Hydrogen/Natural Gas Blends for Heavy and Light-Duty Applications

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Abstract

NRG Tech is developing engine technology that is applicable for use in heavy-duty vehicle applications. This technology deals specifically with the use of mixtures of hydrogen and natural gas (called HCNG). This application of HCNG technology is unique for two reasons. One is the very high brake mean effective pressures (BMEPs) required by the engines. The other is the very large reductions in regulated exhaust emissions that can be achieved relative to both diesel and natural gas alternatives. The design strategy uses mixtures of hydrogen and natural gas containing at least 30% molar hydrogen, incorporates lean burn and possibly some exhaust gas recirculation for charge dilution to control NOx. CO and NMHC emissions will be controlled by an oxidizing catalyst. At this stage in the project, NRG has developed three candidate engine platforms, ranging from 7.4 to 8.4 liters displacement, of its own for evaluation. Testing on one of the platforms has shown NOx levels of 0.22 g/hp-hr using a weighted eight-mode steady state test with CO emissions essentially eliminated.

Introduction

The project is designed to bring hydrogen fuels to the marketplace in the short term. Because of the current high cost of hydrogen and the high purity hydrogen requirements of current fuel cell technology, the successful commercial implementation of hydrogen as a fuel is very much in the future. Because of this situation, a strategy is needed for earlier commercial implementation of hydrogen as a fuel. That strategy is to supplement natural gas with hydrogen for use by internal combustion engines. The rate of supplementation ranges between 30 and 50% by volume hydrogen (called HCNG). This range allows for enough hydrogen to significantly enhance the combustion of natural gas while remaining within an operational window that does not require extensive engine modifications.

Goals and Objectives

The goals and objectives for the project are:

- Develop a critical database to determine
    - Criteria for achieving ultra-low exhaust emissions
        - With internal combustion piston engines
        - For applications that now use diesel engines
- Develop engine configurations that can replace existing diesel engines
    - Utilizing HCNG fuel
    - Achieving equivalent power
        - Relative to: 4.0 g/hp-hr NOx, 15.5 g/hp-hr CO, and 1.2 g/hphr NMHC

NRG Tech has investigated the following design variables:

- Compression ratio
- Combustion chamber design
- Ignition system
- EGR-to-lean burn ratio
- Exhaust catalysts
- Water injection

Current Results

Tests on engine compression ratio ranged from 9.1 to 15.0 to 1. The desirable range for this technology range between 12 and 15 to 1. The optimum combustion chamber shape appears to be one that minimizes the surface to volume ratio. However, care must be taken to avoid engine knock. This can require non-optimal designs for emissions, but will allow knock-free operation.

An important result of our work has been the development of the proper fueling system for the engine. Table 1 shows the emissions results of testing two different fueling system designs. At low engine rpms each system appears equal in performance. However, at higher engine rpms, one system is clearly superior to the other. Incorporating the proper fueling system and fueling strategy is crucial to the successful implementation of HCNG technology.

Table 1. Effect of Fueling System Design

System Type	RPM	Equivalence Ratio	BMEP (psi)	NOx (g/hp-hr)
Design 1	1700	0.51	101	0.06
Design 2	1700	0.52	103	0.05
Design 3	3000	0.55	105	0.08
Design 4	3000	0.55	101	0.92

Testing the effect of ignition systems, spark plug location, and number of spark plugs yield mixed results. If the combustion chamber and the fueling system are not optimized, high-energy ignition systems and multiple spark plugs show improved performance. However, when the combustion chamber and fueling system are engineered properly, high-energy ignition systems and multiple spark plugs show minimal positive effects.

Table 2 shows the emissions results for a 7.4L V8 engine developed by NRG Tech. The two engine rpms chosen represent maximum engine torque and maximum engine horsepower. Various fractions of each power level for each rpm including idle make up the test. The emissions from each point are multiplied by a weighting factor (shown in the table) and added together to result in an overall value of emissions that represent a typical heavy-duty driving application. The design goal of this engine is to replace an existing 5.9L, 200 hp engine currently used in heavy-duty applications.

Table 2. 8 Mode Steady State Emissions Summary. 200 hp Platform, NRG Hydrogen-Enriched Natural Gas Bus Engine

Individual Modes		NOx (g/hp-hr)	THC (g/hp-hr)	NMHC (g/hp-hr)	CO (g/hp-hr)	Weighting Factor
1800 rpm	- 100% Load	0.37	3.70	0.07	0.00	0.15
	- 75% Load	0.20	5.80	0.10	0.00	0.15
	- 50% Load	0.10	5.48	0.10	0.00	0.15
	- 10% Load	0.25	5.10	0.10	0.00	0.10
2800 rpm	- 100% Load	0.10	5.63	0.26	0.00	0.10
	- 75% Load	0.09	4.71	0.19	0.00	0.10
	- 50% Load	0.11	6.01	0.26	0.00	0.10
	- Idle	0.40	17.44	0.36	0.00	0.15
Weighted 8 Mode (g/hp-hr)		0.22	7.00	0.18	0.00	
Weighted 8 Mode (g/kw-hr)		0.29	9.38	0.24	0.00	

Additional tests were performed on a supercharged 4.6L engine where 0.11 g/hp-hr of NOx was achieved at 120 psi BMEP.

Equivalence ratios ranging from 0.48 to 0.56 were used to achieve these emissions results. The electronic controls developed in the project were used to set the proper air-fuel ratio depending upon operating conditions and the allowable tradeoffs with NMHC emissions.

Conclusions

NRG Tech has determined the proper configuration and allowable design deviations of the crucial engine parameters required to make HCNG fuel a viable commercial success. Emissions results show that NOx emissions compatible with proposed future emissions standards for heavy-duty vehicles are achievable with this fuel, but only if properly implemented.