Experimental Study of CH_4/H_2 Mixtures in Internal Combustion Engines

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ABSTRACT

In this study, an experimental study on the performance of a spark ignition engine fuelled with CH_4/ H_2 mixtures (90% CH_4 + 10% H_2 and 80% CH_4 + 20% H_2) was performed at different engine speed and different injection timing coefficient (ITC). This present work was carried out on a Lombardini engine. This is a four-stroke cycle two-cylinder spark ignition engine with a bore × stroke of 72x62 mm and a compression ratio of 10.7:1. Experiments were made as 1200, 1600, 2000, 2400, 2800, 3200 and 3600 rpm and 100, 140, 160, 200 and 240 injection timing coefficients. In experiments, performance and emission parameters are investigated. For 90%CH4+10%H2 and 80% CH_4+20% H_2, maximum brake thermal efficiency values are obtained 160 and 200 ITC at 2600 rpm, respectively. Minimum specific fuel consumption values are obtained 160 injection timing cefficient at the each mixture.

Keywords: Hydrogen, Methane, Engine, Emissions, Injection timing coefficient

1 INTRODUCTION

Wallace and Cattelan [1], experimentally studied natural gas and hydrogen mixtures in a combustion engine. Experiments were conducted on studying emissions out of an engine fuelled with a mixture of natural gas and approximately 15% hydrogen by volume. In their study, BSFC of 85/15 CNG/H_2 mixture is less than that of natural gas. BSFC values reduce for both natural gas and 85/15 CNG/H_2 mixture while BTDC values increase. Karim et al.[2], conducted an experiment with 100/0,90/10, 80/20,…,30/70, 20/80 CH_4/H_2 proportions by varying equivalence ratios. Bauer and Forest [3], reported a test conducted on a single cylinder cooperative fuel research engine operating on mixtures of hydrogen in methane of 0%, 20%, 40% and 60% by volume. Each fuel was tested at the speeds of 700 and 900 rpm, full and part loads, and equivalence ratios from stoichiometric to the partial burn limit. Wang et al.[4], investigated the combustion behavior of a direct injection engine operating on various fractions of NG–hydrogen blends. Shrestha and Karim [5], investigated hydrogen as an additive to methane for spark ignition engine applications. The performance of a gas fuelled spark ignition engine is enhanced when relatively small amounts of hydrogen are present with methane. Akansu et al. [6,7], Çeper et al. [8, 9] and Kahraman et al. [10], examined the burning of methane-hydrogen mixtures in internal combustion engines. They stated that methane-hydrogen mixtures helped decreasing exhaust emissions, such as HC, CO, CO_2, and the engine efficiency could be increased under certain conditions. Sierens and Rosseel [11] investigated 100/0, 90/10 and 80/20 CNG/H_2 percentage mixtures. They examined AV 8 crusader T7400 spark engine at 3800 rpm (CR 8.5:1).

This paper focuses on the effect of hydrogen addition on methane engine's performance and emission at various engine speed and injection timing coefficients. Tests were conducted on a two cylinder spark ignition engine using variable composition hydrogen-NG mixtures at full load.

2 NATURAL GAS AND HYDROGEN SPECIFICATIONS

Natural gas (methane) has a lower flame speed while hydrogen has a flame speed about eight times higher than that (Table 1). Therefore, when the excess air ratio is much higher than unity, the combustion of methane is not as stable as with Hythane. As a consequence of the addition of hydrogen to natural gas, a better combustion is achieved even in a wide range of operating conditions (excess air ratio (EAR), compression ratio, etc.), exposing itself with a higher efficiency and lower CO_2 and other emissions. The volumetric heating value of natural gas–hydrogen mixtures will decrease with the increase in hydrogen fraction in fuel blends, and this is due to the lower volumetric heating value of hydrogen–air mixtures compared to that of natural gas–air mixtures.

Fuel properties	N.Gas	H_2
Density at 1 atm and 300 K (kg/m^3)	0.754	0.082
Stoichiometric air-to-fuel ratio (% by volume)	9.396	2.387
Stoichiometric air-to-fuel ratio (% by weight)	0.062	0.029
Laminar flame speed (m/s)	0.38	2.9
Quenching distance (mm)	1.9	0.6
Mass lower heating value (MJ/kg)	43.726	119.7
Volumetric heating value (MJ/m^3)	32.97	10.22
Octane number	120	
C/H ratio	0.2514	0

Table 1: Natural gas and Hydrogen properties

3 EXPERIMENTAL APPARATUS AND TEST PROCEDURE

The present study was conducted on a Lombardini engine. The engine is a four-stroke cycle two-cylinder spark ignition engine with a bore × stroke of 72x62 mm and a compression ratio of 10.7:1(Figure 1). Baturalp Tayland brand hydrokinetic dynamometer was used for the tests. The schematic view of the test equipments is shown in Figure 2.

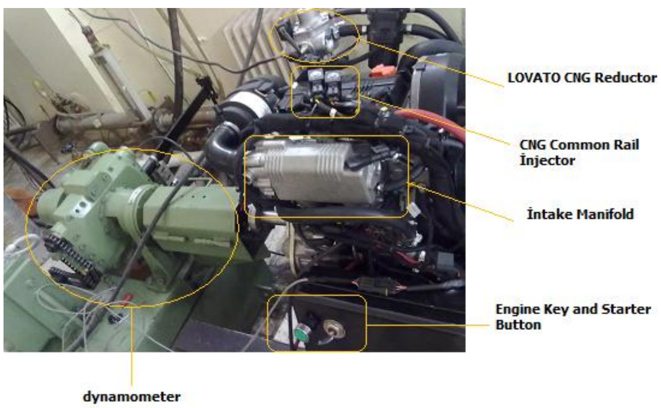


Figure 1: Lombardini engine on the brench

4 EXPERIMENTAL RESULTS

All work was conducted in the Engine Laboratory in the department of Mechanical Engineering at the University of Erciyes. A Sun MGA 1500 gas analyzer was used to measure CO, NO, CO_2, HC and λ values.

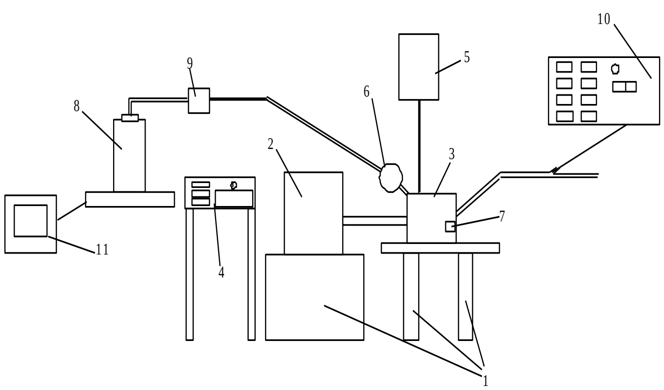
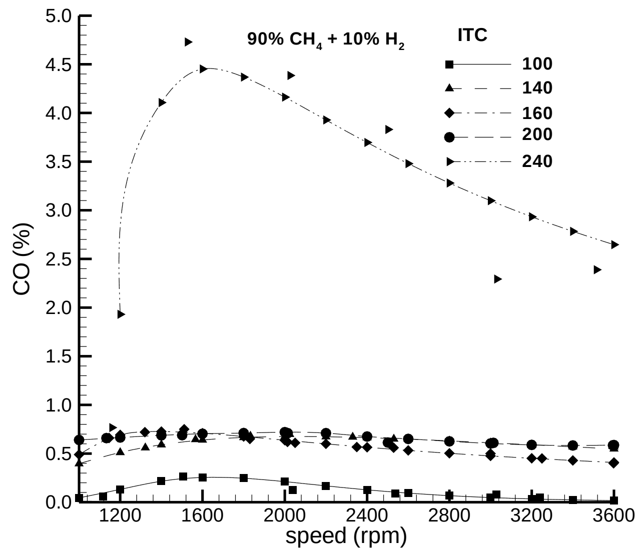


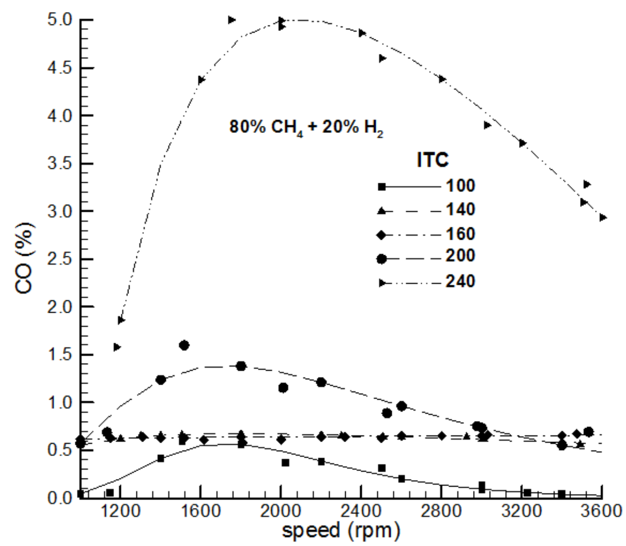
Figure 2: Experimental rig
1- Engine Test Chassis 2- Hydrokinetic Dynamometer 3- Engine 4- Control Unit 5- Main Fuel Tank 6-Regulator 7- Fuel Select Key 8- Gas Fuel Tank 9- Mass Flow Meter 10- Exhaust Gas Analyzer 11- Digital Balance

4.1 Emission Parameters

Figure 3 shows CO emissions versus the engine speed for 90% CH_4 + 10% H_2 and 80% CH_4 + 20% H_2 at different injection timing coefficients. The lowest CO emission values are obtained at 100 ITC and the highest values are obtained 240 injection timing coefficient. At the other ITC values, CO emissions values are close each other. With the increase of engine speed CO emission values are generally decreasing.



(a) 90 % CH_4 + 10 % H_2

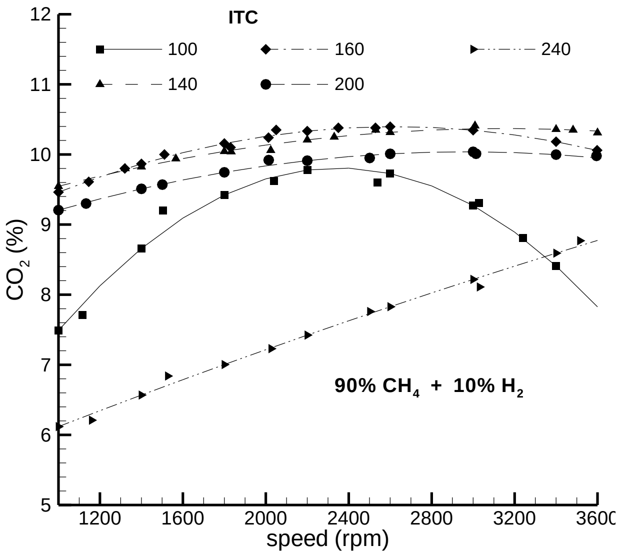


(b) 80 % CH_4 + 20 % H_2

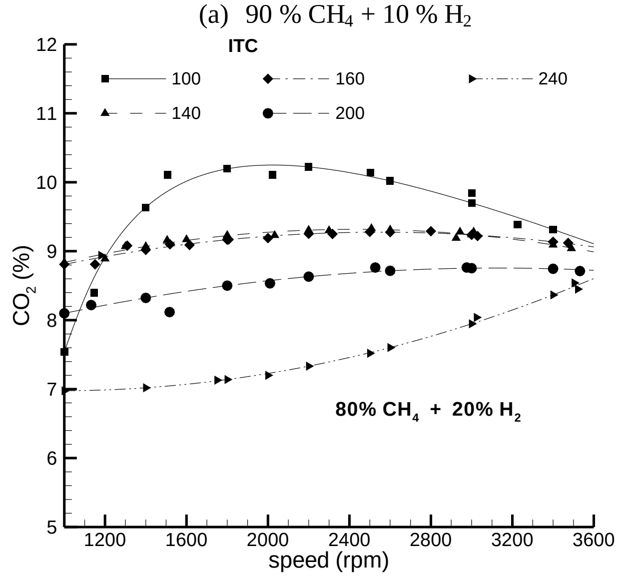
Figure 3: CO emission values versus the speed for different ITC and mixture.

Figure 4 shows CO_2 emissions versus the engine speed for 90% CH_4 + 10% H_2 and 80% CH_4 + 20% H_2 at different injection timing coefficients. For 90% CH_4 + 10% H_2, the lowest CO_2 values are obtained 240 ITC at 1200 rpm and the highest values are obtained 160 ITC at 2400 rpm. For

80% CH_4 + 20% H_2, the highest CO_2 values are obtained at 100 ITC and the lowest CO_2 values are obtained 240 ITC same with for 90% CH_4 + 10% H_2.



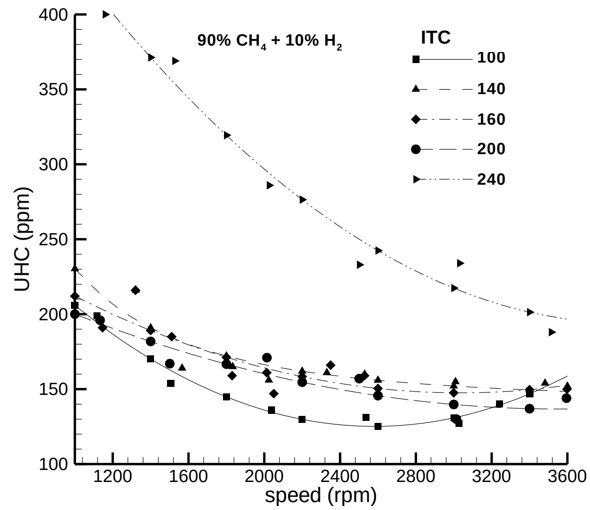
(a) 90 % CH_4 + 10 % H_2



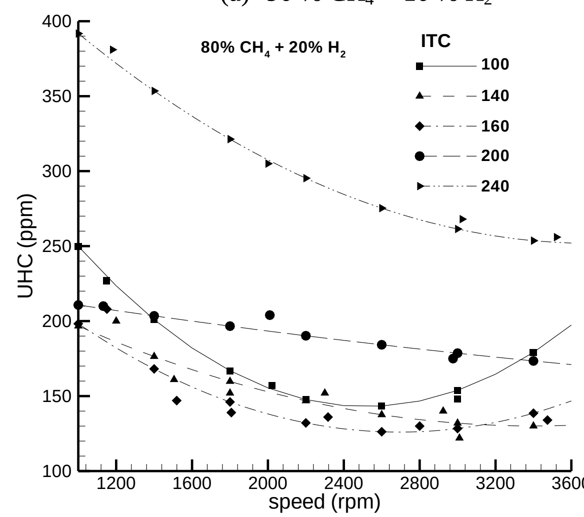
(b) 80 % CH_4 + 20 % H_2

Figure 4: CO_2 emission values versus the speed for different ITC and mixture.

Figure 5 shows HC emissions versus the engine speed for 90% CH_4 + 10% H_2 and 80% CH_4 + 20% H_2 at different injection timing coefficient. For 90% CH_4 + 10% H_2, the lowest UHC values are obtained 100 ITC at 2400 rpm and the highest value are obtained 240 ITC at 1200 rpm. For 80% CH_4 + 20% H_2, the highest UHC values are obtained same with for 90% CH_4 + 10% H_2 but the lowest UHC values are obtained 160 ITC at 2600 rpm.



(a) 90 % CH_4 + 10 % H_2



(b) 80 % CH_4 + 20 % H_2

Figure 5. HC emission values versus the speed for different ITC and mixture.

NO emission values are obtained high values from 5000 rpm so it didn't show figures. It is shown that as table for ITC and engine speed.

90% CH_4 +10 % H_2		80% CH_4 +20 % H_2	
Injection Timing Coefficient 160			
Speed	NO	Speed	NO
1320	3281	1519	4720
1511	3980	1615	4868
1830	4240	1807	5000
2013	5000	2000	5000
2050	5000	2317	5000
2350	5000	2500	5000
2529	5000	3029	5000
3598	5000	3474	5000

Table 2: NO emission for 90% CH_4 +10 % H_2 and 80 % CH_4 + 20 % H_2 at ITC 160, respectively.

$90\% CH_4 +10\% H_2$		$80\% CH_4 +20\% H_2$	
Injection Timing Coefficient 140			
Speed	NO	Speed	NO
1566	3280	1505	4612
1833	3620	1600	4413
2024	3780	1800	4693
2330	5000	2033	4990
2530	5000	2300	5000
3009	5000	2508	5000
3600	5000	3010	5000
3482	5000	3490	5000

Table 3: NO emission for 90% CH_4 +10 % H_2 and 80 % CH_4 + 20 % H_2 at injection timing coefficient 140, respectively.

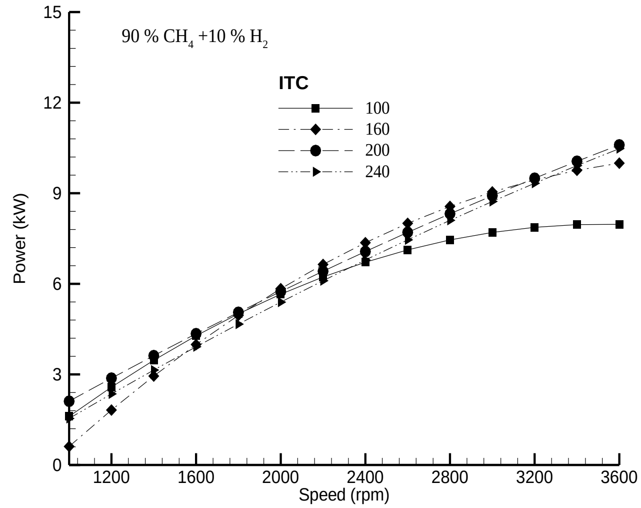
$90\% CH_4 +10\% H_2$		$80\% CH_4 +20\% H_2$	
ITC	NO	ITC	NO
120	1352	120	1520
140	1335	140	1805
160	1358	160	1860
180	1412	180	2050
200	1430	200	2028
220	1409	220	1951
240	1480	240	1730
255	1362	255	1228

Table 4: NO emission for 90% CH_4 +10 % H_2 and 80 % CH_4 + 20 % H_2 at 1500 rpm and different injection timing coefficient.

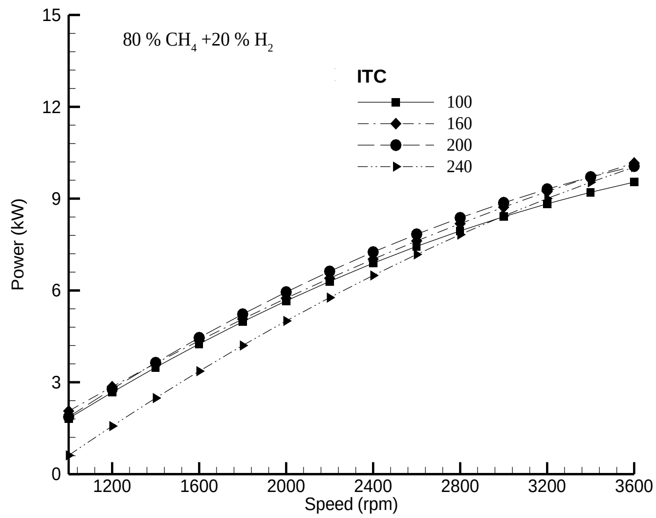
4.2 Performance Parameters

Figure 6 shows engine power versus the engine speed for different ITC and mixtures. Engine power is increasing with the increasing engine speed at all ITC for both of mixtures. Maximum powers are obtained at 160 ITC for two mixtures.

Torque values are illustrated with engine speed for different injection timings and mixture in figure 7. In this figures, maximum torque values are obtained at 160 ITC for two mixtures. These values are reading 2400 rpm and 2600 rpm for 90% CH_4+10% H_2 and 80% CH_4+20% H_2 respectively. With the increasing engine speed, torque values are increasing the decreasing.



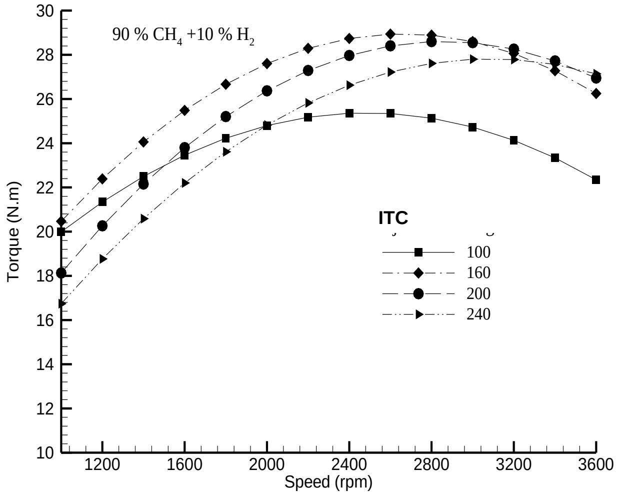
(a) 90 % CH_4 + 10 % H_2



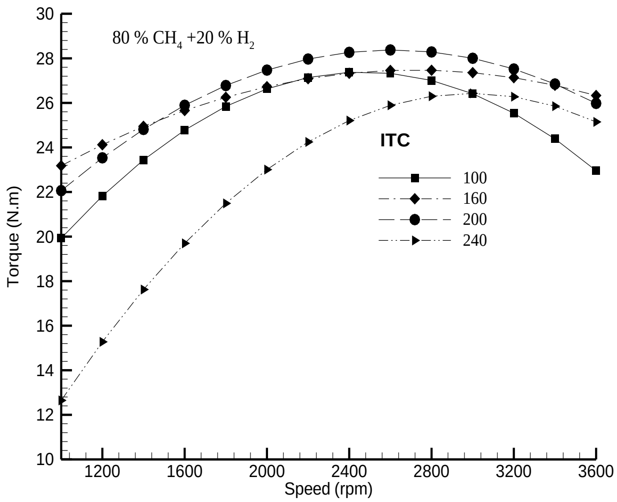
(b) 80 % CH_4 + 20 % H_2

Figure 6: Power values versus the speed for different ITC and mixture.

Figure 8 shows brake thermal efficiency values versus the speed for mixtures and different injection timing coefficient. Both of these figures are illustrated same curve, first increase then decrease. Maximum brake thermal efficiency values are obtained 160 ITC at 2400 rpm and 200 ITC at 2600 rpm for 90% CH_4 + 10% H_2 and 80% CH_4 + 20% H_2 respectively. With the engine speed brake thermal efficiency values are decreased.

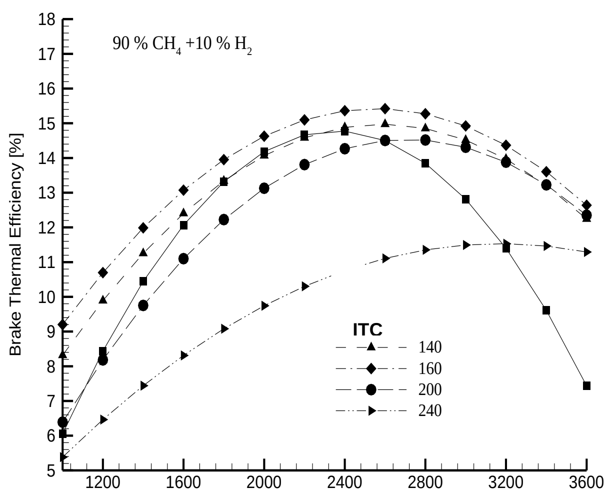


(a) 90 % CH_4 + 10 % H_2

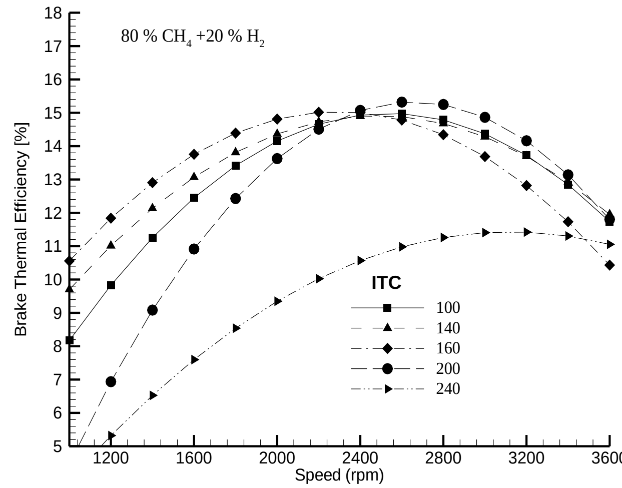


(b) 80 % CH_4 + 20 % H_2

Figure 7: Torque values versus the speed for different ITC and mixture.

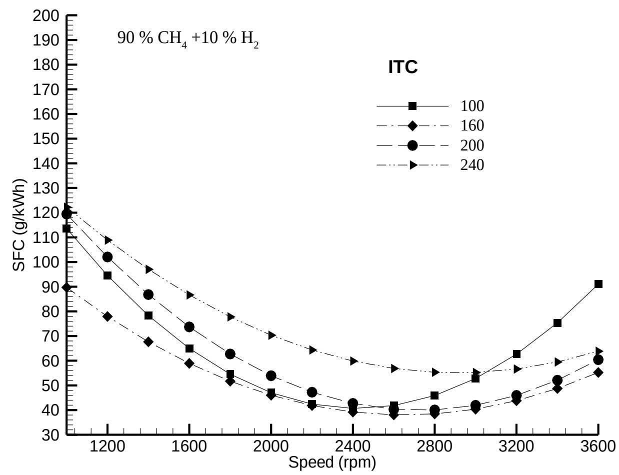


(a) 90 % CH_4 + 10 % H_2

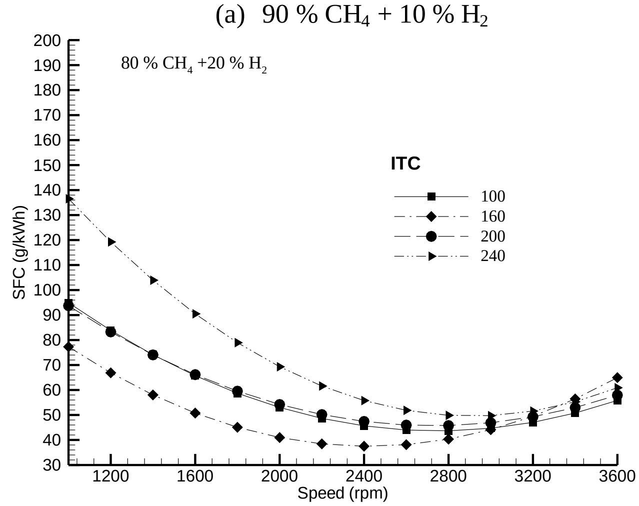


(b) 80 % CH_4 + 20 % H_2

Figure 8: Brake thermal efficiency values versus the speed for different ITC and mixture.



(a) 90 % CH_4 + 10 % H_2



(b) 80 % CH_4 + 20 % H_2

Figure 9: Specific fuel consumption values versus the speed for different ITC and mixture

Figure 9 shows specific fuel consumption (SFC) values versus the speed for mixtures and different injection timing coefficient. Two of these figures are illustrated same curve, first decrease then increase. Minimum SFC values are obtained 160 ITC at nearly 2600 rpm and 2400 rpm for 90% CH_4 + 10% H_2 and 80% CH_4 + 20% H_2 respectively. With the engine speed SFC values are increased.

5 CONCLUSION

An experimental study on performance and emission of a spark ignition engine operating on CH_4 with 10% and 20% (in volume) hydrogen enrichment was conducted. The main results are summarized as follows.

1- The maximum efficency, torque and power values were obtained 160 and 200 ITC at 90/10 and 80/20 CH_4/H_2 mixtures, respectively.
2- The minumum SFC values were obtained 160 ITC each fuel mixtures.
3- The lowest of UHC emissions were seen 100 and 160 ITC at 90/10 and 20/80 CH_4/H_2, respectively.
4- The lowest of CO emissions were seen 100 ITC at each fuel mixtures.

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REFERENCES

[1] Wallace J.S., Cattelan A.I., Hythane and CNG fuelled engine exhaust emission comparison. Proceedings 10th World Hydrogen Energy Conference, Cocoa Beach, USA, June 20–24, 1994:1761–70.
[2] Karim G.A., Wierzba I, Al-Lousi Y., Methane–hydrogen mixtures as fuels. Int J Hydrogen Energy, 20, 1996:625–31.
[3] Bauer C.G., Forest T.W., Effect of hydrogen addition on the performance of methane-fueled vehicles. Part I: effect on S.I. engine performance. Int J Hydrogen Energy, 26, 2001: 55–70.
[4] Wang J, Huang Z., Fang Y., Liu B., Zeng K., Miao H., Jiang D., Combustion behaviors of a direct injection engine operating on various fractions of natural gas–hydrogen blends. Int J Hydrogen Energy, 32(15), 2007:3555–64.
[5] Shrestha S.O., Karim G.A., Hydrogen as an additive to methane for spark ignition engine applications, Int. J Hydrogen Energy 24, 1999:577-586.
[6] Akansu S.O, Dulger Z, Kahraman N. and Veziroglu T.N., Internal combustion engines fueled by natural gas–hydrogen mixtures, *Int J Hydrogen Energy* 29 (2004), pp. 1527–1539
[7] Akansu SO, Kahraman N, Ceper B. Experimental study on a spark ignition engine fuelled by methane–hydrogen mixtures. Int. J. Hydrogen Energy 2007;32:4279–84
[8] Ceper B, Akansu SO, Kahraman N. Investigation of cylinder pressure for H_2/CH_4 mixtures at different loads. Int. J. Hydrogen Energy 2009;34:4855–61.
[9] Ceper BA, Birsen EB, Akansu SO, Kahraman N., Experimental Study Of Hydrogen In Internal Combustion Engines, Clean Technology Conference and Expo 2009, May 03-07, 2009 Houston, TX
[10] Kahraman N, Ceper B, Akansu SO, Aydın K. Investigation of combustion characteristics and emissions in a spark-ignition engine fuelled with natural gas hydrogen blends. Int. J. Hydrogen Energy 2009;34:1026–34.
[11] Sierens R. and Rosseel E., Variable composition hydrogen/natural gas mixtures for increased engine efficiency and decreased