Hydrogen Gas-Fueled Diesel Engine Feasibility Demonstration

R. Reynolds
DSN Engineering Section

The feasibility of a hydrogen gas-fueled diesel engine was demonstrated in a test program at Cornell University. The test engine was operated over a range of conditions to represent operation of a large diesel engine in the Goldstone Energy Program. The results of the test program supplied insight into the design requirements for a large-scale performance test program.

I. Introduction

A test program was undertaken at Cornell University under JPL contract to provide a feasibility demonstration of a hydrogen-fueled diesel engine. This fueling system is proposed as a means of operating the diesel engine power plants at Goldstone on a fuel derived from solar energy.

II. Prologue

Cornell University has a contract from the Department of Transportation for the investigation of emissions from a hydrogen-fueled, spark ignition engine. The investigation is being performed by Howard S. Homan, under the direction of Professor P. C. T. de Boer.

The test facility is a 606-cm^3 (37-in.^{3}) displacement, Waukesha Cetane Cooperative Fuel Research (CFR) engine, equipped with a hydrogen-fuel injection valve that is unique to Cornell. The valve was designed to allow adjustment of injection duration and timing and to investigate emissions with respect to the independent variables of compression ratio, fuel/air ratio, and injection schedule parameters. The design of the valve is such that injection can be achieved during a combustion event, so that diesel operation can be simulated. Ignition was by a spark plug, energized by a conventional ignition system. The facility is equipped with instrumentation to allow measurement of efficiency, power output, engine operating pressures, fuel flows, and exhaust emissions. Additional equipment is used to safely supply, monitor, and control high-pressure hydrogen.

III. Test Description

The test program was devised to explore compression ignition over a range of compression ratios, equivalence ratios ϕ (ϕ = (fuel/air ratio actual)/(fuel/air ratio stoichiometric)), and injection timing to represent projected operation of a hydrogen-fueled Caterpillar model D399 diesel engine. Table 1 is a list of these parameters.

The following parameters were measured to derive engine performance data:

(1) Engine rpm.

(2) Fuel flow rate.

(3) Intake air flow rate.

(4) Torque.

(5) Intake air pressure.

(6) Injection duration timing.

(7) Cylinder pressure vs time.

(8) Nitric oxide (NO_x) emissions.

(9) Cylinder water jacket temperature.

(10) Exhaust oxygen content.

In addition, any pertinent conditions or events associated with a test were noted, including ignition parameters, and subjective engine operation "quality."

Alternate ignition aids, a continuous spark system, a timed spark system, and a glow plug were supplied to aid operation where compression ignition was unsuccessful.

IV. Test Results

Included are three figures from the Cornell test report: Fig. 1, exhaust oxygen content; Fig. 2, indicated efficiency, and Fig. 3, total nitric oxides.

The data for Fig. 1 were sampled from the exhaust of the engine with an oxygen meter. The ordinate and abscissa on the graph are mole fraction of oxygen and equivalence ratio, respectively. The dashed lines are indicative of zero and complete combustion, as noted. As indicated, the combustion efficiency of the engine, as represented by these data, is poor; this is probably due to configurational effects of prechamber shape, injector location, and prechamber orifice size and location. Figure 2 is a plot of indicated thermal efficiencies as a function of equivalence ratio. Baseline data were taken on the engine with diesel oil fueling, as a comparison to the hydrogen fueling. Although there is significant scatter in the data, due to the limited number of data points, there is a trend that indicates higher efficiency on hydrogen at low equivalence ratios (this is the region of normal operation of the Caterpillar engines). This is very encouraging, and provides a potential performance advantage in reducing hydrogen generation and storage requirements.

Figure 3 provides the emissions as a function of equivalence ratio. There are not enough data points to make specific conclusions, although there seems to be little difference between diesel oil and hydrogen.

Ignition by compression was unsuccessful on the range of compression ratios and equivalence ratios. We were successful in both glow plug and spark ignition. Figures 4 and 5 show a cylinder pressure trace versus crankshaft position. Figure 5 is with spark ignition, and Fig. 4 is with glow plug. Engine operating parameters are similar. The glow plug ignition is far more satisfactory as indicated by pressure rise and peak amplitudes.

Table 1. Test parameters

Compression ratio	15.5:1 to 30.25:1
Equivalence ratio	0.1 to 0.8
Engine configuration	Prechamber (divided combustion chamber)
Engine speed	1200 rpm (nominal)
Injection timing	TDC ± 5° (best torque)
Intake air pressure	101325 N/m^2 (1 atm) (absolute)
Intake air temperature	22 ± 6°C (72 ±10°F)
Ignition aid	As required

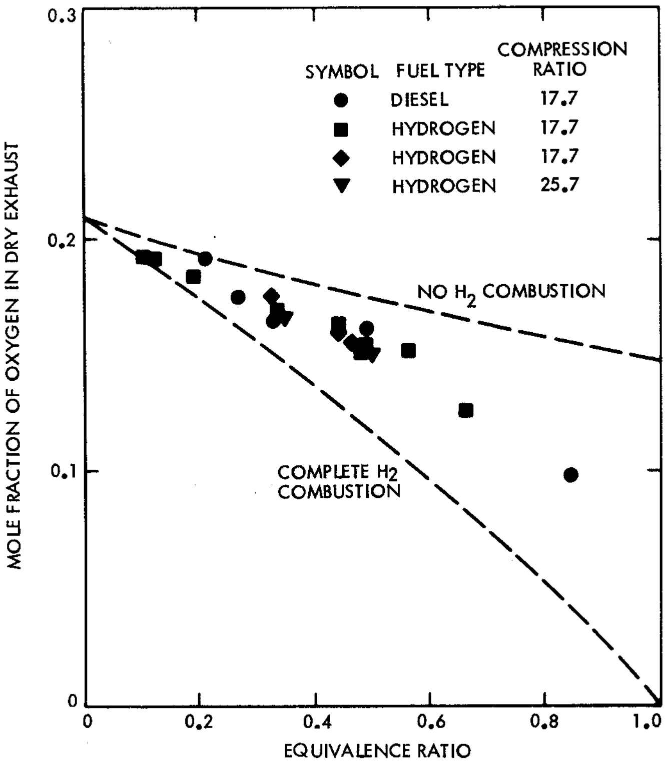

Fig. 1. Oxygen content of exhaust

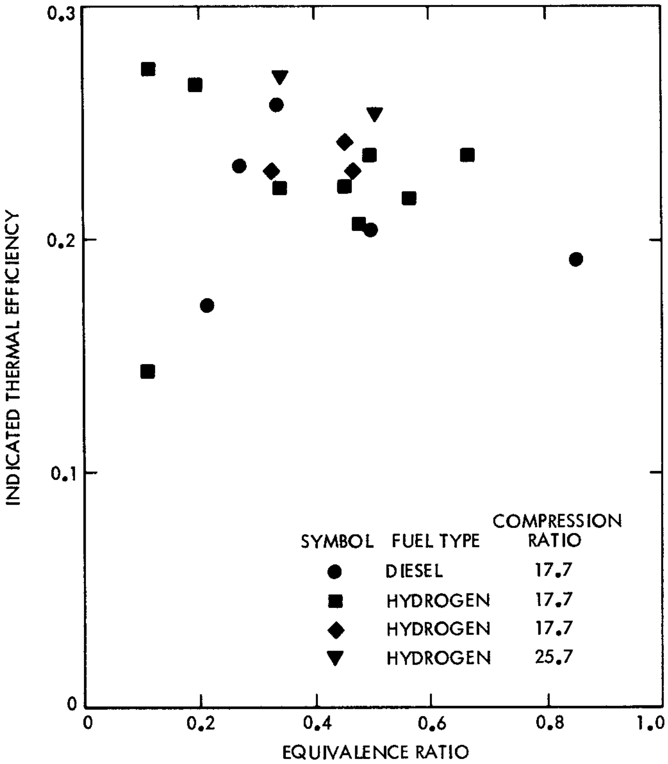

Fig. 2. Indicated efficiency

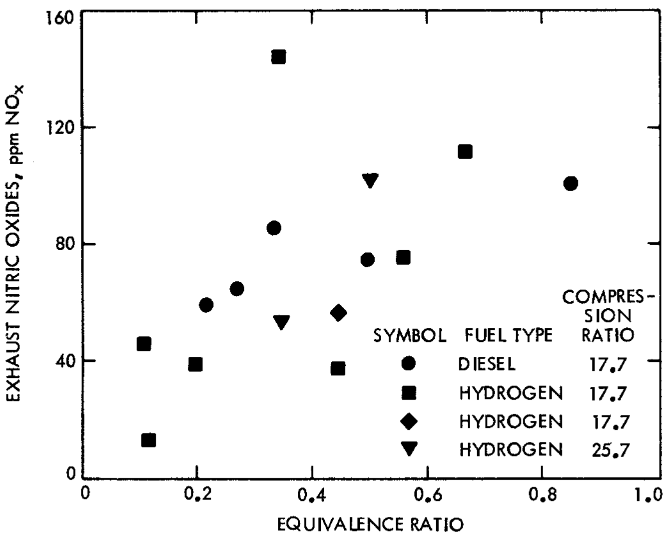

Fig. 3. Total nitric oxides

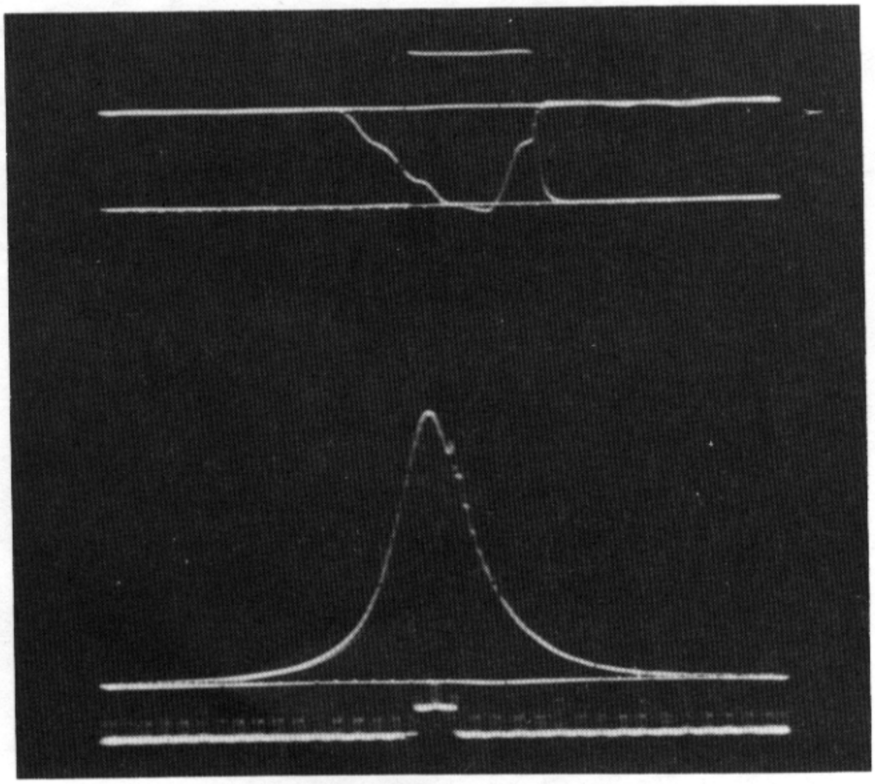

Fig. 4. Data display of engine operating on hydrogen glow plug ignition (compression ratio = 17.6:1)

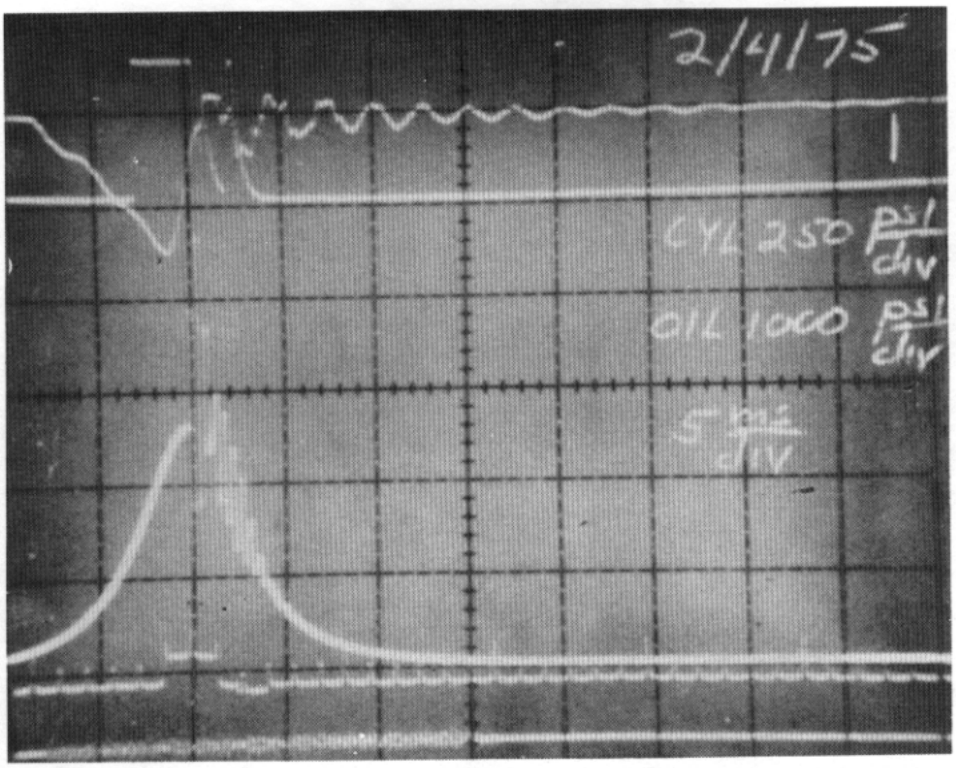

Fig. 5. Data display of engine operation on hydrogen (continuous spark ignition; compression ratio = 17.5:1)

NASA — JPL — Coml., L.A., Calif.