engine. They found that the use of boron in lubricating oil did not cause a significant change in CO_2, CO and HC emissions, but caused a significant decrease in NO_X emissions by 11.4-12.9%.

Verhelst et al [20] made a systematic investigation of methanol as a fuel in internal combustion engines. Improved thermal efficiency can be achieved when methanol is used as pure fuel or blend component for IC engines. This is due to the advantages of methanol, such as high latent heat evaporation, fast combustion rate, and no carbon-carbon bond, which leads to increased compression ratio and shrinkage.

Akbıyık et al. [21] tested four different torque values (5, 10, 15, 20 Nm) at a constant 3000 rpm using four different fuels (gasoline, gasoline + 50 g natural gas, M20 and M20 + 50 g natural gas). In the tests, they stated that the lowest specific fuel consumption and the best emissions were achieved with gasoline + 50 g natural gas fuel, and that the first and second law efficiencies of all fuel types increased with the increase in torque values in the energy and exergy analysis. They found that the combination of 50 g of natural gas fuel and gasoline gave the best results.

Chen et al. [22, 23, 24] They reviewed innovative research on natural gas/methanol dual fuel engines. They stated that the combustion of methanol and natural gas can be controlled in a complementary strategy and thus, the combustion rate of natural gas can be significantly increased by the introduction of methanol, resulting in better thermal efficiency and reduced hydrocarbon emissions. Akbıyık et al. [25] investigated the effects of using CNG (natural gas) and gasoline in spark ignition engines on engine emissions, performance and lubricating oil by adding boron additive to engine oil. As test results, they found that engine performance decreased over time from the moment the engine oil was first added, but when boron-added oil was used in the engine, the decrease in engine performance was less than when boron-free engine oil was used. They reported that the use of boron additive in lubricating oil not only reduces NO_X emissions but also causes the properties of the lubricating oil to change less as the engine temperature decreases.

Dumanlı et al. [26] experimentally examined 4 different torque values (5, 10, 15, 20 Nm) in the engine with different volumetric ratios of methanol and gasoline fuel mixtures (M10, M20, M30, M40) at a constant 3000 engine speed. As a result of the study, engine performance, emission and energy analysis were carried out.

Akbıyık and et al. [27] in an experimental study, found that adding natural gas at different rates (50, 100, 150 and 200 g/hour) to the intake air at a constant 3000 rpm affected the engine performance and emissions at different torque values (5, 10, 15 and 20 Nm) examined its effect. As a result of the experiment, it was determined that adding natural gas to gasoline reduces fuel consumption, emissions decrease as the torque value increases, and thermal efficiency increases as the natural gas addition rate increases.

Singh et al. [28] The combustion and emissions of SI engines operating in dual fuel mode with natural gas/gasoline have been examined experimentally. They found that gasoline engine knocking performance at medium and high engine loads could be eliminated by the use of natural gas. Pan et al. [29] They examined the combustion characteristics of a methane enriched gasoline engine. They found that adding methane to gasoline accelerates the combustion process in the initial stage under conditions of low compression ratios, lean combustion and fuel stratification.

Yin et al. [30] Dual direct coding technology is a very promising method to determine the mixture organization and combustion process of dual-fuel engines. In this way, the performance of a modified dual-fuel turbine operating on methanol and diesel fuel was investigated separately at various methanol energy replacement amounts and diesel replacement timings. Independent coupling in methanol and diesel, staying real-time and accurate thanks to the dual-direct coupling system with two different in-cylinder injectors according to engine operating performance. The results show that dual-direct cooling technology has great potential for extending the turbine operating range with the specified thermal heat exchange and exhaust emissions. Simio et al. [31] In this study, the engine running on compressed natural gas was fed with various percentages of natural gas and hydrogen mixtures and tested under different conditions. A detailed combustion and emission analysis was performed. The response of the engine management system to different fuels was evaluated when rapid speed and torque changes occurred.

As mentioned above, adding alternative fuel by operating in dual-fuel, dual-injection mode is an effective approach to increase thermal efficiency and reduce emissions. For a spark ignition engine there is a lot of work in dual fuel combustion mode. Both natural gas and methanol can be added to a gasoline engine when operated in dual-fuel combustion mode. However, the impact of gasoline, methanol and natural gas in triple fuel mode on the engine performance and emissions of SI engines is still unknown. For this reason, there is no information in the literature comparing the combustion performance and emissions of mixed fuel engines running on gasoline, methanol and natural gas. In this study, the effects of using three fuel mixtures in SI engines on engine performance and emissions were examined. This study provides useful information in combustion optimization to increase the thermal efficiency of engines and reduce exhaust emissions.

2. Material and Method

2.1. The experimental setup

In the experimental setup, Lombardini LGW 523 MPI 2-cylinder gasoline engine, Net Brake 80 electric dynamometer, Federal exhaust emission device, computer, liquid fuel flowmeter and mass flowmeter for gaseous fuels were used. The shape of the experimental setup is given in Figure 1. The engine used in the experiments is a Lombardini LGW 523 MPI 2-cylinder, water-cooled, injection engine. The technical specifications of the engine are given in table 1. The dynamometer used in the experiments has the capacity to measure 83 Nm torque and 70 kW power. Federal emission devices were used to determine emissions. For liquid fuels, it is determined by weight with the help of a load cell. Alicat mass flowmeter was used for gaseous fuels. The properties of the fuels used in the experiments are given in Table 2. The content of natural gas used in the experiments is given in table 3. Specifications and error range of the equipment and sensors are given in Table 4.

2.2. Test method

In this study, 6 different fuels were used and compared at 3000 rpm and tested at different torque values. 6 different fuels (gasoline, M20, M20+50 Natural Gas, M20+100 Natural Gas, M20+150 Natural Gas, M20+200 Natural Gas) were used in the experiment. M20 fuel is a volumetric mixture of 20% methanol and 80% gasoline. 50, 100, 150 and 200 g of natural gas per hour were added to this fuel from the engine's intake manifold. The amount of natural gas was determined by an Alicat mass flow meter. Using these fuels, power, fuel consumption and emission values were compared at 4 different torque values (5, 10, 15 and 20 Nm) at a constant engine speed of 3000 rpm.

Table1.Lombardini LGW 523 engine features [21]

Engine Type	Unit	Result
Number of cylinders	pcs.	2
Diameter of the cylinder	mm	72
Stroke	mm	62
Cylinder volume	cc	505
Stroke ratio		10.7:1
Revolution maximum	rpm	5500
Maximum of the power (5000 rpm)	kW/HP	15/20.4
Maximum of the torque (2150 rpm)	Nm	34
Engine curb weight	kg	52

Figure 1. Schematic view of the experimental setup

Table 2. Fuel Properties of the gasoline, methane and methanol [23]

Fuel properties	Gasoline	Methane	Methanol
Density [kg/m^3]	720–775	0.67	792
Adiabatic flame temperature [K]	2030	2320	1878
Lower heating value [MJ/kg]	42-44	50	20.1
Flame speed [m/s]	0.57	0.37	0.52
Stoichiometric air fuel ratio	14.6	17.24	6.45
Auto-ignition temperature [ºC]	440	600	470
Flammability limits [vol.%]	1.4-7.6	5.3-14	6-37
Octane no RON	95	130	110
Octane no MON	85	105	87

Table 3. Natural gas component [23]

Chemical component	Chemical Formula	Rate (%)
Methane	CH_4	90.8
Ethane	C_2H_6	3.6
Propane	C_2H_8	1.1
Butane	C_4H_{10}	0.4
Pentane	C_5H_{12}	0.1
Nitrogen	N_2	3.5
Carbon Dioxide	CO_2	0.4

Table 4. Specifications and error range of the experimental equipment and sensors.

Instrument	Values	Accuracies
Liquid flow meter	0.001–5 kg	±0.001%
Gas flow meter (Alicat)	1–1000 SLPM	±0.4%
Electric Dynamometer (Netfren)	70 kW/8000 rpm	±1 rpm
Exhaust gas analyzer (Federal)		
CO	0–10% Vol	0.001% vol
CO_2	0–18% Vol	0.010% vol
O_2	0–22% Vol	0.010% vol
NO_x	0–5000ppm	1.0ppm
HC	0–9999ppm	1.0ppm
Lambda	0.5–9.999	0.001

3. Results and Discussion

One of the most important parameters in determining engine performance is power. In engines, power varies according to torque and speed. Since speed and torque are constant in the experiments, the power values are the same, but there are small differences, and this is due to the limits allowed in the experiments. The power change depending on torque is given in Figure 2.

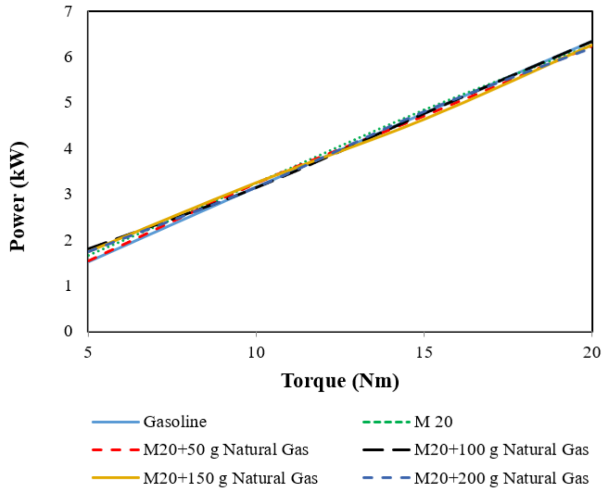

Figure 2. Power change due to torque

Figure 3 shows the change in different torque values of 6 different fuels at 3000 rpm. BSFC shows the amount of fuel consumed per unit power. Compared to gasoline, alcohol fuels have lower calorific values and higher stoichiometric A/F ratios, causing more fuel to be used for the same output power. For this reason, in the use of alcohol fuels, the BSFC is slightly higher than in gasoline [32-35]. The addition of natural gas reduced the specific fuel consumption value. As the torque value increased, the specific fuel consumption value decreased. The reduction rate between 5 and 20 Nm torque values is 55% for gasoline fuel, 52% for M20 fuel, 54% for M20+50 g natural gas fuel, 48% for M20+100 g natural gas fuel, 51% for M20+150 g natural gas fuel and 51% for M20+200 g natural gas fuel. There has been a 55% reduction in natural gas fuel consumption.

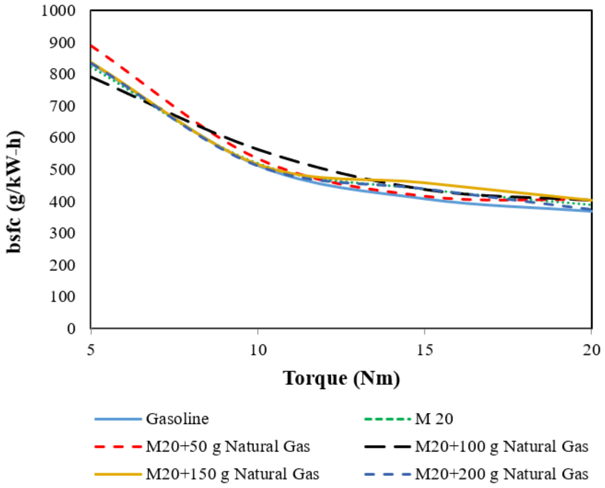

Figure 3. Specific fuel consumption change depending on torque

Fuel consumption curves are given in Figure 4. Adding methanol to gasoline increased fuel consumption. Fuel consumption decreased by adding natural gas. The lowest fuel consumption was obtained with gasoline + 200 g/h natural gas fuel, and the highest fuel consumption was obtained with M20 fuel. Fuel consumption values increased with increasing torque amounts.

When Figure 5 is examined, it is seen that CO decreases with increasing torque values. As the torque value increases and the air velocity entering the cylinders increases, turbulence in the combustion chamber increases, resulting in a more homogeneous mixture. Since this will improve the combustion of fuel, there will be a decrease in CO at high speeds. The lowest CO emission values were obtained for gasoline + 100 g natural gas and gasoline + 150 g natural gas fuels. As can be seen from the graph, the addition of methanol increased CO emissions at 5 and 10 Nm torque values and has the lowest values at other torque values. In addition to natural gas, the lowest values were obtained at 100 and 150 g additions. At high torque values, combustion improves, and CO emissions decrease with increasing pressure and temperature.

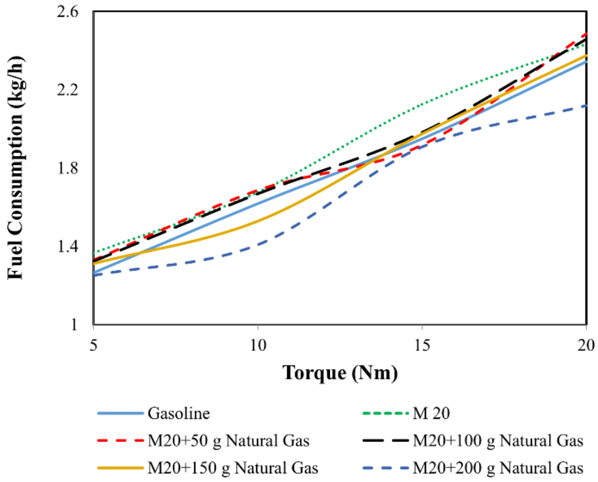

Figure 4. Fuel consumption changes depending on torque

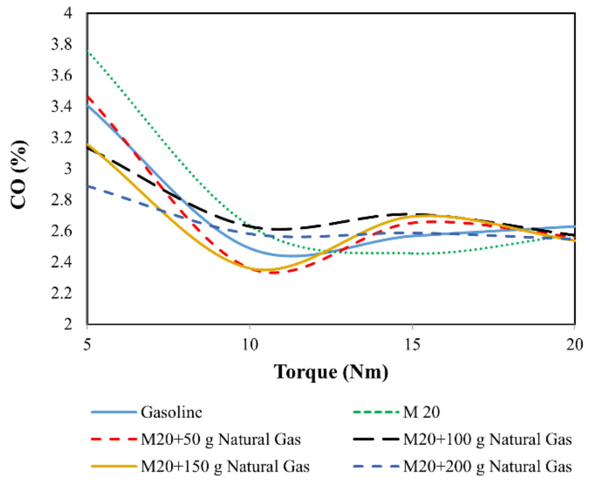

Figure 5. CO change due to torque

Figure 6 shows the measured HC emissions of the study. Hydrocarbon emissions are caused by fuel expelled from the exhaust without being burned. When Figure 6 is examined, HC emissions are less in methanol mixtures. HC emissions decrease as the natural gas addition rate increases. Since methanol's lower calorific value and stoichiometric A/F ratio are much lower than gasoline, HC emissions decrease [35]. In addition, with increasing torque values, it increases up to 15 Nm torque and then decreases slightly.

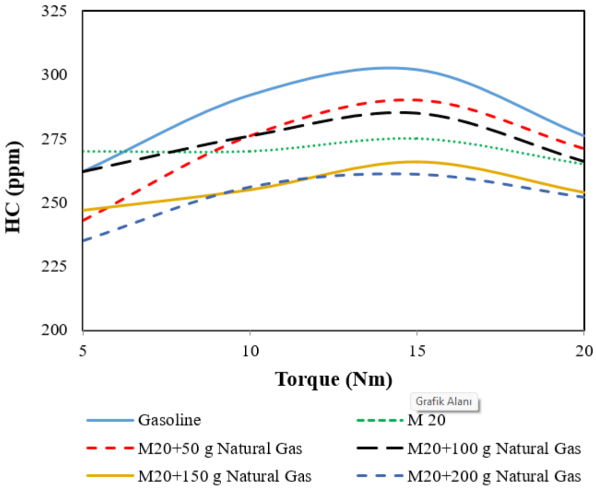

Figure 6. HC change due to torque

Figure 7 shows the CO_2 emission changes for fuels with different torque values. CO_2 is a gas that causes global warming. Fuels with fewer or no carbon atoms are preferred in terms of CO_2 emissions. When the graph in Figure 7 is examined, there is a decrease in CO_2 emissions in the methanol mixture. As the proportion of natural gas in the fuel mixture increases, CO_2 emission values decrease. As the torque value increases, CO_2 emissions increase. The reason for the decrease in CO_2 emissions with methanol is the low C/H ratio of methanol and the fact that the C atom in its structure is less than that of gasoline.

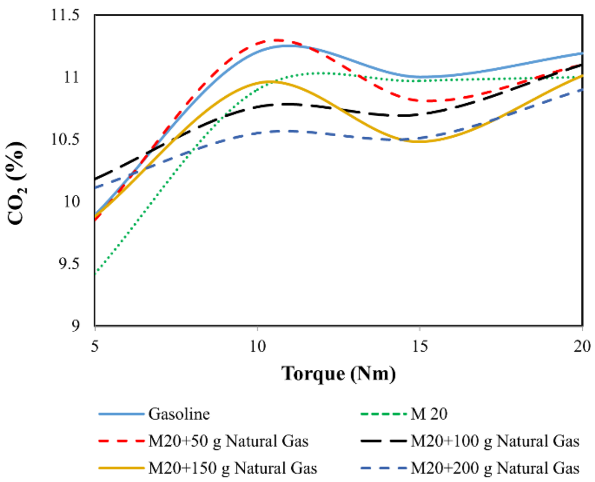

Figure 7. CO_2 change due to torque

NO_X emission changes for each fuel at different torque values are given in Figure 8. When the graph in Figure 8 is examined, it is seen that NO_X emissions are lower in methanol operation than in gasoline, and emissions decrease with the addition of natural gas. In each fuel type, NO_X emissions increase with increasing engine load. At maximum torque, the most filling is taken into the cylinder and temperatures increase. High temperatures cause NO_X emissions to increase. The reason why NO_X emissions are low in studies involving methanol and natural gas additions is that methanol has a high evaporation temperature and natural gas is given in gaseous form, thus cooling the mixture and ultimately reducing the cycle temperature.

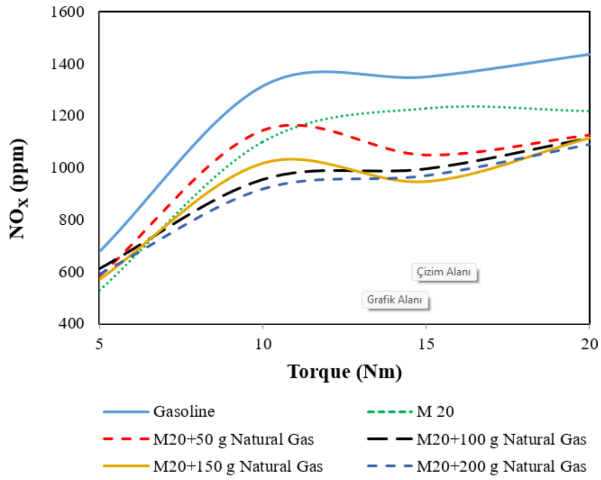

Figure 8. NO_X change depending on torque

4. Conclusion and Recommendations

In a study conducted by adding both natural gas and methanol to a spark-ignition gasoline engine, its effect on engine performance and emissions was examined. In this study, power, fuel consumption and emissions (CO, CO_2, HC and NO_X) were examined, and 6 fuels were compared. In the results obtained.

- There was no change in power.
- The addition of methanol increased the BSFC, and the addition of natural gas decreased the BSFC. As the torque value increased, the BSFC value decreased.
- Addition of methanol increased the amount of fuel consumption, and addition of natural gas decreased the amount of fuel consumption. As the torque value increased, the amount of fuel consumption increased.
- The emission values of fuels with added methanol and natural gas gave better results when compared to gasoline fuel.

Abbreviations

SI : Spark Ignition
CO : Carbon monoxide
CO_2 : Carbon dioxide
HC : Hydrocarbon
NO_X : Nitrogen Oxides
IC : Internal Combustion

BSFC : Brake Specific Fuel Consumption
RON : Research Octane Number
MON : Motor Octane Number

CRediT authorship contribution statement

Talip Akbıyık: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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