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Natural Gas Fueled Fire Apparatus Considerations

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Introduction

Natural gas, in either a compressed or liquefied form, is a fuel that can be used in the transportation industry. Over the past several decades there have been numerous programs to study and develop its use in heavy vehicles, and CNG powered buses are popular in several regions of the U.S. This paper provides an overview of Natural Gas Vehicle (NGV) technology and offers guidance to Fire Chiefs considering the application of this technology to fire apparatus.

Forms of Delivery

Natural Gas is primarily methane, with small amounts of ethane, propane, butane and some heavier alkanes. In its natural condition it is colorless and odorless. Agents are added to household natural gas to give it a detectible odor.

CNG (Compressed Natural Gas)

CNG is made by compressing natural gas to less than 1 percent of its volume at standard atmospheric pressure. It is stored and distributed in hard containers, at a normal pressure of 2900-3200 psi. CNG storage cylinders can be made of steel, aluminum, or composites. Lightweight composite (fibre-wrapped plastic) cylinders are especially beneficial for vehicular use because they offer significant weight reductions when compared with earlier generation steel and aluminum cylinders.

LNG (Liquefied Natural Gas) [1]

Natural gas will become a liquid if it is cold enough. Since a liquid takes up much less space than a gas, the main advantage of LNG is the improvement in vehicle range without adding the large tanks required with CNG. Natural gas in its liquid state takes up only 1/600th of the volume that it does when a gas.

LNG is principally used for transporting natural gas to markets, where it is regasified and distributed as pipeline natural gas. The relatively high cost of production and the need to store it in expensive cryogenic tanks have prevented its widespread use in transporation applications.

To convert natural gas to its liquid state it must be cooled to a temperature of -163º C (-261º F). Before chilling, any impurity that would freeze at these temperatures must be removed. The natural gas fed into the LNG plant must therefore be treated to remove water, hydrogen sulfide,

[1] *LNG Review*, The National Alternative Fuels Training Consortium (NAFTC), West Virginia University, Morgantown, WV

carbon dioxide and other impurities. The LNG must be maintained at this cryogenic temperature during storage both at the fill station and while in the vehicle. For on-vehicle storage this is accomplished by using a specially designed super-insulated tank. As the fuel gradually warms it will boil off and a relief valve will discharge the vaporized natural gas to the atmosphere so that safe pressures are maintained in the tank. At this time the LNG and its vapor is not odorized, it is completely odorless and not detectable.

NGV Engines for Heavy Duty Apparatus

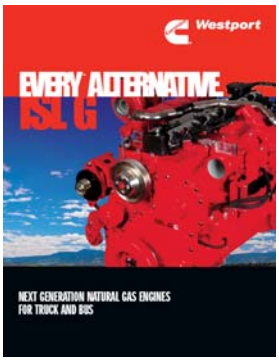
Diesel Engine Conversion Approaches

The Cetane number of CNG is too low to provide acceptable performance when burned in a diesel engine. There are two methods of converting diesel engines to run on natural gas. The first is to add spark plugs, essentially turning the diesel engine (CI or compression ignition) into a gasoline engine (SI or spark ignition) engine. This method requires considerable rework by either the engine OEM or an up-fitter.

The second method is to mix a small amount of diesel fuel with the natural gas in the combustion chamber. The diesel ignites from the piston compression, subsequently igniting the natural gas. This is commonly referred to as dual-fuel operation or fumigation. This dual-fuel approach has definite disadvantages as it provides poor low-speed performance, produces higher exhaust emissions, and has a tendency to knock.

Industry Trends

The use of natural gas to power heavy duty vehicles was driven primarily by clean emissions concerns over the past few decades. The establishment of the new EPA diesel emission regulations and the success of diesel engine manufacturers in meeting the new regulations has effectively negated this market incentive. LNG has never been a technology of choice for heavy vehicles, and the popularity of CNG has been limited primarily to urban bus fleets. As a result of this lack of market acceptance, most of the major OEMs have dropped their natural gas programs. Volvo-Mack and John Deere are the most recent players who had strong development programs but have now declared they will not produce NG engines in the future. The one remaining U.S. OEM offering product in this niche market is the partnership between Cummins and Westport. Engines are offered on a modified ISL block with horsepower ratings up to 320 HP and 1000 ft-lbs of torque.



Performance

Power

Heavy duty diesel truck engines typically outperform those powered with natural gas, though natural gas engines may perform well in less demanding applications. Diesel engines are powerful enough to haul heavy loads and climb steep hills, and their high fuel economy allows drivers to travel further between refuelings. Drivers of LNG heavy-duty trucks frequently report that LNG engines are less powerful than diesel engines.[2]

Fuel Economy

A side by side comparison between a Cummins C8.3 diesel engine and Cummins C-Gas Plus engine showed that "…average fuel economy was 5.17 mpeg (miles per energy equivalent gallon) for the natural gas trucks and 6.73 mpg for the diesel trucks. This represents a 23.2% fuel economy penalty for the natural gas trucks. This is not unexpected when comparing a throttled engine (C-Gas Plus) with a non-throttled engine (C8.3) in a light load and high idle application."[3]

It is important to note that the duty cycle in this test was similar to typical fire apparatus operation which is dominated by long periods of idling.[4] It is reasonable to assume, therefore, that fire apparatus powered by natural gas engines will also have a lower fuel efficiency. Fleet testing of CNG pick-up and delivery vehicles by UPS also showed a diesel-equivalent fuel economy penalty of 27 to 29%.[5]

Emissions

EPA Regulated Emissions

Natural gas is clean burning when compared with other hydrocarbon based fuels but it is not emission free when used in heavy duty diesel engines. Tests comparing pre-2007 diesel engines to natural gas engines showed a significant reduction in emissions for the natural gas vehicles. This picture, however, has been reversed when considering diesel engines certified to 2007 or later EPA regulations.

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[2] Nikki Swartz, *TRUCKS: Fueling the Diesel vs. Natural Gas Debate*, Waste Age, May 1, 2000,
[3] E.J. Lyford-Pike, *An Emission and Performance Comparison of the Natural Gas C-Gas Plus Engine in Heavy-Duty Trucks*, National Renewable Energy Laboratory, April 2003 p.14.
[4] R. Lackore, Fire Apparatus Manufacturers Association, *Fire Apparatus Duty Cycle White Paper*, August 2004.
[5] K.Chandler, K. Walkowicz, N. Clark, *UPS CNG Truck Fleet Final Results*, National Renewable Energy Laboratory, Aug 2002.

A clear picture of the current emissions comparison can be obtained by studying the official emission test results as posted on the EPA website at www.epa.gov/otaq/certdata. The available EPA download lists the results submitted by the engine manufacturers that were used by the EPA to verify compliance to the 2007 standards. The following table provides emission test results of US EPA 2007 diesel engines and comparable natural gas fueled engines. Note that even though the natural gas engines have a lower average power output, they do not burn cleaner than their 2007 diesel counterparts.

Fuel	Manufacturer	Test Model	Displacement (CID)	Rated HP	@ Rated RPM	@ Torque	@ RPM	Units	NOx	PM	CO	NMHC/ OMNMHCE
Diesel	Cummins Inc.	ISC 330	505	320	2200	1000	1400	g/bHp-hr	1.140	0.000	0.100	0.000
Diesel	Cummins Inc.	ISC 360	505	350	2200	1050	1400	g/bHp-hr	1.000	0.000	0.300	0.000
Diesel	Cummins Inc.	ISL 330	540	310	2100	1100	1300	g/bHp-hr	1.000	0.000	0.100	0.000
Diesel	Cummins Inc.	ISL 365	540	350	2100	1250	1400	g/bHp-hr	1.100	0.000	0.100	0.020
								Ave	1.060	0.000	0.150	0.005
Nat. Gas	Cummins Inc.	LG-320	540	320	2300	1000	1400	g/bHp-hr	1.240	0.010	0.700	0.000
Nat. Gas	Cummins Inc.	C+8.3-280G	505	280	2400	850	1400	g/bHp-hr	1.530	0.008	1.296	0.200
Nat. Gas	Cummins Inc.	C+8.3-280G	505	280	2400	850	1400	g/bHp-hr	1.540	0.008	2.015	0.200
Nat. Gas	Cummins Inc.	LG-320	540	320	2300	1000	1400	g/bHp-hr	1.240	0.010	0.400	0.000
								Ave	1.388	0.009	1.103	0.100

Greenhouse Gas

Since CO_2 is not currently regulated by the EPA the relative impact of greenhouse emissions is not available from this data. In general, natural gas has the lowest CO2 emissions per unit of energy of the fossil fuels. LNG emits more greenhouse gas because of the energy required to purify, liquefy and transport it (20 to 40 percent more carbon dioxide than burning natural gas alone).

LNG Fuel Loss

Society of Automotive Engineers publishes LNG tank design guidelines that recommend a thermal insulation system that limits conduction, convection, and radiation such that LNG product loss at static pressure shall be less than 1% per day at 34.5 KPa (5.0 psi).[6] This rate of loss may be significant for volunteer departments or other fire departments where apparatus could sit idle or in reserve for extended periods of time. Given the potential loss rate an apparatus could lose 25% of its fuel capacity if it sits without attention for more than a month at a time.

[6] SAE International J2343 *Recommended Practice for LNG Medium and Heavy-Duty Powered Vehicles*

Packaging

CNG – Significant Packaging Penalty

Compressed natural gas vehicles require a greater amount of space for fuel storage than conventional gasoline or diesel powered vehicles. Since it is a compressed gas, rather than a liquid like gasoline, CNG takes up more space for each GGE (Gallon of Gas Equivalent). Therefore, the tanks used to store the CNG take up additional space.

In one design using a Cummins-Westport C-Gas Plus natural gas engine the vehicle required a total of 9 pressure vessel tanks to provide fuel capacity equivalent to a 50 gallon diesel tank yielding a maximum range of 200 miles.[7]

CNG buses typically locate the tanks on the roof. Refuse trucks locate the cylinders in front of the packer body. Tanks on a fire apparatus would detract from valuable space needed for storing rescue equipment.

LNG – Minor Packaging Penalty

Since LNG is a liquid, the volume of space required for on-board vehicle storage is roughly equivalent to that of diesel fuel. The difference involves the shape of the tank as well as the insulation required to keep the cryogenic fuel at low temperatures. Whereas a diesel tank can be designed to fit efficiently in a chassis depending on the available space, the LNG tank must hold pressure and therefore is restricted to a cylindrical shape. Both the insulation and the pressure holding requirements mean that an LNG fueled apparatus will have some packaging penalty which will likely come at the expense of equipment storage.

Fueling

CNG Fill Stations

Two types of fuel stations are available. The Time-Fill station uses a pump to compress the gas as it enters the vehicles tank. If a CNG vehicle returns to one location overnight or during the day, for a period of hours, Time-Fill is the most efficient and economical means of fueling. The typical line pressure of 20 to 60 PSI is increased to 3000 to 3600 PSI which takes hours to accomplish.

[7] E.J. Lyford-Pike, *An Emission and Performance Comparison of the Natural Gas C-Gas Plus Engine in Heavy-Duty Trucks*, National Renewable Energy Laboratory, April 2003

In a Fast-Fill configuration, the CNG compressor takes the low line pressure gas and compresses it up to 5000 PSI into appropriately rated CNG storage vessels. CNG vehicles then pull up to CNG Fast-Fill dispenser which resembles an ordinary liquid fuel dispenser like you see at a gasoline station. Fast-Fill CNG fueling requires about the same amount of time as fueling with any conventional fuel.

In either case, the vehicle must return to the station for fueling. This would not be acceptable at a fire-scene where the apparatus may be required to pump for hours on end and is refueled on-scene. Although it would be technically possible to construct a CNG mobile refueling vehicle, they are not commonly available.

LNG Fill Stations

At present, the cost of a typical LNG refueling station is high, between $350,000 to well over a $1,000,000 for the mechanical systems alone. These costs compare unfavorably with the cost of a conventional gasoline station, at about $50,000 to $150,000. Several issues tend to create the large difference in cost. The primary one is the need for specialized equipment for storing and handling the cryogenic liquid. Pumps must be equipped with special nozzles to protect users from problems related to pressurized or cryogenic materials.[8]

Maintenance

As with any technology that is less common, the need for trained and experienced maintenance personnel must be considered. The UPS fleet study concluded that total operational cost was highly influenced by the maintenance effort expended. Fire departments considering an NGV apparatus should ensure that they have maintenance personnel and facilities experienced and proficient in the selected technology.

Safety

Explosion Hazard of CNG

Natural gas characteristics potentially make it a greater safety hazard than diesel. Not only is natural gas highly flammable, but its vapors at low temperatures are dense and can form clouds of flammable vapor concentrations. The National Fire Protection Association gives natural gas the highest hazard ranking for flammability, while designating diesel as moderately flammable. Diesel fuel is less flammable because it usually does not form ignitable mixtures unless it is heated.

[8] Bruce Wilding, *Natural Gas Technologies - Low-Cost Refueling Station*, Idaho National Laboratory, www.inl.gov/lng/projects/refuelingstation, Sep. 2005

Although CNG vehicles have a good safety record with regard to the percentage of accidents, the effect of a CNG explosion when it does occur is pretty significant. The city of Seattle Fire Department issued a report on an explosion of a CNG passenger car as a result of a car fire. The vehicle exploded as the fire fighters were approaching with a hand-line.[9] The explosion potential must surely be considered in any decision to fuel fire apparatus with CNG.

Fire Hazards of LNG

LNG at the storage site can be a significant hazard. If LNG spills near an ignition source, the evaporating gas in a combustible gas-air concentration will burn above the LNG pool. The resulting "pool fire" would spread as the LNG pool expanded away from its source and continued evaporating. A pool fire is intense, burning far more hotly and rapidly than oil or gasoline fires. It cannot be extinguished — all the LNG must be consumed before it goes out. Because an LNG pool fire is so hot, its thermal radiation may injure people and damage property a considerable distance from the fire itself.[10]

Explosive Hazards of LNG

In its liquid state, LNG is not explosive. For an explosion to occur with LNG, it must first vaporize, then mix with air in the proper proportions (the flammable range is 5% to 15%), and then be ignited. If LNG comes in contact with water it vaporizes violently and turns into a gas very rapidly. This may be considered a more serious concern for fire apparatus where both water and flames are prevalent at the fire scene.

Conclusion

Although the interest in natural gas as a transportation fuel may continue to have economic merit in certain applications, the preponderance of the data suggests that it is not a prudent fuel for use on fire apparatus for the following reasons:

- Packaging
  - The size of the tanks required for CNG fuel storage would drastically reduce the amount of space available on the apparatus for fire-fighting equipment.
- Fueling Logistics
  - Even if a department invests in the infrastructure to provide a reliable source of CNG or LNG in their area, an apparatus reliant on this source would be crippled if asked to respond outside of its home territory. This would have serious implications in situations of widespread natural disasters or homeland security events where apparatus may be sent long distances for mutual aid or support.

[9] City of Seattle FD, Fire-Fighter Near Miss, Auto Fire with Compressed Natural Gas (CNG) Fuel Tank Explosion, April 2, 2007
[10] CRS Report for Congress *Liquefied Natural Gas (LNG) Import Terminals: Siting, Safety and Regulation* January 28, 2004

  - Fire apparatus need to be refuel on the fire scene without shutting down the engine. While diesel fuel is readily available from a mobile source, there is no current infrastructure of mobile CNG or LNG refueling vehicles prepared to respond to a fire scene.
- Safety
  - Given the high-pressure and highly explosive nature of CNG or LNG, it is probably more prudent to stick with diesel fuel when working around fires.

Disclaimer

The concerns outlined in this paper are not intended to reflect on the application of CNG or LNG to transportation markets other than the fire industry. The content is intended to provide fire personnel with an overview of the topic, and to point out the issues that must be considered.