ENGINE PERFORMANCE AND ANALYSIS OF H_2/NH_3 (70/30), H_2 AND GASOLINE FUELS IN AN SI ENGINE

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Abstract

In this paper is presented a comparison between hydrogen-ammonia (70/30 H_2/NH_3), hydrogen (100%) and gasoline fuels in internal combustion engine. Performance and emission parameters have been experimentally analyzed for different engine speed and ignition timings. Tests have carried out on Lombardini engine which is four stroke cycle, two cylinder spark ignition engine with a bore × stroke of 72x62 mm and a compression ratio of 10.7:1. Emission values (CO, HC and NO) and performance values (SFC, torque, power) have been investigated. An advantage of ammonia and hydrogen is that they do not contain carbon, eliminating emissions of carbon oxides from the engine.

Keywords: SI engine, H_2/NH_3 mixture, H_2, gasoline, emissions,

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1. Introduction

Internal combustion engines continue to dominate in many fields like transportation, agriculture and power generation. Ammonia can be regarded as a hydrogen carrier and used as a fuel, and its combustion does not produce carbon dioxide.

Zamfirescu, and Dincer[1] were analyzed based on some performance indicators including the system effectiveness, the driving range, fuel tank compactness and the cost of driving. The cooling effect of ammonia was another advantage and was included in the efficiency calculations. Cooling with ammonia represents up to 20% from the engine's power, being thus a valuable side benefit of ammonia's presence on-board allowing for downsizing of the engine cooling system and obtaining some air conditioning. If the cooling effect is taken into consideration, the system's effectiveness can be improved by ~11%. Morch et al.[2] were analyzed a fuel system for ammonia fuelled internal combustion engines using metal ammine complexes as ammonia storage. The use of ammonia/hydrogen mixtures as an SI-engine fuel was investigated in the same context. Ammonia and hydrogen were introduced into the intake manifold of a CFR-engine. Series of experiments with varying excess air ratio and different ammonia to hydrogen ratios was conducted. This showed that a fuel mixture with 10 vol.% hydrogen performs best with respect to efficiency and power. A comparison with gasoline was made, which showed efficiencies and power increased due to the possibility of a higher compression ratio. The system analysis showed that it is possible to cover a major part of the necessary heat using the exhaust heat. It is proposed to reduce the high NOx emissions using SCR as exhaust after treatment. Reiter and Kong [3] experimentally investigated combustion and emission of compression-ignition engine using dual ammnonia-diesel fuel. In their study, ammonia vapor was introduced into the intake manifold and diesel fuel was injected into the cylinder to initiate combustion. The test engine was a four-cylinder, turbocharged diesel engine with slight modifications to the intake manifold for ammonia induction. results indicated that ignition delay increased with increasing amounts of ammonia due to its high resistance to autoignition. The peak cylinder pressure also decreased because of the lower combustion temperature of ammonia. Exhaust carbon monoxide and hydrocarbon emissions using the dual-fuel approach were generally higher than those of using pure diesel fuel to achieve the same power output, while NOx emissions varied with different fueling combinations. Recently ammonia is recognized by many as a potential combustion fuel and a series of research and demonstrations are performed [4]. In many safety aspects, liquid ammonia is similar to liquid propane but with the advantage of being highly resistant to autoignition. It may not cause significantly additional environmental hazards in storing ammonia since the safety guidelines are well established. In comparison to hydrogen, ammonia requires an additional step to produce. However, there is no existing infrastructure for distributing hydrogen, and ammonia has significant advantage over hydrogen in handling, including transportation and storage. A techno-economic study shows that it is worthwhile to convert hydrogen to ammonia and use ammonia as an energy carrier [5]. This is because the energy consumed in handling hydrogen will exceed the energy consumed in both producing and handling ammonia should both be used as a fuel. Lee et al.[6] In the present investigation effects of partial ammonia substitution on hydrogen/air flames were studied experimentally and computationally, motivated by safety considerations in hydrogen usage in general and combustion considerations in engine applications. Results show substantial reduction of laminar burning velocities with ammonia substitution in hydrogen/air flames, similar to hydrocarbon (e.g., methane with a similar molecular weight to ammonia) substitution. In all cases, ammonia substitution enhances the NOx and N_2O formation. At fuel-rich conditions, however, the amount of NOx emissions increases and then decreases with ammonia substitution and the increased amount of NOx and N_2O emissions with ammonia substitution is much lower than that under fuel-lean conditions. Duynslaegher et al.[7] determined by using molecular beam sampling mass spectrometry the structure of a $NH_3/H_2/O_2/Ar$ flat premixed flame burning at 50 mbar. Simulated mole fraction profiles were obtained by using four kinetic mechanisms but only two of them give results according to the experimental ones. Furthermore, a first study on a spark ignition engine was performed to define which parameters must be apply to reach the best efficiency as possible and to reduce the formation of pollutants when ammonia was used as fuel in engines.

CH_4/H_2 mixtures have been investigated according to engine performance and emissions parameters [8-9]. Akansu and Bayrak investigated that a single-cylinder four-stroke SI engine was operated with LPG (C_4H_{10}/C_3H_8, 70:30), hydrogen and methane mixture (H_2/CH_4, 30:70). Experiments were conducted at excess air ratio between 0.8 and 1.5. [10].

2. Experimental setup and testing procedure

This present work was carried out on a Lombardini engine. This is a four-stroke cycle two cylinder spark ignition engine with water cooling and injection. The engine details are given in Table 1. The experimental set-up is shown schematically in Fig. 1.

Table 1 Engine specifications.

Cylinder Number	2
Cylinder Volume	505 cc
Electronic Engine Control Unit	Bosch Motronic
Cylinder Bore	72 mm
Stroke	62 mm
Engine Power	20.4 HP 5000 d/d
Engine Torque	34 NM 2150 d/d
Compression Ratio	10.7:1

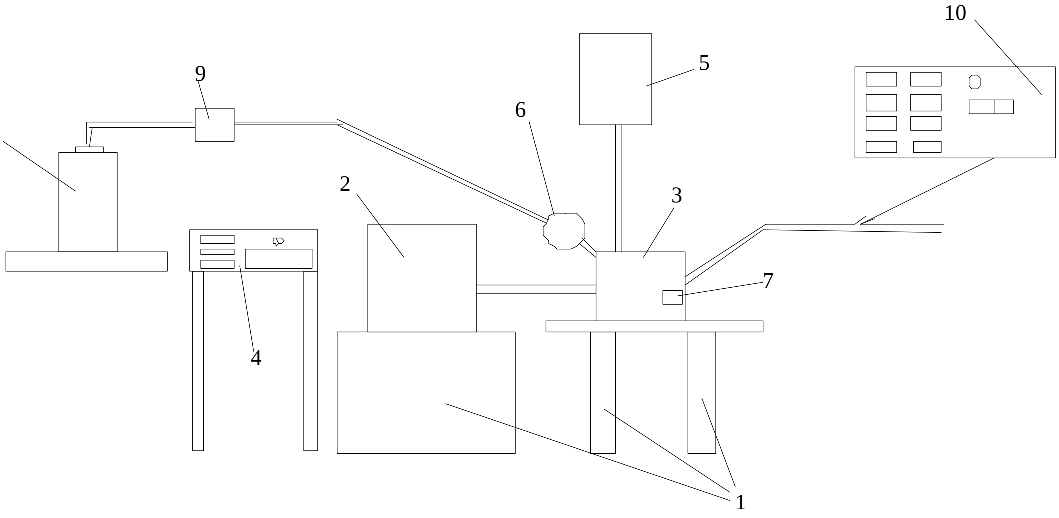

Fig.1 Experimental setup

1- Engine Test Chassis 2- Hydrokinetic Dynamometer 3-Engine 4- Control Unit 5- Main Fuel Tank 6-Regulator 7-Fuel Selection Switch 8- Gas Fuel Tank 9- Mass Flow Meter 10- Exhaust Gas Analyzer

The experiments have been performed in the Engine Laboratory in the Department of Mechanical Engineering at Erciyes University. Tests have been measured in Baturalp-Tayland brand hydrokinetic dynamometer. This equipment gives power, torque and engine speed. Calibration procedures have been done before experiments. In this study, experiments have been carried out with 30/70 NH_3/H_2 proportions, 10/90 NH_3/H_2 proportions,100 % hydrogen , 100% CH_4 and gasoline fuels by varying ignition timings. The fuel is supplied to the engineӛs intake port through with injections. The experiments have been made at 1400 ± 10 rpm, almost idle position. The emissions of CO, THC and NO have been measured with a Sun MGA 1500 gas analyzer.

3. Results and discussions

All test measurements were analyzed at a constant load of 7 ± 0.35 Nm and 1400 ± 20 rpm.

3.1. Performance parameters

3.1.1 Brake Thermal Efficiency

Fig. 2 depicts brake thermal efficiency (BTE) values versus spark timing for H_2, CH_4, H_2/NH_3 (70/30 and 90/10), and gasoline. The highest BTE values are obtained about 15 % H_2/NH_3 (70/30). The minimum BTE values are obtained about 10.84 % at Hydrogen fuel. When spark timings increase, firstly BTE increase after that BTE decrease. When BTE of gasoline compare with BTE of H_2, H_2/NH_3 and CH_4, BTE of hydrogen values are lower than gasoline because of volumetric decrease at hydrogen. In case of NH_3 additive to hydrogen, volumetric efficiency will be higher than hydrogen, so BTE values of H_2/NH_3 mixtures are higher than H_2. However, NH_3 comparison with gasoline was made, which showed efficiencies and power increased due to the possibility of a higher compression ratio [2]. Fig. 3 shows laminar burning velocity for NH_3, H_2, CH_4, C_3H_8 [6].

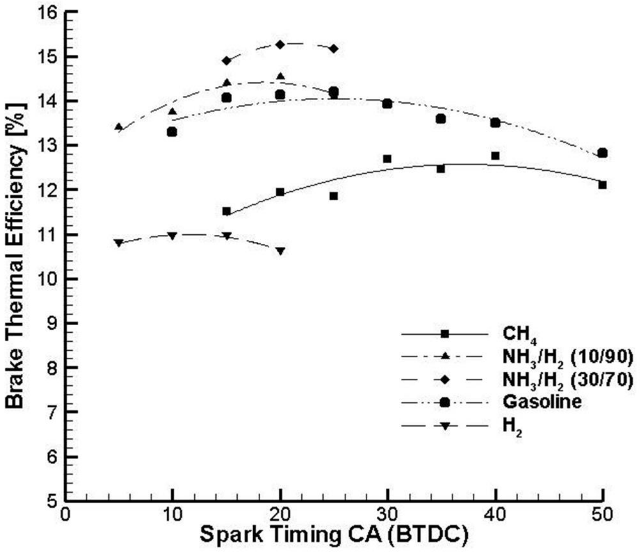

Fig. 2 Brake Thermal Efficiency versus spark timing

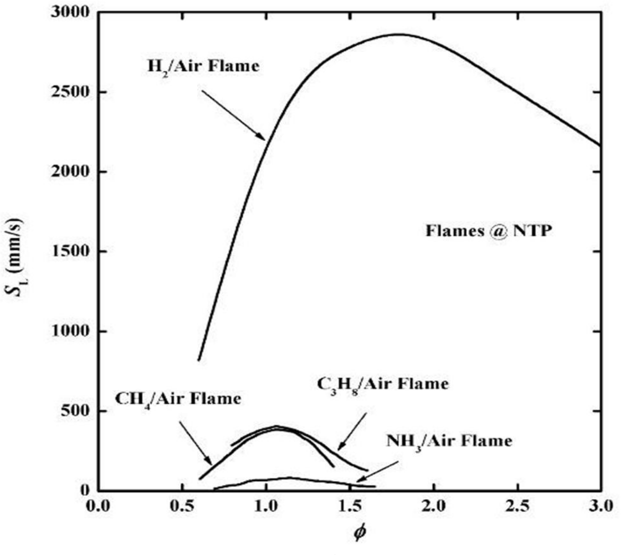

Fig. 3 Laminar burning velocity for NH_3, H_2, CH_4, C_3H_8 [6].

To obtain higher BTE at NH_3, NH_3 fuel requires higher temperature than gasoline. Spark timing for maximum performance must be advanced slightly for ammonia but sensitivity to spark timing is little greater than with hydrocarbons. Increasing the cylinder wall temperature aids in effecting successful and reliable operation [11]. The temperature may not exceed hydrogenôs auto ignition temperature without causing premature ignition. Thus, the absolute final temperature limits the compression ratio [12]. Hydrogen was the best additive in terms of good engine performance at low additive concentration with normal compression ratios [13]. So, it can be said that BTE values are high at H_2/ NH_3 mixtures.

3.1.2 Torque and Power

Table 2 gives average torque [N·m] and power [kW] values. Torque and power values are 7 ± 0.35 Nm, 1.06 ± 0.4 kW. All measurements were performed almost same condition (almost same temperature ±1 C and atmosphere pressure) for (70/30 H_2/NH_3), (90/10 H_2/NH_3), hydrogen (100%) and gasoline fuels in internal combustion engine.

Table 2 average torque and power values for NH_3, H_2, CH_4 and gasoline

	CH_4	H_2/NH_3 (70/30)	H_2/NH_3 (90/10)	Gasoline	H_2
Torque [Nm]	6.83	7.03	7.02	7.34	6.65
Power[kW]	1.02	1.06	1.05	1.10	1.04

3.1 Emission Parameters

The emissions of CO, THC and NO have been measured with a Sun MGA 1500 gas analyzer. When H_2 and H_2/NH_3 mixtures are used in engines, CO_2, CO and HC emissions parameters do not occur. NO emission values are shown in Table 3 for each fuel. For NH_3/H_2 (30/70) mixtures have the highest NO emission values bigger than 5000 ppm so gas analyzer system does not show the values of NO. NO values of other fuels are increasing with increasing CA BTDC. NOx emission values generally increase with increasing hydrogen content. However, if a catalytic converter, an EGR system or lean burn technique are used, NOx emission values can be decreased to extremely low levels for CH_4-H_2 mixtures [14-15].

Table 3 NO emission values versus ignition timing for CH_4, NH_3/H_2, gasoline and H_2

NO					
CA (BTDC)	CH_4	NH_3/H_2 (30/70)	NH_3/H_2 (30/70)	Gasoline	H_2
5			+5000		2779
10			+5000	657	3576
15	347	+5000	+5000	926	3918
20	425	+5000	+5000	971	4980
25	719	+5000	+5000	1103	
30	851			1285	
35	1252			1345	
40	1498			1660	
50	1901			2105	

CO and HC emission values are given for CH_4 and gasoline in Table 4. CH_4 emission values are lower than gasoline comparison with HC and CO. The values near zero for CO, CO_2 and HC emissions are obtained at H_2 and H_2/NH_3 operation.

Table 4 CO and HC emission values for CH_4 and gasoline

CA (BTDC)	Gasoline		CH_4	
	CO	HC	CO	HC
5	1.53	946	1.26	267.7
10	1.62	1037	1.31	423.9
15	1.58	517	1.33	520.5
20	1.70	597	1.42	336.9
25	1.74	619	1.36	531.3
30	1.81	667	1.42	565.8
35	1.86	1112	1.43	589.9
40	1.76	1438	1.4	462.3
50	1.70	866.67		

4. Conclusions

An experimental study on the performances and emissions of a spark ignition engine operated with ammonia/hydrogen mixtures were conducted. The main results can be summarized as follows.

- Ammonia/hydrogen mixtures constitute a suitable fuel for SI engines.
- The maximum efficiencies was obtained in H_2/NH_3 mixtures.
- CO, HC and CO_2 emissions were measured at very low levels for H_2/NH_3 mixtures and H_2.
- The largest NOx emissions occur with H_2/NH_3 mixtures. If a catalytic converter is used, NOx emission values can be decreased.

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Nomenclature

BTDC	Before top dead center
BTE	brake thermal efficiency
CA	Crank angle
CO	Carbon monoxide
EGR	Exhaust gas recirculation
HC	Hydrocarbon
H_2	Hydrogen
NH_3	Ammonia
NO	Oxide of nitrogen
SFC	Specific fuel consumption

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