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Technical Statement on Commercial Natural Gas in CNG- and LNG-Fueled Mobile Heavy-Duty Engine Applications

EXECUTIVE SUMMARY

Commercial natural gas utilized as a compressed natural gas (CNG) or liquefied natural gas (LNG) fuel in mobile heavy-duty engine applications must consistently demonstrate specific properties to achieve desired performance requirements; however, no national or international government or private organization has adopted a specification for natural gas as an engine fuel. To that end, the Truck and Engine Manufacturers Association (EMA) has developed the following recommended specifications for the purpose of identifying a standard commercial CNG or LNG fuel with consistent properties suitable for testing and evaluation:

- Methane Number (AVL method or other, as specified): 80 minimum
- Lower Heating Value (BTU/scf): 900 minimum, 1000 maximum
- Total Sulfur Content (ppm by volume): 15 maximum
- Hydrogen Sulfide Content (ppm by volume): 3 maximum
- Water content/Dew Point: 10°F (6°C) below coldest winter ambient temperature expected

INTRODUCTION

EMA is an international membership organization representing the interests of, among others, manufacturers of heavy-duty internal combustion engines used in on- and off-highway applications.

Natural gas fuels, including CNG and LNG, have been used in heavy-duty internal combustion engines for many years. Until recently, however, their use principally has been associated with stationary engines. As expectations regarding their expanded use in mobile heavy-duty applications continue to rise, so, too, do manufacturers' concerns regarding the composition of the fuel that will be used in those engines. For example, while stationary source users have, to date, been able to "customize" engines to meet emission and performance needs using natural gas available at a single location, mobile source engines must have a consistent fuel available regardless of the refueling location and require either CNG or LNG fuel to provide adequate operation between refueling.

EMA recommends that government agencies responsible for the regulation of natural gas, as well as natural gas producers, distributors, and users, consider the adoption of specifications for commercial natural gas designed for use in CNG- and LNG-fueled mobile heavy-duty internal combustion engines. Ideally, natural gas fuel with the recommended specifications would be available through the pipeline. To the extent that any pipeline modifications necessary to accommodate those specifications would be too costly, the fuel should be made available at compression or liquefaction facilities throughout the nation.

CONSIDERATIONS IN THE DEVELOPMENT OF NATURAL GAS SPECIFICATIONS

Natural gas is a naturally occurring gas mixture consisting primarily of methane, combined with other hydrocarbons, carbon dioxide, nitrogen and hydrogen sulfide. It is an energy source used widely for heating, cooking, and electricity generation and, to a much more limited extent, as a fuel for engines and vehicles.

Raw natural gas must undergo processing to remove impurities, including water, to meet the specifications of a marketable fuel. The by-products of such processing include ethane, propane, butanes, pentanes, and higher molecular weight hydrocarbons; hydrogen sulfide (which may be converted into pure sulfur); carbon dioxide; water vapor; and sometimes helium and nitrogen.

The United States Environmental Protection Agency has adopted specifications for natural gas as a certification test fuel. See, 40 CFR Part 86.113 and 40 CFR Part 1065.715. No national or international government or private organization, however, has adopted a specification for natural gas utilized as a CNG or LNG engine fuel. The only known U.S. specification for such fuel is set forth in Title 13 Section 2292.5 of the California Code of Regulations.

Specifications for pipeline natural gas designed for use in internal combustion engine applications typically are different from natural gas properties defined by regional utility gas companies and gas interchange pipeline requirements, as well as those associated with other gas sources, such as landfill gas, digester gas, and wellhead gas.

When used in mobile heavy-duty internal combustion engines, natural gas must meet criteria designed to provide the engine with acceptable power, performance, durability, and exhaust emission levels. Those criteria remain consistent regardless of the state of the fuel *i.e.,* gaseous, compressed (as CNG), or liquefied (as LNG). It is critically important that minimum acceptable specifications for commercial natural gas used as a CNG or LNG fuel in mobile heavy-duty engines (for purposes of this Statement defined as “Standard Natural Gas”) be defined. The following factors should be taken into consideration when determining Standard Natural Gas specifications.

Engine Operation, Performance, and Durability

Two distinctly different heavy-duty internal combustion engine systems use Standard Natural Gas as a fuel: premixed combustion systems and diffusion combustion systems. Thus, any specifications adopted for Standard Natural Gas must address the needs of both systems.

In premixed combustion systems, gaseous fuel is present in the combustion chamber before combustion is initiated at the desired point in the engine cycle by either an electric spark (in spark-ignition engines) or injection of a second fuel (in dual fueled engines). Such systems use “Methane Number” to indicate the propensity of the premixed fuel to ignite spontaneously before the intended and desired initiation of combustion. If the controlled initiation of combustion is lost to a spontaneous process, severe engine damage can result. Thus, for premixed engines, maintenance of an appropriate minimum Methane Number is critical to engine durability.

Diffusion combustion engines inject natural gas directly into the engine's combustion chamber under high pressure at a point in the engine cycle when immediate initiation of combustion is desired.

The fuel metering systems for CNG- or LNG-fueled heavy-duty internal combustion engines vary widely in design both between and within the above described combustion systems. Nevertheless, they all must respond to engine demand and deliver the appropriate amount of fuel to provide the required power at operating conditions. That "appropriate amount" of fuel is determined not only by the volume of fuel delivered, but also by the energy content of the fuel.

The heating value of a gas is a direct measure of the fuel's energy content per volume or mass. There are two heating value measurements: higher heating value (HHV) (otherwise known as the gross heating value (GHV)) and lower heating value (LHV) (otherwise known as net heating value (NHV)). Heating values differ based on the condensation of water. Engine combustion does not benefit from the energy content associated with the condensation of water.

The heating value of the fuel must be maintained within designated limits or the fuel system will either be incapable of delivering enough fuel (in the case of a fuel with a low LHV) or it will not have proper resolution to control the low flows needed at low power and idle (in the case of high LHV). In addition, many engines have no ability to sense the heating value of the fuel, so a change in heating value will affect the power output, possibly damaging the engine or power system if the LHV is too high.

An alternative measure of energy content available in natural gas is the Wobbe Index. Similar to LHV and HHV, the Wobbe Index can be expressed as either net or gross; whereby the Net Wobbe Index is determined by the LHV normalized by the square root of the gas specific gravity, and the Gross Wobbe Index is determined by the HHV normalized by the square root of the gas specific gravity. The Wobbe Index provides a viable comparison of fuels for combustion systems that utilize steady-state flow through an orifice, such as burners, but generally is not as effective for systems with variable flow, such as engines.

Regardless of the combustion system, the hydrogen sulfide content of the fuel must be controlled to prevent damage to internal engine components.

Emission Characteristics

The engine-out emissions from natural gas fueled internal combustion engines can be as low as those of diesel engines with sophisticated aftertreatment systems; however, precise control of stoichiometric combustion is required to achieve that result. At the same time, engine operation and the related emission characteristics are dependent on the Methane Number and the LHV of the fuel. Therefore, the fuel's Methane Number and LHV must fall within the recommended limits.

Emissions from premixed natural gas fueled internal combustion engines usually show trade-offs between NOx emissions and incomplete combustion emissions (*i.e.*, carbon monoxide (CO) and hydrocarbons (HC)). Emissions from diffusion natural gas fueled internal combustion engines are typically low in CO and HC emissions, with NOx emissions higher than those from premixed natural gas engines but lower than those from conventional diesel engines. Most of those trade-offs, however, are not of sufficient magnitude to eliminate the need for aftertreatment emission control devices.

Regardless of the combustion process and the aftertreatment system utilized for exhaust emission control, the fuel cannot contain species (such as sulfur) that can deactivate the exhaust aftertreatment catalyst. Thus, the sulfur levels of natural gas must be controlled.

Storage and Handling

Natural gas fuel may be stored on a vehicle or piece of equipment either as a pressurized gas (CNG) or as a cryogenic liquid (LNG). CNG and LNG must be handled the same as other pressurized gases or cryogenic liquids. Additional precautions to avoid gas leaks and prevent accumulation of any leaked gas to explosive fuel-air mixtures should be taken.

CNG and LNG fuels can be stored for a significant amount of time without changes in the fuel's properties that would affect its ability to be utilized for use in heavy-duty mobile applications. Storage and handling of natural gas depends greatly on the form of the gas. Specifically, CNG must be stored at ambient temperature and high pressure. LNG must be stored at low temperature and at slightly higher than ambient pressure. The flammability and potential volatility of accumulated gas have led regulators to adopt stringent fuel storage and handling requirements. For example, storage and handling facilities typically include a venting system that diverts gas to a safe atmospheric location in the event of a system component failure.

Transfer of either CNG or LNG from a bulk storage facility to a mobile heavy-duty engine source requires both facility compatibility and operator training. For example, CNG typically is delivered at 3600 psi requiring that the fuel transfer system reliably deliver the fuel at that pressure without leakage. Similarly, LNG is typically delivered at -260 °F (-160 °C) requiring that the fuel transfer equipment maintain its integrity even though it is subject to significant temperature changes between atmospheric and cryogenic levels.

Health and Safety

By itself, natural gas will not ignite. For ignition to occur, an air to gas mixture of between 4 and 14 percent and an ignition source with a temperature of 1100 °F (593 °C) or more are required.

Natural gas has no odor; for safety purposes, however, it is typically treated during processing with a sulfur-containing odorant to make it more easily detectable. Although required, the sulfur content needs to be controlled because of its effect on exhaust aftertreatment catalysts described under "Emission Characteristics" above, and the hydrogen sulfide levels must be further controlled to prevent damage to other engine components.

Natural gas is not toxic, but it can produce carbon monoxide (CO) if it does not burn completely. Engines operating on CNG or LNG can burn the fuel completely, resulting in very low CO emissions or can operate relatively rich, resulting in incomplete combustion and high CO emission levels. Thus, it is very important that such engines be properly maintained and CO levels monitored, particularly if the gas properties vary over time. In addition, ambient air CO levels should be monitored at refueling stations and in any confined space in which the engine may be operated to avoid the formation of flammable or explosive fuel-air mixtures.

Warranties

Engine manufacturers are legally required to provide an emissions warranty on their products (which are certified using EPA's natural gas test fuel specification) and, typically, also provide commercial warranties regarding the use of natural gas fuel in their engines. Without a fuel specification that controls the parameters of CNG or LNG that impact engine operation, the fuel used could create warranty liability. Moreover, without an appropriate fuel specification, manufacturers cannot assess and manage warranty liability.

Economics

The cost of natural gas fuels varies depending on the geographic area, gas processing, and other factors. Pipeline natural gas fuel, not subject to specifications, currently is priced lower than petroleum-based diesel fuel on an energy equivalent basis. As noted above, however, Standard Natural Gas must meet recommended properties.

That said, the relative cost of converting an existing fleet to CNG or LNG fuel may be higher than the cost of continuing to utilize diesel fuel because of the major engine, vehicle/equipment, and refueling system changes that are required.

NATURAL GAS SPECIFICATIONS

In order to design and maintain their engines properly, EMA members and their customers require fuels having consistent properties. Thus, it is critical that Standard Natural Gas meet certain defined specifications when it is dispensed at a refueling location. Engine manufacturers have limited data regarding the use of CNG or LNG fuel with current engine technologies. Thus, EMA has developed its recommended specifications solely for the purpose of identifying a Standard Natural Gas fuel with consistent properties suitable for testing and evaluation. The development and publication of this Technical Statement does not imply or constitute an endorsement for the use of CNG or LNG by EMA or its member companies. The recommended specification is not an approved national fuel standard, and it should not be used as such.

Based on the considerations set forth below, EMA and its members recommend that Standard Natural Gas meet the following specifications:

- Methane Number (AVL method or other, as specified): 80 minimum
- Lower Heating Value (BTU/scf): 900 minimum, 1000 maximum
- Total Sulfur Content (ppm by volume): 15 maximum
- Hydrogen Sulfide Content (ppm by volume): 3 maximum
- Water content/Dew Point: 10°F (6°C) below coldest winter ambient temperature expected

Methane Content

The methane content of natural gas relates both to the fuel's energy content and its anti-knock tendencies. Depending on the equipment available to analyze fuels, methane content may be stated in terms of gas composition or anti-knock engine test parameters. In terms of gas composition, natural gas used in heavy-duty applications must meet specified concentrations of hydrocarbons (*e.g.,* methane, ethane, propane, butane, pentane, and hexane) and non-hydrocarbons (*e.g.*, hydrogen, oxygen, carbon monoxide, carbon dioxide, and nitrogen). Several gasses may be grouped together to provide processing flexibility: *e.g.,* C_3 (propane) and higher (butane, pentane, hexane, etc.); C_6 (hexane) and higher; or inerts (CO_2 (carbon dioxide) and N_2 (nitrogen)). Alternatively, gas composition can be utilized to calculate the "Methane Number" for a given fuel. EMA and its members prefer use of Methane Number because it not only provides additional flexibility regarding gas composition, but it also predicts the fuel's anti-knock characteristics. Specifically, Standard Natural Gas should demonstrate a minimum Methane Number of 80, calculated by the proprietary AVL method or an equivalent non-proprietary method.

Heating Value

LHV is preferred for engine and vehicle fuels, principally because the energy associated with the vaporization of water content included in the GHV is not available for engine power output.

In internal combustion engines in which the volume of fuel rather than the steady flow rate of the fuel is metered, the appropriate metric for heating value of a fuel is the LHV on a volume basis (units of BTU/scf or MJ/NM^3). Based on historical natural gas fuels utilized in the design, calibration, and production of heavy-duty engines, EMA and its members recommend that Standard Natural Gas meet a minimum LHV of 900 BTU/scf and a maximum LHV of 1000 BTU/scf.

Sulfur Content

As is the case with any fuel utilized in heavy-duty applications, sulfur content must be limited to prevent contamination of aftertreatment systems required to meet EPA emission standards. Similar sulfur requirements exist in other major international markets. And, emission standards requiring the use of emission control technologies that must operate only on ultra-low sulfur fuels are proliferating globally. In addition, sulfur content is critical to the durability of engine components both directly and indirectly through interaction with engine lubricants. Natural gas distribution systems typically require the inclusion of an odorant to assist detection of gas leakage, and many of those compounds contain sulfur. Therefore, it is essential to control the total sulfur content to a maximum of 15 ppm by volume of the finished gas and to limit the hydrogen sulfide levels to a maximum of 3 ppm by volume to prevent damage to other engine components when utilizing Standard Natural Gas.

Water

The water content of natural gas is another important parameter that is dependent on the gas storage and/or transportation methods used. For typical gaseous fuel transportation by pipeline, water content is prescribed by the dew point at or below the coldest winter temperature to prevent water condensation in transport; however, natural gas water content also can be influenced by pressure (CNG) or temperature (LNG). EMA and its members recommend that the maximum water content/dew point for Standard Natural Gas be 10°F (6°C) below the coldest winter ambient temperature expected at the time and location of the fuel's use. The additional margin is intended to address unexpected colder conditions.

CONCLUSIONS

- Natural gas can be a viable fuel for use in heavy-duty engines, vehicles, and equipment.
- Commercial natural gas utilized in CNG- or LNG-fueled mobile heavy-duty internal combustion engines must consistently demonstrate specific fuel properties to achieve desired performance requirements.
- Methane Number and LHV provide viable means to determine if a natural gas supply meets critical engine or vehicle operating requirements.
- Sulfur and water content are critical parameters when determining compatibility of a natural gas supply with heavy-duty mobile application requirements, as well as distribution system requirements.

EMA looks forward to the development of industry consensus standards for the use of commercial CNG and LNG in mobile heavy-duty internal combustion engines. Until such standards are available, EMA recommends that those wishing to use natural gas fuel in mobile heavy-duty engine applications utilize this Technical Statement and any additional information available from the engine manufacturer as a guide in determining if a natural gas fuel supply is satisfactory for use.

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