Technical Perspective

Hydrogen Boosted Engine Operation

INTRODUCTION:
Hydrogen boosted engine operation involves the simultaneous use of multiple fuels.

The concept of using hydrogen boosting in engines is not new. Rudolf Diesel, who invented the engine bearing his name, experimented with enriched combustion air mixtures in the early 1900’s. Since then, various methods of metering gaseous gas into the diesel engine cylinders have been successfully proven in commercial operation. Most of these products utilized mechanical control systems.[1]

To reduce exhaust emissions and overall fuel costs, as well as provide reliable performance, engineers have been challenged with maintaining an optimal balance of diesel and gas fuels across the power range of the diesel engine, and under varying ambient conditions.[2] This is best accomplished through the use of microprocessor controls, combined with automotive sensor and actuator technologies. Today, this digital approach precisely and instantaneously provides the electromechanical feedback system needed to safely operate a diesel engine on a hydrogen boosted mixture; however in a static gaseous fuel feed scenario, the same results can be accomplished.

KEY POINTS:

- Hydrogen boosted Methodology & Operation
- Hydrogen boosted Operation
- Compatibility Of Hydrogen boosted With Diesel Operation
- Hydrogen boosted & Emissions Standards
- Benefits Of Hydrogen boosted
- Hydrogen boosted Applications
- Product Offerings

HYDROGEN BOOSTED METHODOLOGY & OPERATION:
Several key elements govern the efficiency and operation of a compression ignition engine, no matter what concept is used to implement the hydrogen boosted operation.

A diesel engine relies upon compression and heat to ignite its fuel, instead of a spark. It cannot operate on 100% gaseous gas, because some amount of diesel fuel is required for pilot ignition under compression. Gaseous gas ignites at a much higher temperature (1150° ~ 1200° F) compared to diesel fuel (500° ~ 750° F), while propane ignites too low and WILL cause pre-ignition problems; and, compression ignition engines cannot provide enough heat during the compression stroke to ignite pure gas or hydrogen.[3]

There are three proven methods of implementing hi-fuel operation, depending upon where and how the gaseous fuel is introduced prior to combustion.[4]

The first methodology (port injection, or timed-gas admission) introduces the gaseous fuel to the air mixture after it passes through the turbocharger compressor, but before it enters the cylinder. This is done under moderate pressure, usually less than 50 psi. This approach (low pressure injected gas, or LPING) was traditionally used in large stationary installations, but is more recently finding use in trucking applications. Our nearest competitor uses this technology, but our system gives results just as good and better without pressure.

The second method (high-pressure direct injection) introduces the gaseous fuel directly into the combustion chamber under extremely high pressures of approximately 3000 psi.[5] This approach (HPING) is used in very large hydrogen boosted engines that typically operate for extended periods producing prime or continuous power. This is simply not feasible.

The third approach (combustion air gas integration) introduces the gaseous fuel with the intake combustion air prior to the turbocharger, and takes advantage of the precision and response of usually a microprocessor controlling this mixture. This type of system is needed for Natural Gas, but is not really needed for Hydrogen, because Hydrogen will burn over a wider range of stoichiometric mixtures. It also offers the broadest range of operation at the lowest cost, and assures the reliability required for a low cost fuel boosting system.

During initial startup, a hydrogen boosted diesel engine operates on 100% diesel fuel. A diesel can reach an optimum hydrogen boosted ratio under typical operation of approximately 10% diesel and 90% gaseous gas as the hydrogen begins to be produced and to flow from our booster system

It should be noted that diesel pilot quantities ***can be less than 1%*** in some industrial applications. This technology requires a micro-injection approach, often in combination with a combustion pre-chamber. Due to the cost and complexity, the “micro-pilot” hydrogen boosted products are reserved for large stationary engines operating under prime or continuous duty conditions.[6]

The integration of a hydrogen boosted system does not de-rate the engine output capability. The load response and stability remain the same while operating in either hydrogen boosted or 100% diesel mode.

One of the major benefits realized with hydrogen boosted technology is the reduction of exhaust emissions. The United States Environmental Protection Agency (USEPA) has developed current and future emission standards for mobile non-road diesel engines. While no unified standards exist, it is anticipated that stationary diesel engine applications will be required to follow similar limitations as illustrated in Table 1-2 below.

Engines :	TIER 1						TIER 2				TIER 3			
Output (hp)	**Date**	**NOx**	**HC**	**HC+NOx**	**CO 6.0**	**PM 0.74**	**DATE**	**HC+NOx**	**CO**	**PM**	**DATE**	**HC+NOx**	**CO TBA**	**PM TBA**
<11	**2000**	**N/A**	**N/A**	**7.8**			**2005**	**5.6**	**6.0**	**0.60**	**TBA**	**TBA**		
11-25	**2000**	**N/A**	**N/A**	**7.0**	**4.9**	**0.60**	**2005**	**5.6**	**4.9**	**0.60**	**TBA**	**TBA**	**TBA**	**TBA**
25-50	**1999**	**N/A**	**N/A**	**7.0**	**4.1**	0.60	**2004**	**5.6**	**4.1**	**0.44**	**TBA**	**TBA**	**TBA**	**TBA**
50-100	**1998**	**6.9**	**NR**	**NR**	**NR**	**NR**	**2004**	**5.6**	**3.7**	**0.30**	**2008**	**3.5**	**3.7**	**TBA**
100-175	**1997**	**6.9**	**NR**	**NR**	**NR**	**NR**	**2003**	**4.9**	**3.7**	**0.22**	**2007**	**3.0**	**3.7**	**TBA**
175-300	**1996**	**6.9**	**1.0**	**N/A**	**8.5**	**0.40**	**2003**	**4.9**	**2.6**	**0.15**	**2006**	**3.0**	**2.6**	**TBA**
300-600	**1996**	**6.9**	1.0	**N/A**	**8.5**	**0.40**	**2001**	**4.8**	**2.6**	**0.15**	**2006**	**3.0**	**2.6**	**TBA**
600-750	**1996**	**6.9**	**1.0**	**N/A**	**8.5**	**0.40**	**2002**	**4.8**	**2.6**	**0.15**	**2006**	**3.0**	**2.6**	**TBA**
>750	**2000**	**6.9**	**1.0**	**N/A**	**8.5**	0.40	**2006**	**4.8**	**2.6**	**0.15**	**TBA**	**TBA**	**TBA**	**TBA**

Tab!e 1-2. USEPA Non-road Mobile Emission Standards

Note: All units for pollutants are in g/hp-hr

The table shows three columns labeled Tier 1, 2 or 3. The normal progression has been to lower the limits over time. The California Air Resources Board (CARB) has adopted the same limits for California.

The EPA has proposed new non-road exhaust emission standards that are similar to the requirements for engines used in highway trucks and buses, aimed at reducing emissions by more than 90 percent. The proposed standards would take effect for new engines starting as early as 2008 and be fully phased in by 2014. Air regulators from thirteen U.S. states along the eastern seaboard intend to bring the California-style diesel emission standards to their states. Emission limits would include reduced particulate matter, hydrocarbons, carbon monoxide and oxides of nitrogen emissions from stationary, portable and mobile diesel fueled engines.[7]

BENEFITS OF HYDROGEN BOOSTING:

- The reduced consumption of diesel or other fuel by the engine under hydrogen boosted operation means that run times per tank of fuel are significantly extended. This provides longer back-up coverage during extended outages.

- Because gaseous gas is the predominant fuel, smaller diesel tanks are a viable option, with additional benefits - less fuel is stored on site - with their limit of 660 gallons, indoor installations are feasible), refueling is done less often, and with smaller amounts of fuel present, permits may be easier to obtain.

- The cost of a midrange to large diesel engine is approximately half to two-thirds that of a spark-ignited gaseous engine of equivalent output. Applying hydrogen boosted technology to a diesel engine, offers the advantages of a gaseous fueled engine at nearly the cost of a diesel-powered unit.

- A hydrogen boosted engine has built-in fuel redundancy. If the gaseous gas supply is interrupted for any reason, the controls will automatically direct the unit back to 100% standard operation without interruption of operation. This is also possible with a spark-ignited gas engine because the emission control system actually controls the injection process.

- Test results are on file from the EPA laboratory in northern Virginia that conducted emissions testing on converted diesel engines for the U.S. Navy. These real-time recordings showed significant emissions reduction, including a 99% reduction of visible smoke (carbon particulate matter, or PM, in parts per million), 50% less oxides of nitrogen (NO_x), and a 25% reduction of carbon dioxide (CO_2).[8]

- Hydrogen boosted engines have thermal loads equivalent to the same engine operating on 100% diesel fuel. The durability testing, performance testing, and oil analysis indicate that the hydrogen boosted gas / diesel engine could experience longer life, extended service intervals, and reduced oil service costs when compared to a standard diesel engine.[9]

- The extended running time capability makes hydrogen boosted units especially valuable in regions where refueling may be difficult in the event of a disaster or other lengthy interruption of services (hurricane or flood-prone areas, for instance).

- With less on-site fuel storage, hydrogen boosted engines are well-suited to locations where fuel handling or storage may be costly or difficult, and Hydrogen boosting extends the operating range of the engine or vehicle with the higher BTU content of Hydrogen.

- The use of hydrogen boosted powered engines is an excellent fit for areas that require low exhaust emissions. California, Texas and many other areas of the country continue to reduce the limits of diesel engine emissions, creating a need for alternative fuels, low sulfur diesel formulations, and emerging technologies like this one.

- Hydrogen boosting makes good sense for cold climates. With less diesel fuel reserve required, heating of the fuel to prevent gelling is much more manageable.

- The USEPA has proposed a new and more stringent non-road low-sulfur diesel and emission standards plan. The rule introduces a 500 ppm cap on sulfur emissions by mid-2007, followed by a 15 ppm limit by 2010.10 It will be very costly for oil refineries to reach these limits, potentially resulting in a major increase in the cost of diesel fuel in the future. The incorporation of hydrogen boosted engines will result in more significant cost savings to mitigate the anticipated increase in the price of diesel fuel.

Source References:

1. Karl W. Stinson, ME., Diesel Engineering Handbook, 12th Edition, Norwalk, CT, Business Journals, Inc., 1980,8.

2. Sean H. Turner, Christopher S. Weaver, P.E., "Dual-Fuel Gas / Diesel Engines: Technology, Performance, and Emissions," Chicago, IL, Gas Research Institute (CR1) Engine Technology Group, 1994, vi.

3. Stinson, op. cit., 50.

4. N. John Beck, Robert L. Barkhimer, William P. Johnson, Hoi C. Wong, and Kresimir Gebert, "Evolution of Heavy Duty Gas Engines -Stoichiometric, Carbureted and Spark Ignited to Lean Burn, Fuel Injected and Micro-Pilot," 6-8 August, 1997, Society of Automotive Engineers, International Future Transportation Technology Conference (SAE Technical Paper Series 972665), 1.

5. Turner, op. cit., 19, 44.

6. Ibid., 19.

7. U.S. Environmental Protection Agency (EPA), April 2003, Low Emission Program Summary, EPA Document Number 402-F-03-008, Internet Address: http://ww.epa.gov/nonroad/f03008.htm.

8. Electronic Fuel Control Company, Division of Airport Industrial Center, 30 May 2001, "Electronic Fuel Control" and "Emission Compliance," Internet Address: http://www.electronicfuelcontrol.com.

9. Paul J. Beck, Bruce A. Hamilton, Robert Shepherd, Richard A.. Cemenska and Louis A. Lautman, "Performance Engine Durability and Oil Life Analysis of Pilot Ignition Gas Engines," 6-8 August, 1997, Society of Automotive Engineers, International Future Transportation Technology Conference (SAE Technical Paper Series 972664), 5

10. Chris Baltimore (Reuters), Environmental News Network, "EPA Mulling Reduction In Off-Road Diesel Emissions," Internet Address: http://www.enn.com/news/wire-stories/2002/12/12312002/reu 49278.asp