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FUEL ISSUES FOR GAS ENGINES AND NGVs

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ABSTRACT

Interest has grown considerably in the U.S. and worldwide in using natural gas in stationary reciprocating engines (e.g., power generation and machinery drives) as well as in natural gas vehicles (NGVs). NGVs are seen in a compressed gas form (e.g., 3000 or 3600 psig) or in a liquefied form (LNG)--both which increase the storage density of the fuel (a critical factor in the vehicle market). In many gas uses, fuel properties are not of major concern. With reciprocating engines and NGVs, however, fuel composition and property changes can impact equipment (i.e., engine and refueling station) operation and performance. Particularly in NGVs, fuel issues come to the forefront because of the *sensitivity* of some engines (e.g., those running near knock-limited power), the extreme pressure and temperature regimes in which the gaseous or liquid fuel may be exposed (relative to ambient), and the low emission targets being sought. This paper will outline many of these areas and provide an update on knowledge of fuel property cause/effect relation on stationary engine, vehicle, and NGV station operation.

INTRODUCTION

There are often complex, elusive issues which arise in the operation of stationary gas engines, NGVs, and NGV refueling stations. One of the more controversial is fuel composition, properties or "quality." Often confusion exists as to the seriousness of some fuel-related issues. In part, this results from the complexity and variability of equipment in use and the number of dimensions along which fuel properties may change and influence equipment operation and performance. The objective of this paper is to provide background and insight on the interactive effect fuel has on performance of these equipment. This is intended to help foster awareness in the industry of some of the major fuel issues, debunk some misconceptions, and provide technology and information transfer. Some of these issues (e.g., fuel metering effects) will likely be familiar, while others may be new. References are cited for those readers who want to explore these issues in more detail.

GENERAL FUEL VARIABILITY

GRI began looking into fuel issues for this market segment in 1990. A program was started with AGA Laboratories, IGT and G. Steinmetz to document fuel property variations in twenty-six major U.S. cities. This included components routinely detected by a gas chromatograph and which have a meaningful influence on fuel properties. This means individual hydrocarbons through C_5, with hexane and heavier hydrocarbons being summed up as C_6+ and assumed to be n-hexane. Carbon dioxide, nitrogen, oxygen (if present) were included; some data were collected on water and sulfur. The resulting database(1) contains over 6800 analyses collected in cooperation with the U.S. gas industry. A companion SAE technical paper was written(2) which provides an overview of selected engine/fuel issues.

Figure 1 shows the weighted average non-methane hydrocarbon species for each city sampled and Table 1 shows summary data statistics. Figure 2 shows weighted frequency distributions for various natural gas species and properties. In general, these data show reasonable consistency throughout the U.S. Some areas have extremely stable fuel, while other regions have ongoing fluctuations within a given range. Two areas of exception were identified: (1) a Rocky Mountain region where a blend of ethane and air are added to natural gas and (2) use of propane/air peakshaving by some utilities. This survey established a baseline for understanding potential variations in fuel properties and have helped in assessing fuel effects related to specific equipment operational issues. A number of these issues will be discussed in the following text.

GAS ENGINE OPERATION

Addressing fuel issues for gas engines is not trivial. Though relatively small volumes of gas engines are produced annually (compared to gasoline and diesel engines), an amazing variety of gas engine *types* exist. These include stoichiometric open-chamber engines, lean-burn open-chamber engines, and lean-burn pre-combustion chamber engines. Many are four-stroke engines, but several thousand natural gas pipeline engines (collectively, millions of horsepower) are direct-injected, spark-ignited two-strokes that in several cases have been running for decades. Most gas engines are spark-ignited, but a small portion use diesel-pilot ignition ("dual fuel" engines). Some engines are being developed which are direct-injected, compression-ignited similar to diesel engines. On top of this complexity, such engines can have a variety of engine compression ratios, boost levels, and emission control strategies. From a technical viewpoint, such diversity makes it difficult to come up with standard answers to the question of how fuel changes impact engine operation.

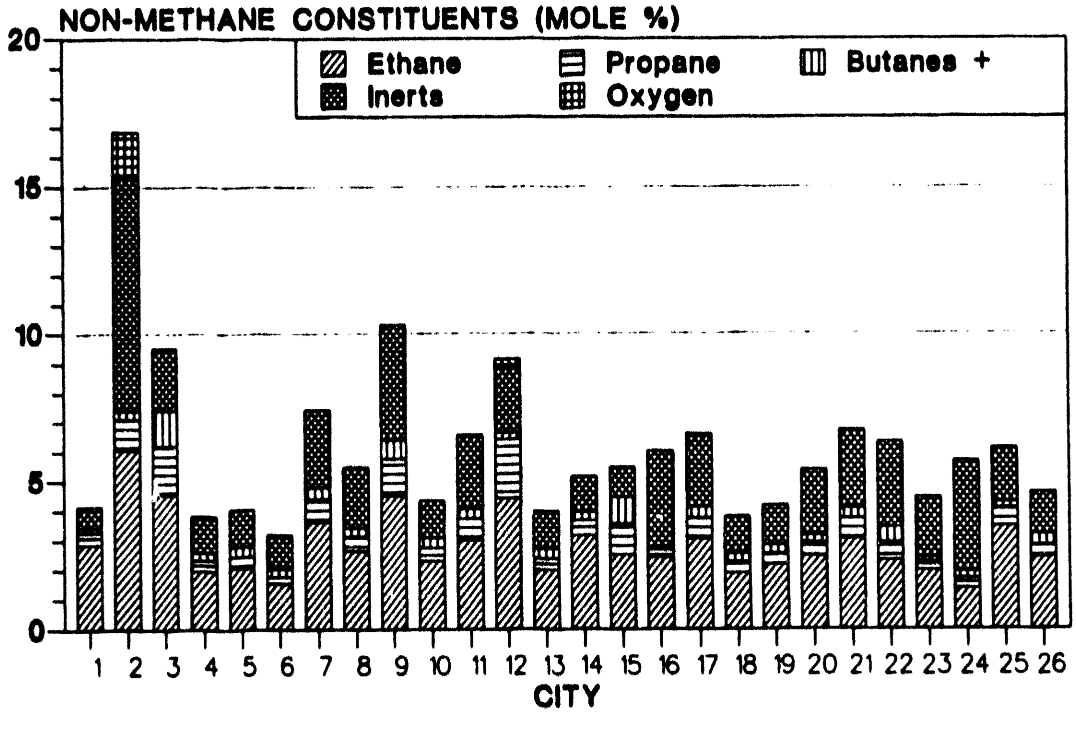

Figure 1: Weighted Average Non-Methane Hydrocarbons For 26 Cities

Figure 2: Weighted Frequency Distributions For Gas Constituents And Properties

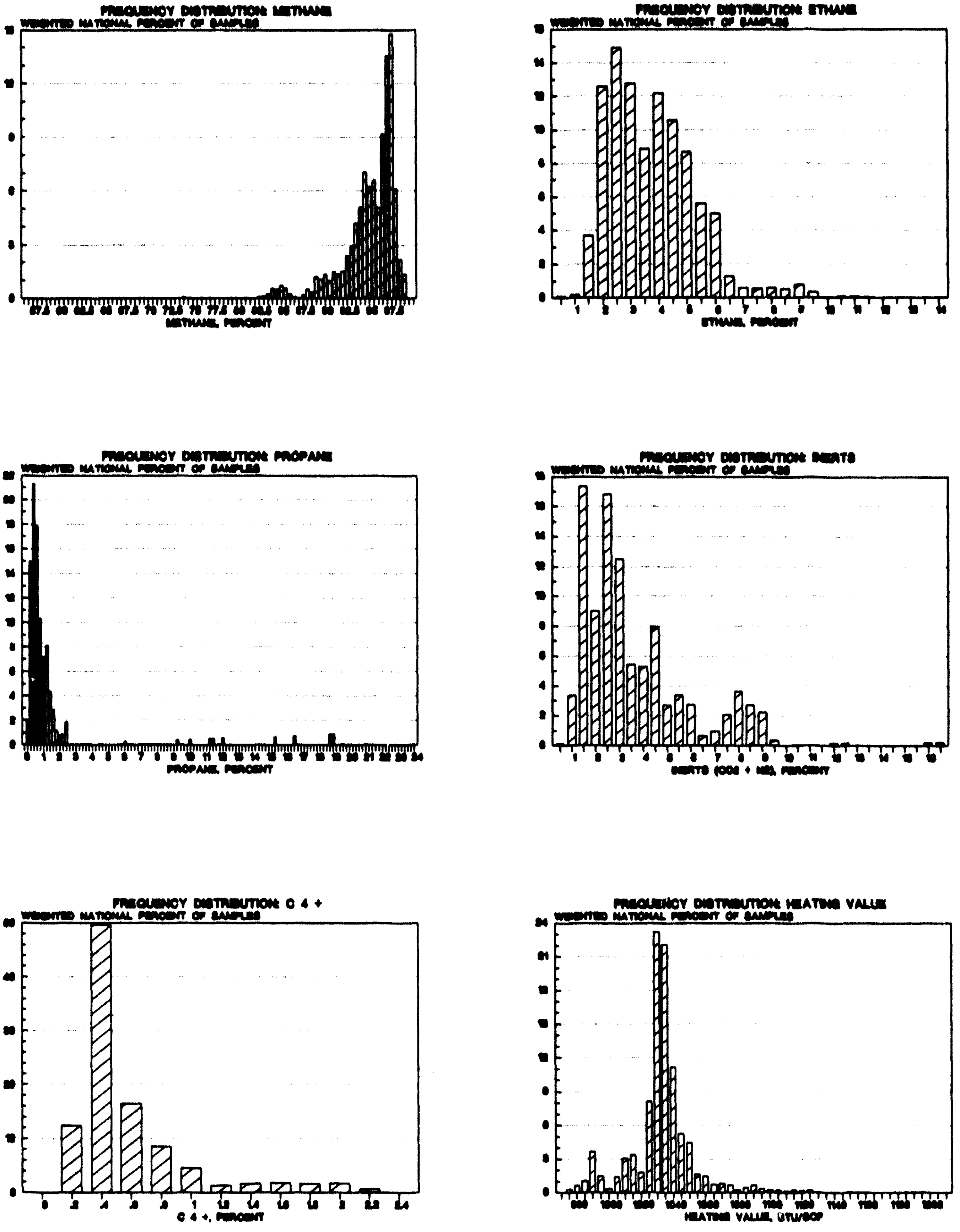

Figure 2: Weighted Frequency Distributions For Gas Constituents And Properties (cont.)

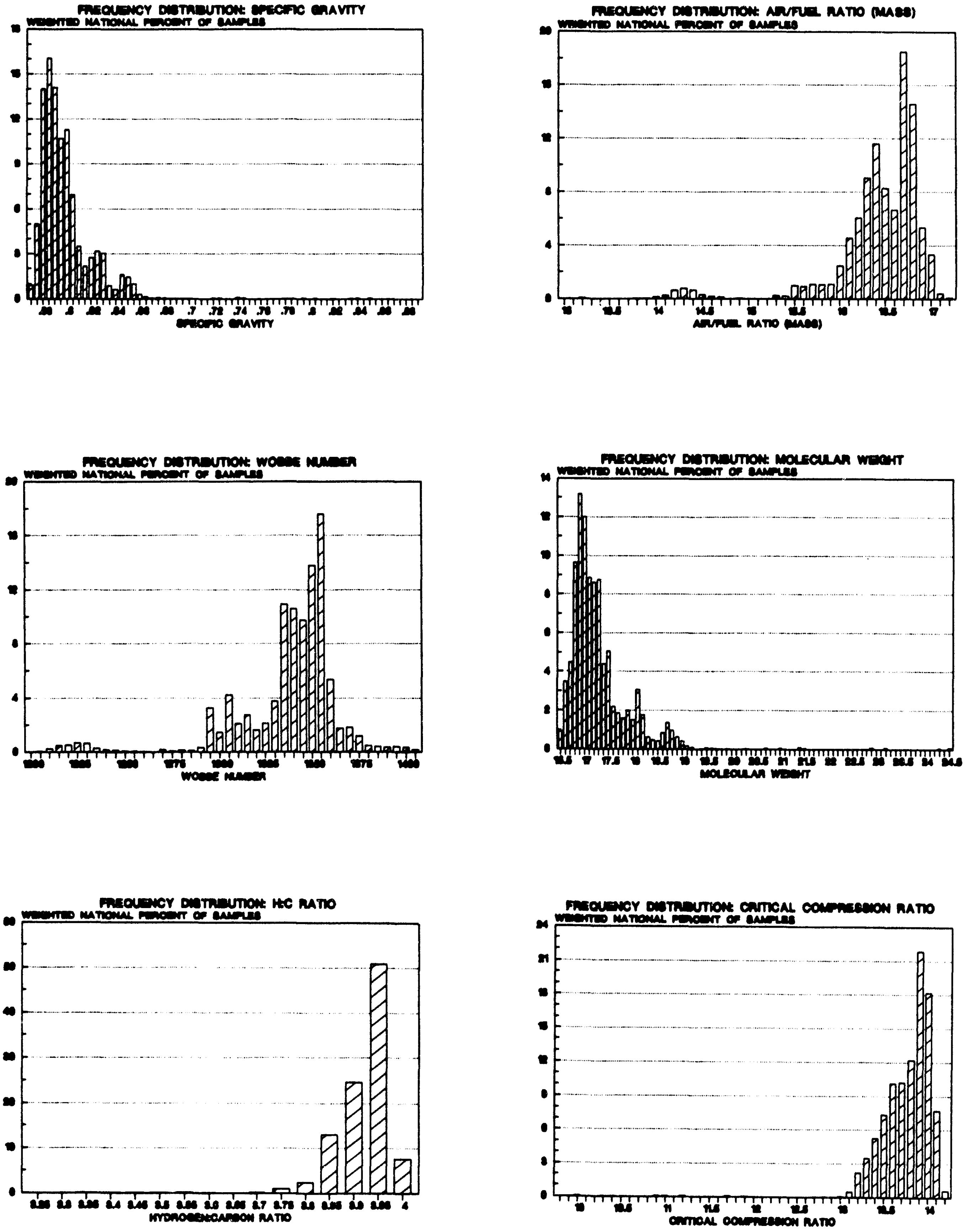

Table 1: Weighted Statistics For Natural Gas In 26 Major U.S. Cities

	Mean	Min. With P/A	Min. W/O P/A	Max. With P/A	Max W/O P/A	10th %-ile	90th %-ile
Methane (Mole %)	93.9	55.8	74.5	98.1	98.1	89.6	96.5
Ethane (Mole %)	3.2	0.5	0.5	13.3	13.3	1.5	4.8
Propane (Mole %)	0.7	0.0	0.0	23.7	2.6	0.2	1.2
C_{4+} (Mole%)	0.4	0.0	0.0	2.1	2.1	0.1	0.6
CO2, N2, O2 (Mole %)	2.6	0.0	0.0	15.1	10.0	1.0	4.3
Heating Value (BTU/scf, HHV)	1033	970	970	1208	1127	1006	1048
Heating Value (MJ/m^3, HHV)	38.46	36.14	36.14	45.00	41.97	37.48	39.03
Wobbe Number (BTU/scf)	1336	1201	1201	1418	1418	1331	1357
Wobbe Number (MJ/m^3)	49.79	44.76	44.76	52.85	52.85	49.59	50.55
Specific Gravity	0.598	0.563	0.563	0.883	0.698	0.576	0.623
Air/Fuel Ratio (Mass)	16.4	12.7	13.7	17.1	17.1	15.9	16.8
Air/Fuel Ratio (Volume)	9.7	9.1	9.1	11.4	10.6	9.4	9.9
Molecular Weight	17.3	16.4	16.4	25.5	20.2	16.7	18.0
Hydrogen/Carbon Ratio	3.92	3.24	3.68	3.97	3.97	3.82	3.95
Lower Flammability Limit, %	5.00	4.30	4.56	5.25	5.25	4.84	5.07

In the broadest sense, fuel changes impact engine operation in three key areas: (1) **fuel metering**, (2) **emissions/power characteristics**, and (3) **knock potential**. These parameters cannot be dealt with independent of each other--e.g., changes in metering accuracy can either increase or decrease emissions/power output as well as increase or decrease potential for engine knock. While recognizing this, these subtopics will be discussed as if each were independent.

Engine Fuel Metering

Like most gas appliances, fuel is delivered to gas engines via a fuel control strategy. This is done either by carburetion or through independent electronic or mechanically controlled valves (orifices). King's SAE paper(3), sponsored by GRI, illustrates basic equations describing natural gas flow through an orifice as well as an explanation of the magnitude of engine operating changes (i.e., effects) that would occur when switching between two different fuels (i.e., cause). An equation from this paper shows the following approximate relationship(1):

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1. Wobbe Number (WN) is a measure of energy flow rate through an orifice and is found by $WN = HV/\sqrt{S.G.}$. Equivalence ratio (phi, ϕ) is the actual fuel/air ratio divided by the stoichiometric fuel/air ratio (F_s). Q_c is heating value per pound and generally around 20,000-21,000 BTU/lb (LHV); HHV values are about 10% higher than LHVs.

$$\phi_2 = \phi_1 * (WN_2/WN_1) * [(Q_{c1}/Q_{c2}) * (F_{s1}/(F_{s2})]$$

In its most simplest approximation, this relation can be distilled by dropping the Q_c and F_s ratio terms because their product tends to be a constant (an interesting chemical phenomenon)(2). This means that a first-order approximation of fuel metering cause/effect on equivalence ratio is obtained by ratioing the respective Wobbe Numbers of the two fuels as follows:

$$\phi_2 = \phi_1 * (WN_2/WN_1)$$

This relation is shown graphically in Figure 3, which includes a spectrum of fuels. The direct proportionality holds true over a broad range, though the presence of inerts and oxygen/air in the lower Wobbe Number range creates some non-linearity. This relation, while *seemingly* simplistic, goes far in describing the most pervasive manner in which fuel composition impacts gas engine combustion.

In general, Wobbe Number is held fairly constant in the gas industry. The 10-90th percentile span from the fuel survey is 1331-1357, with a mean value of 1336--nominally a ± 1.5% range for most fuels. The maximum and minimum were 1418 and 1201, indicating a broader spread at the fringe. The high-ethane region identified previously has a relatively low Wobbe Number--about 8% from the mean. While different from the norm, this region does tend to have a consistently different fuel--which can aid in recalibrating equipment to this specific region. Higher Wobbe Numbers tend to be encountered in regions located close to production sources. Gases in the 1350-1400 range typically have higher levels on non-methane hydrocarbons and low levels of inert gases.

The analysis linking ϕ and WN is specific to control of a combustion device--i.e., where the concern is the ratio of fuel and air relative to stoichiometry. It is not in principle a mass/volume/energy flow metering scenario. In a classic metering relation, the primary fuel-related issue is molecular weight or specific gravity. From this perspective, the fuel survey showed that the 10-90 percentile span for specific gravity was 0.576-0.623, with an average value of 0.598. This implies that fuel-related metering impacts would be about ±4 percent, whereas the engine/combustion Wobbe Number metering effect is about a factor of two lower in impact. The reason for this significant difference is largely due to the inverse correlation that exists between specific gravity and fuel stoichiometry. That is, there is a partial cancelling effect(3). This is a perhaps a subtle issue requiring greater elaboration. The author encourages interested people to read King's paper and other sources on this subject.

With regard to mass or volumetric metering, the amount of fuel that passes through an orifice under ideal conditions is related to fuel pressure, temperature and properties--basically, density of the fuel. For example, many light-duty NGVs operate with fuel injector pressures around 100 psig. At 90 psig, fuel density in the rail drops by 8.8%, yielding a sensitivity of about 0.9% per psig. Temperature-related density sensitivity is on the order of 0.2%/°F at temperatures around 70°F. Obviously, from a metering-only viewpoint, accurate temperature and pressure measurements are at least as important as having a handle on fuel properties.

In closing, it should be recognized that accurate mass or volumetric metering of fuel to an engine is really a means to an end point--it is not the ultimate goal. For this reason, the author refrains from mentioning mass air/fuel ratio and focuses exclusively on equivalence ratio--the ultimate goal. This will

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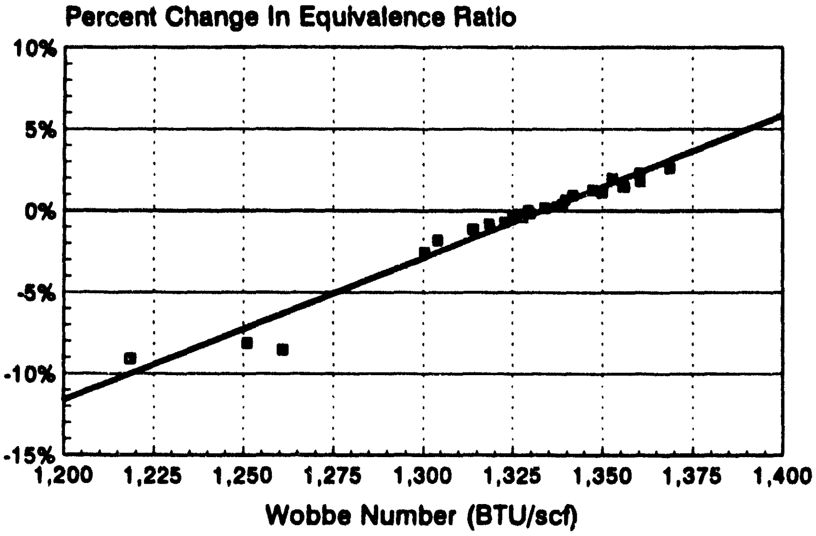
2. A broad range of natural gas fuels have an amazingly narrow $Q_c * F_s$ value of 1378-1380 BTU (HHV) per pound of air consumed (under stoichiometric combustion conditions). This relates to molecular structure and H/C ratio of the fuel. Hydrogen has a value of 1393, gasoline is about 1371, and diesel fuel is about 1281. Note that the presence of oxygen in the fuel affects this value considerably.

3. The GRI fuel survey shows the following relation between specific gravity and stoichiometric A/F ratio (mass basis). $S.G. = -0.0252 * (A/F)_s + 1.007$ with an R^2 of 0.9.



Choked-Flow Conditions, Baseline U.S. Average

Figure 3: Impact Of Wobbe Number On Equivalence Ratio

be elaborated on in the next section. In general, Wobbe Number (a key determinant for engine metering) is kept fairly constant in the gas industry (though some excursions do exist).

Engine Emissions/Performance

Many factors influence the emissions and operating performance of reciprocating engines. For those interested in this topic, two resources are recommended(4)(5). Details of this area are beyond the scope of this paper, but a linkage will be drawn with the previous discussion of fuel metering accuracy.

As a quick primer, gas engines fall into two broad classes: (1) stoichiometric (or "rich" burn) and (2) lean burn. Stoichiometric engines operate near the chemically correct mixture of air and fuel (i.e., $\phi = 1.0$) and are often equipped with three-way catalysts for control of NOx, CO, and non-methane hydrocarbon emissions. Exhaust oxygen sensors are used for feedback correction. These concepts are broadly applied on today's automobiles. The exhaust oxygen sensor is critical in that it helps correct for changes in engine condition, ambient conditions, and fuel properties.

Lean-burn gas engines operate with a large excess of air--ϕ is generally on the order of 0.6-0.7 for low-emission open-chamber lean-burn engines, while prechamber and dual-fuel engines run even leaner ($\phi = 0.46\text{-}0.6$). With turbocharging, lean-burn engines can provide low NO_x emissions and excellent full-load fuel efficiency (on the order of 36-44%, LHV depending on size and combustion system). Due to the general lack of suitable oxygen sensors, however, most of these engines operate in an "open-loop" control mode. That is, there is no feedback correction to accommodate engine, ambient or fuel changes.

Engine engineers spend many hours in engine development using dynamometers to characterize (i.e., "map") an engine. In today's climate, most of this is in fine tuning trade-offs between efficiency, power, knock limit, and emissions. In some instances, this can be a delicate balance. While obtaining low emissions in the laboratory is generally possible, an even greater challenge is to devise sensors, controls and algorithms which are capable of ensuring that "in-use" emissions are on par with lab results. This is the primary purpose of On-Board Diagnostic requirements for vehicles.

The main overriding parameter for achieving emissions consistency is equivalence ratio (ϕ, phi)--especially for premixed combustion process (note that λ, lambda, is the inverse of ϕ and termed the excess air ratio). This is well established in the literature (see Heywood) and confirmed in single-cylinder engines tests conducted by Southwest Research Institute (SwRI) for GRI(6). These tests showed no statistically significant emission effects from widely different natural gas fuels when engine equivalence ratio was held constant (reinforcing the need for control of ϕ).(4)

For most engines, NO_x control is the most difficult challenge. NO_x vs ϕ trade-off sensitivity for stoichiometric and lean-burn engines are different. On stoichiometric engines, slight changes in ϕ (e.g., 1-2 percent) to the lean side can result in dramatic increases in NO_x due to the abrupt drop-off in catalyst NOx reduction efficiency when operating lean of the peak catalyst efficiency point (which generally exists around $\phi = 1.005$-1.01). Figure 4 shows this relation. This sensitivity virtually mandates a feedback oxygen sensor to correct for all factors which influence ϕ (which includes factors beyond just fuel). Running slightly richer has less severe impact--CO and HC emissions increase marginally, but NO_x removal stays high. For this reason, stoichiometric gas engine controls typically have a strong rich bias.

The challenge for stoichiometric fuel control systems is to devise adaptive learning strategies that can recognize and accommodate expected changes in fuels and other parameters. Discussions with control experts gives indications that some existing adaptive learning strategies can effectively accommodate a broad range of natural gas fuels. (However, not all control systems are as evolved.) Presuming such systems become commonplace in the future, it is the author's opinion that combustion/emissions fuel effects on stoichiometric, naturally aspirated gas engines will likely be of minimal concern on the vast majority of natural gas fuels.

Lean-burn engines also have sensitivity to fuel/air metering accuracy, though not as dramatic as stoichiometric engines. When operating richer--e.g., with a higher Wobbe Number fuel--engine power and NO_x levels increase and knock potential increases. When operating leaner--e.g, with a lower Wobbe Number fuel--the opposite effects will occur (up to a limit). If run too lean, the engine moves beyond the flammability limit of the fuel, resulting in misfires, hesitation and possibly stalling. In practice, the cause/effect relation between fuel changes on lean-burn engines depends on the "degree of lean-ness." In general, the margin for fuel metering is about ±5 percent with open-chamber, low-emission lean-burn engines operating near $\phi = 0.675$ (though manufacturers will state that other factors "eat up" some of this margin). This is shown in Figure 5. Obviously, if the engine is running right at the "lean limit" decreases in Wobbe Number could shift the equivalence ratio beyond the flammability of the fuel(5). As in stoichiometric engines, use of exhaust feedback control systems can be a solution to fuel shifts. Reliable, durable, and cost-effective feedback sensors (e.g., wide-range oxygen sensors) are needed for most low-emission lean-burn engines.

In closing, experience with engines has shown that accurate control of ϕ is the primary goal for repeatable engine emissions and performance (at least those using spark-ignited, homogeneous combustion). Closed-loop exhaust oxygen sensors and adaptive learning algorithms are seen as the most direct, pragmatic approach to achieving this end given the known or expected variability in engine condition, ambient conditions, and fuel properties. Reliance on equipment-based solutions is warranted

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4. The importance of ϕ on engine operation cannot be overemphasized. Evaluation of engine operation or emissions based on air/fuel ratio is of questionable value. For example, an air/fuel ratio of 16.5:1 will be lean on some fuels while rich on others--air/fuel ratio must be referenced to stoichiometry to be put into proper context.

5. As discussed in King's paper, a shift in Wobbe Number may also result in a fuel with a slightly different flammability limit. This could alter the equivalence ratio at which the lean-limit exists.

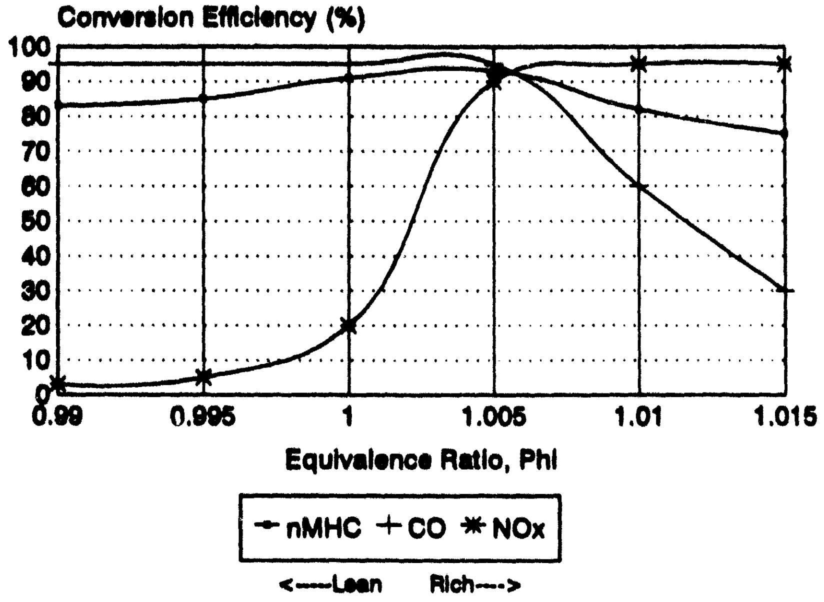

Figure 4: Influence Of Equivalence Ratio On Three-Way Catalyst Efficiency

given the low probability that wholesale changes in the operations of the natural gas industry will transpire over near-term (due to the low volumes of fuel used by engines compared to other natural gas markets).

Gas Engine "Octane Rating" and Knock Resistance

Gasoline users are familiar with the terms Octane and Octane Number. In essence, Octane Number is a non-dimensional value obtained by comparing a test fuels' resistance to knock relative to two reference fuels on a specific test engine. There are other less-common knock rating methods, such as Performance Number and Methane Number (for gaseous fuels), but Octane Number is the most widely known.

GRI-sponsored research performed at SwRI by Kubesh has applied ASTM Octane Rating methods to various natural gas fuels. These data are documented in a GRI report(7) and companion SAE paper(8). These tests show that pure methane has a Motor Octane Number (MON) index of approximately 140. Most natural gases have MONs in the range of 115-130, while peakshaving gases containing high levels of propane (e.g., 17-25%) have MON ratings of 105-110. Pure propane has a rating of about 96-97.

Kubesh developed two mathematical relations that can be used to estimate MON rating of natural gas fuels. The range of applicability of these relations cannot be stated with certainty, but it is believed to cover most conventional fuels containing saturated (i.e., paraffinic) hydrocarbons.

Linear Coefficient Relation

$$\text{MON} = 137.78 \cdot \text{Methane} + 29.948 \cdot \text{Ethane} + (-18.193) \cdot \text{Propane} + (-167.062) \cdot \text{Butane} + 181.233 \cdot CO_2 + 26.994 \cdot N_2$$

Where Methane is equal to methane mole fraction, Ethane equals ethane mole fraction, etc.

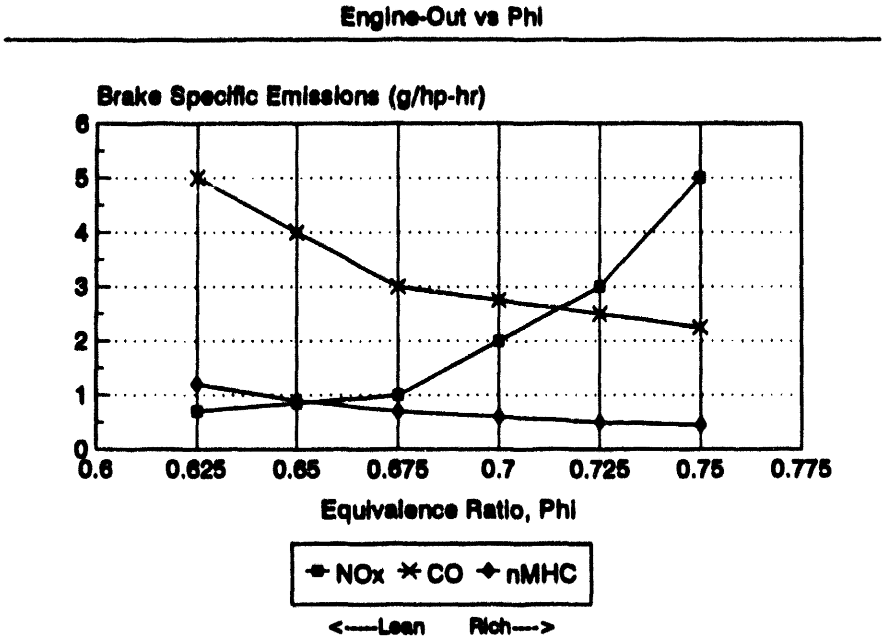

Figure 5: Influence Of Equivalence Ratio On Lean-Burn Engine Emissions

Hydrogen/Carbon Ratio Relation

$$MON = -406.14 + 508.04 * H/C - 173.55 * (H/C)^2 + 20.17 * (H/C)^3$$

Where H/C is the ratio of hydrogen atoms to carbon atoms.

These equations both provide an excellent fit to the experimental data points. Figure 6 is a graphical representation of the H/C vs MON relation.

To (possibly) help put the Octane Number scale into context, the author has modified an exhibit by Heywood[6] and incorporated data from Kubesh's work and Westbrook et al(9). Figure 7 shows the Research Octane Number[7] for a broad range of saturated (i.e., paraffinic or alkane) hydrocarbons containing up to eight carbon atoms. The basic trends are:

- Long, straight chains (i.e., "normal") hydrocarbons decrease in RON value significantly. For example, methane has a RON value of about 140 while n-heptane has an RON value of 0.
- Hydrocarbon branching generally increases RON value.

However, a simple mixing relationship cannot be used to predict the Octane Rating of a mixture of individual hydrocarbons. This is clear from the linear coefficient relationship--each hydrocarbon has a weighted impact on knock resistance. Thus, Figure 7 is mostly of academic interest--empirical

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[6] Ibid., p 472.

[7] The author has shifted between Motor (MON) and Research (RON) values because Westbrook's data only showed RON values. MON values are lower than RON due the greater severity of the MON test. On gasoline pumps, consumers normally see the average of the two [(R+M)/2].

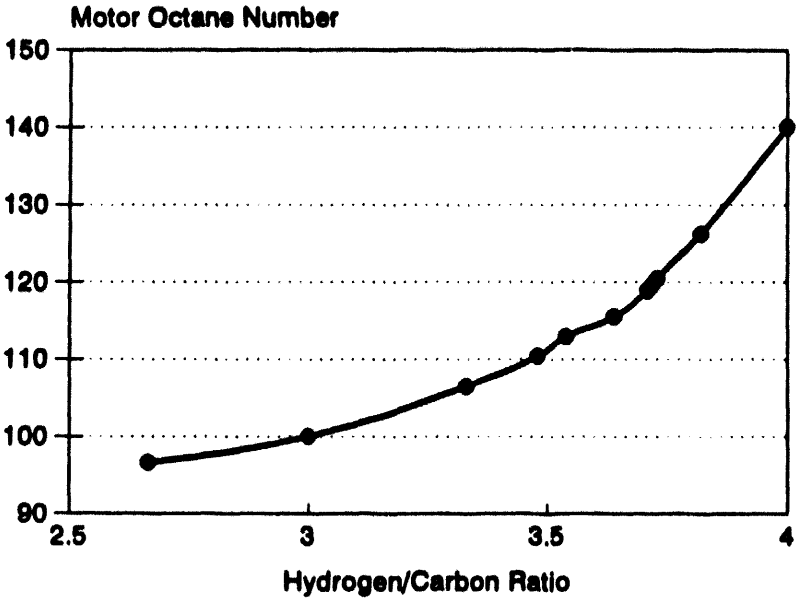


Figure 6: Correlation Of Motor Octane Number and H/C Ratio

testing is the best means of accurately determining the Octane Number of a fuel mixture.

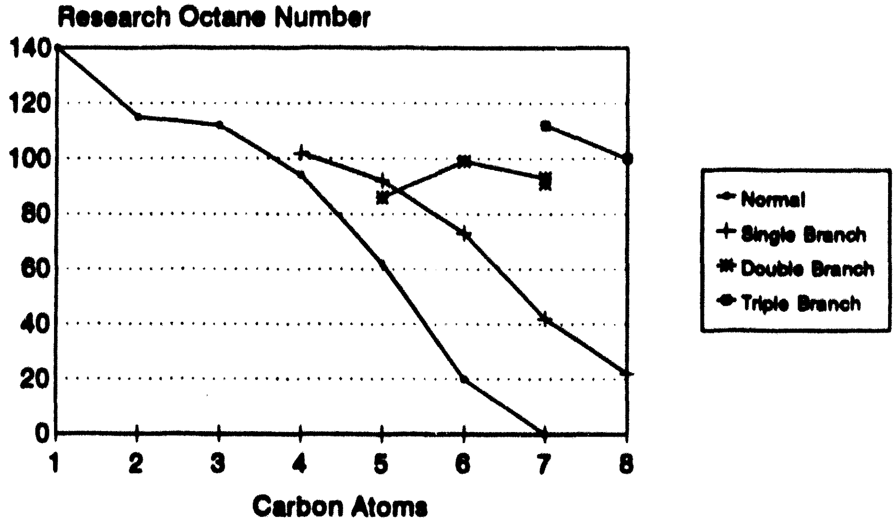
In closing, Kubesh's empirical data shows that the Octane Number of nearly all conventional natural gas fuels is extremely high on this scale. A mixture of 75% methane and 25% propane exhibited an estimated (R+M)/2 anti-knock rating of 112. From a knock resistance viewpoint, even the most outlandish gas blends have knock resistance much greater than commercial gasolines.

Gas Compression and NGV Refueling

Virtually all end-use delivered natural gas was once in a compressed state...interstate gas transportation normally occurs at 1000-1500 psig (or higher). The concept of compressing and handling high-pressure gas is not new to the gas industry. Despite this, NGVs go beyond typical transmission pressure levels (e.g., 3000-4000+ psig). What are some of the fuel issues associated with compressed gas at these levels? Examples include water content and water dewpoint, hydrocarbon dewpoint, compressibility factors, pressure-volume-temperature relations, compressed energy content, and others. These are all important factors influencing gas compression, refueling operations, retail metering, as well as vehicle operation and range. The following text will discuss some of these factors.

Heating Content, Gas Density and Vehicle Range

The most important aspect of NGVs is their fuel storage capability and driving range, which is dictated mainly by vehicle design (storage volume, tank pressure rating, and fuel economy) as well as the ability of the refueling station to *correctly* fill the tanks. Ultimately, the figure-of-merit is the amount of energy in the on-board storage tanks--which takes into account fuel heat content and compressibility. How does fuel composition relate to this? Further, the industry appears to be heading towards a unit of retail measure termed the "gasoline gallon equivalent" (GGE)--what is this and how does fuel alter this index?



SAE 912314 (Westbrook, Pitz, Leppard)
SAE 922359 (Kubesh, King, Liss)

Figure 7: Relation Between Carbon Number, Branching, and Research Octane Number

The author believes that a nominal heating content for gasoline is 114,000 BTU/gallon (lower heating value--LHV). Using an average natural gas composition as shown in Table 2, it can be estimated that 123 scf of natural gas equal a gallon of gasoline [GGE = (114,000 BTU/gallon)/(926.2 BTU/scf)]. This is an apples-apples comparison of both fuels, using lower heating values.[8]

Ideally, NGV stations should operate in a fashion that provides a constant energy density (BTU/ft^3) of compressed gas. However, much to the consternation of the gas industry, stations do not even always fill tanks to the proper pressure levels. To elaborate, compared to the ideal fill at 3000 psig @70°F, 2400 psig gives 18.2% less energy, 2600 psig gives 11.7% less energy, 2800 psig gives 5.6% less energy, and 3600 psig gives 14.3% more energy. Pressure fill inaccuracies result in a 1.4%/50 psig compressed energy sensitivity impact around the set point of 3000 psig and 70°F. Clearly, an accurate fill is an important goal for consistent vehicle range. Temperature compensation (or mass fill concepts) can lead to this ideal(10).

To see the impact of fuel on range, envision a vehicle storage system with a "water" volume capacity of 6.5 ft^3. Using our average fuel, we have 74.49 lbs of fuel at 3000 psig (6.5 ft^3*11.46 lb/ft^3) on board with a total energy content of 1,516,318 BTUs (74.49 lbs*20,356 BTU/lb = 1.516 MMBTU). Assuming a fuel economy of 15 mpg (about 7600 BTU/mile, using 114,000 BTU/gallon), this vehicle should go about 200 miles before running completely out of fuel.

With this baseline, what happens when other fuels are plugged into the calculations of GGE and energy density? Table 3 shows four fuels that are meaningfully different than the U.S. average. The 10th and 90th percentile fuels were taken directly from the fuel survey. The high-ethane was derived from the survey results of one region; the propane/air peakshaving gas is a 20% blend of propane and air (in equal proportions) mixed with 80% of the average fuel.

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[8] The standard temperature and pressure (STP) reference points are 60°F and 14.73 psia.

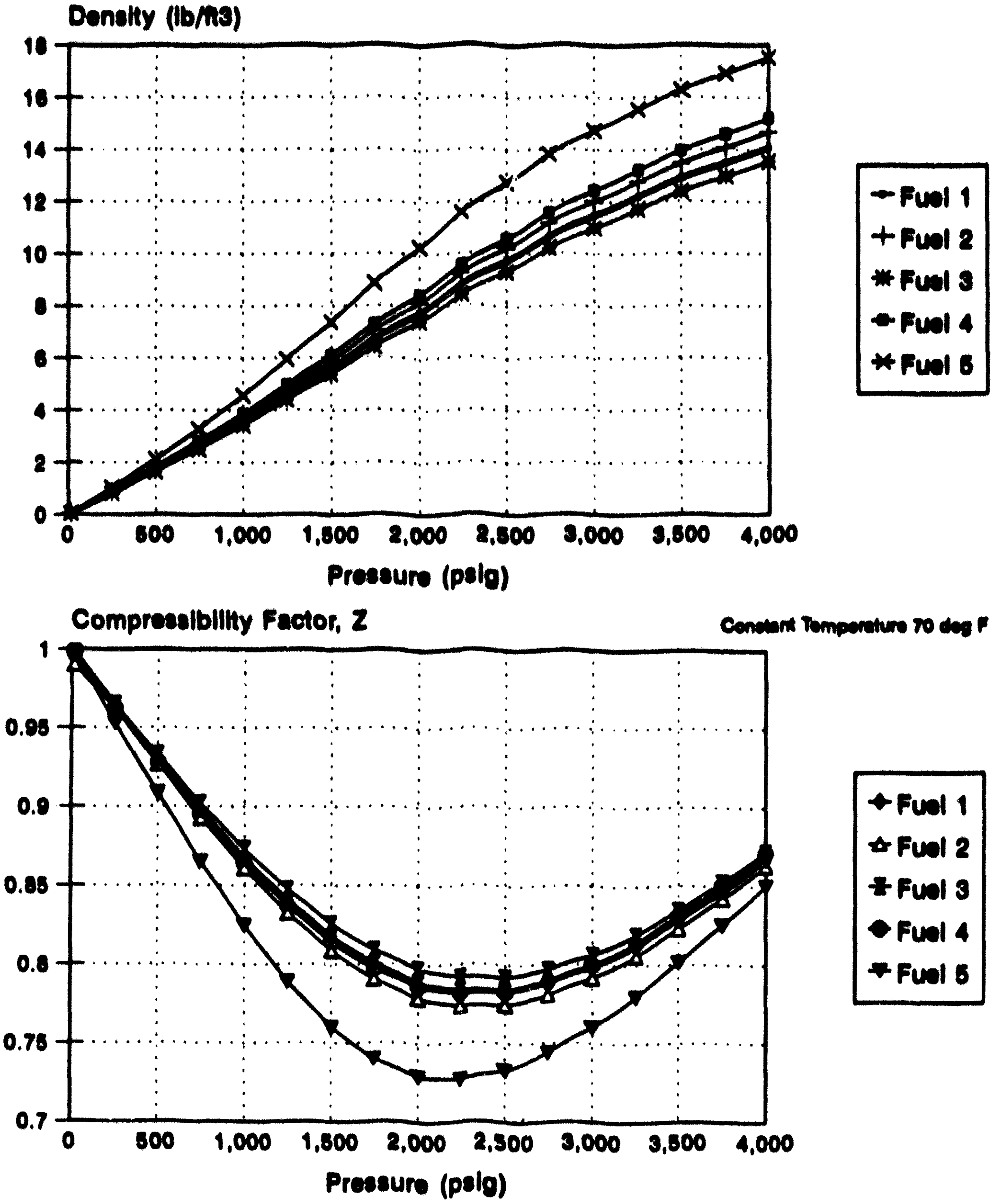


Figure 8a,b: Relationship Of Iso-Thermal Density And Compressibility Factor For Various Fuels

The differences in GGE (at STP) are shown. For the 10-90th percentile fuels, shifts in GGE value are minor--on the order of ± 0.5%. The other two atypical fuels have greater impacts (though the magnitude is not much more than "gasohol" blends have on gasoline).

With regard to compressed gas energy storage density, we see that the 10-90th percentile range for natural gas would have a nominal ±1.4% impact on vehicle driving range--about the equivalent of 50 psig underfill. The two atypical fuels--i.e., the high ethane and propane content--have larger impacts. Figures 8a,b illustrates the reason why compressed energy density is different than the GGE value (which is referenced to standard conditions). This shows how gas density and compressibility factor change with increasing pressure for each of the five fuels under constant temperature conditions. The 10-90 percentile and the average fuel fall within a fairly tight region. The density of the high ethane

Table 2: U.S. Average Composition and Properties

Species	U.S. Avg. (Mole %)	LHV (BTU/scf)	HHV (BTU/scf)	Relative Density	Spec. Volume (ft3/lb)
Methane	93.3	909.4	1010.0	.5539	23.654
Ethane	3.2	1618.7	1769.6	1.0382	12.620
Propane	0.7	2314.9	2516.1	1.5226	8.6059
n-Butane	0.08	3010.8	3262.3	2.0068	6.5291
i-Butane	0.10	3000.4	3251.9	2.0068	6.5291
n-Pentane	0.07	3706.9	4008.9	2.4912	5.2596
n-Hexane +	0.04	4403.8	4755.9	2.9755	4.4035
Carbon Dioxide	0.80	--	--	1.5196	8.6229
Nitrogen	1.71	--	--	0.9963	13.484

Calculated Values Of Average Gas Mixture

LHV (BTU/scf)	LHV (BTU/lb)	Density (lb/ft3, STP)	Density (lb/ft3 @ 3000 psig, 70oF)	Z-Factor(3000 psig, 70oF)	SCF/Gallon
926.2	20,356	0.0457	11.460	0.7988	123.1

Table 3: Comparison Of Five Diverse Fuels

Species (Mole %)	U.S. Avg.	10th %-tile	90th %-tile	Hi-Ethane	P/A Peaking
	Fuel 1	Fuel 2	Fuel 3	Fuel 4	Fuel 5
Methane	93.3	89.6	96.5	82.5	74.64
Ethane	3.2	4.6	1.8	6.9	2.59
Propane	0.7	1.15	0.4	1.0	10.56
n-Butane	0.08	0.10	0.04	0.10	0.06
i-Butane	0.10	0.12	0.06	0.11	0.08
n-Pentane	0.07	0.08	0.04	0.07	0.04
n-Hexane +	0.04	0.05	0.02	0.04	0.02
Carbon Dioxide	0.80	1.30	0.46	0.78	0.64
Nitrogen	1.71	3.00	0.68	7.1	9.18
Oxygen	0.0	0.0	0.0	1.4	2.19
Calculated Values Of Mixtures					
Heating Value (BTU/scf, LHV)	926.2	927.7	921.3	895.8	971.7
Heating Value (BTU/lb, LHV))	20,356	19,663	20,939	18,023	17,352
GGE (SCF/gallon)	123.1	122.9	123.7	127.3	117.3
GGE, % From Fuel 1	--	-0.2	0.5	3.4	-4.7
Density (lb/ft3, STP)	0.0457	0.0474	0.0442	0.0496	0.0559
Density (lb/ft3, compressed)	11.46	11.953	10.98	12.42	14.71
Compressed Energy In 6.5 ft3, (MMBTU)	1.516	1.528	1.495	1.455	1.660
Compressed Energy, % From Fuel 1	--	0.8	-1.4	-4.0	9.5

fuel is marginally higher, though Z-factor vs pressure relationship is virtually identical to the average fuel. Fuel 5, representing the propane/air blend, has a noticeably different density and compressibility relationship and yields a range increase of over 9%. This fuel is obviously different from typical fuels. Note that the values would be different at other temperature points.

In closing, understanding fuel-related range impacts requires more than evaluation of volumetric energy content--the overall determination must include analysis of gas compressibility and density at the final stored conditions. For most typical fuels encountered, there is a relatively minor fuel effect on energy storage density. Propane/air fuels tend to have a more dramatic impact on stored energy density due to their higher molecular weight and *more positive, non-ideal* behavior.(9) While fuels do have an impact on range, in practice the challenge of achieving an accurate temperature- and pressure-compensated fill tends to overwhelm the fuel issue for most conventional natural gases.

Water Content

One of the more contentious NGV fuel topics is water. This substance is found in natural gas due to natural absorption, similar to its presence in the air we breathe. Like rain and snow from the earth's atmosphere, water can condense from natural gas if the relative humidity exceeds 100%. Water becomes an issue in NGVs because of the extreme temperatures and pressures that the fuel can be exposed to, including station storage pressures from 3500-4500 psig and possible expansion-induced temperatures (at lower pressures) down to -25°F or lower. Water condensation from natural gas can be as a liquid, an ice or frost, or as a hydrate (a clathrate crystalline compound made up of water and trapped hydrocarbons).

Information on water/natural gas psychrometry is well-documented in the industry(11),(12),(13)(14). The water content of natural gas is typically quoted as a maximum of 7 lbs/MMSCF--in practice, values higher and lower do exist. Using a typical natural gas specific volume of about 21.9 ft^3/lb and a water content of 7 lbs/MMSCF, it can be found that water is about 153 ppm on a mass basis. This effectively is the absolute humidity. Using a water specific volume of 21 ft^3/lb, the volumetric concentration at STP is about 147 ppmv. Using the previous example of a 6.5 ft^3 storage system and 11.46 lbs/ft^3 compressed gas density, it can be found that the entire storage system contains about 0.011 pounds of water--or about 5 grams. Obviously, this is not a lot of mass(10).

While seemingly insignificant, problems can occur if water condenses in a concentrated fashion. Of course, the Joule-Thomson expansion--induced by pressure drop through a restriction--can cause significant gas cooling. The combination of gas cooling and tight piping, filters, or orifices can lead to possible freezing and plugging. In the author's viewpoint, herein lies the crux of the water issue in NGVs.(11)

Figure 9 shows the issue of water content in terms of 100% Relative Humidity (100% RH) as a function of gas temperature at 3000 psig. A condition (i.e., temperature and water content point)

---

9. Fluid density is inversely proportional to the compressibility factor ($\rho \propto 1/Z$). Lower Z-factors provide the opportunity for higher densities than expected by ideal gas-law calculations.

10. The author made a reference previously to air and condensation (rain and snow). It is important to note that natural gas has a water holding capacity (i.e., absolute humidity) that is two orders of magnitude (100 times) lower than air--these are really different fluids.

11. The issue of water-induced corrosion is often raised. While not meaning to trivialize an important safety issue, especially out of ignorance, the author is skeptical on this subject given the excellent track record of compressed gas cylinders for NGVs. Freezing is a more immediate, tangible issue. Further, most condensation is presumed to occur at low temperatures where condensate is a solid which is not an effective medium for corrosion processes.

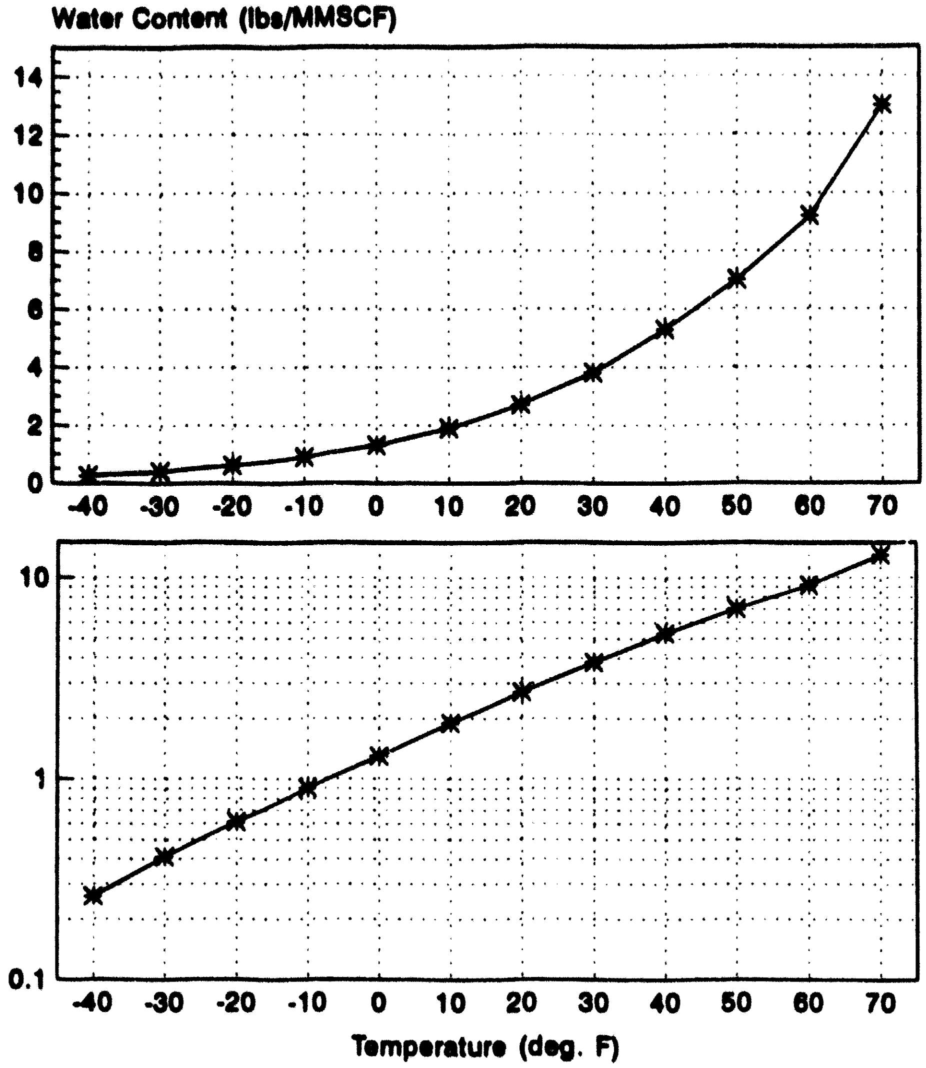


Figure 9: Natural Gas Relative Humidity

above the line represents an over-saturation condition--some form of condensation would occur to bring it down to the 100% RH line. Points below the line should be free of condensate. The amount of water that will condense is the difference between the specific condition and the 100% RH point for that temperature. At these elevated conditions, it becomes probable that water forms as a solid--certainly below 32°F. Even above this point, a solid water phase can form as a hydrate--even at temperatures up to 70°F.

To elaborate, take a gas with a water content of 7 lbs/MMSCF at 3000 psig, 70°F--just slightly below 100% RH. Assume further this gas was cooled by a drop in ambient temperature to 30°F. The saturated water content at this point is about 3.75 lbs/MMSCF at 3000 psig (in reality, tank pressure would drop to about 2500 psig, but this effect on water holding capacity is relatively small and will be ignored). Taking the difference, this implies about 3.25 lbs/MMSCF of water should condense--in this case, completely as a solid. Using the 6.5 ft^3 tank scenario, we have approximately 1630 *standard* cubic feet of compressed gas which implies about <u>2.4 grams</u> of water should condense. Is there any wonder that water is such a controversial issue in the NGV industry? Can so little mass cause *real* problems? No doubt some areas have higher water content, but many areas of the country have even drier gas.

Presently, control of water content is predicated on preventing <u>any</u> form of condensation under the most extreme winter weather conditions. In the viewpoint of many, this is seen as an extreme requirement. Referring back to Figure 9, note the leveling off of this curve as temperature drops to about 10°F. As temperature decreases further, the absolute humidity appears to approach a horizontal asymptote----i.e., a point of diminishing return seems to exist. Yet, even at extremely cold temperatures a dewpoint exists (as shown in the bottom portion where the same data are displayed on a logarithmic scale). The water holding capacity continues to decrease, but the question is, so what? For example, between -10 and -20°F the water holding capacity of natural gas has drops about 0.3 lb/MMSCF. In our 6.5 ft^3 tank scenario, we're talking about possible condensation of about 0.2 grams. Is this worthy of concern? When does water become a *de minimis* concern and dewpoint become an essentially meaningless measure? These are difficult questions to quantitatively answer.

In closing, it is likely that water will continue to remain a controversial topic in the industry. Anecdotal evidence exists on both sides to substantiate either the need or ridiculousness of tight water control measures. One point is clear to the author: dewpoints, while a measure of dryness, become of questionable worth at temperatures below about 10°F. It appears there comes a point where the specter of water problems (operational or safety-related) becomes a matter more of academic debate rather than practical concern. Hopefully, at some point in the not too distant future an acceoptable and justified limit on NGV water content can be found.

Lubricating Oils

Lubricating oil is often present in natural gas either from oil carryover from gas transmission compressors or from NGV refueling compressors. For NGVs, refueling compressors tend to have the potential for being the larger source. The actual amount of oil carried over during compressor operation is dependent on the design of the compressor, the wear on rings and liners, and (if used) the removal efficiency of coalescing filters.

The potential negative or positive role of lube oils in NGVs is uncertain. Anecdotal evidence exists that high levels of lube oil can cause build-up of liquids in tanks and regulators, possibly influencing the performance of the latter. Conversely, one could speculate that trace levels of lubricating oil may have a beneficial effect by coating internal metal surfaces (i.e., acting as a corrosion inhibitor) and possibly lubricating moving parts in the system.

It appears that several NGV station operators are tending toward non-lubricated compressors, watching more closely the level of oil consumption on lubed compressors, or installing coalescing filters downstream of the unit. Recent unreported and draft data from Powertech Labs, in work sponsored by the Canadian Gas Association(15), revealed coalescing filter oil removal efficiency of about 75% on average, with a span of 60-97% (six different samples). More information and insight is needed on this subject.

Propane-Air Peakshaving

Propane-air (P/A) peakshaving is a method used by some gas utilities to meet peak fuel demand--generally during cold winter periods. P/A plants are owned by only a portion of the industry and many of these are used sparingly. P/A plants nominally prepare a mixture of 50% propane and 50% air, having a heating value of about 1258 BTU/scf (HHV). This mix is then capable of being blended with natural gas. In practice, when use, P/A levels typically are on the order of 10-30% send out, though higher levels may be used during extreme periods.

In gas distribution systems, P/A is an acceptable medium for transporting energy to the customer. At low pressures (e.g., up to a few hundred psig) and typical ambient temperatures, P/A has a high level of solubility in natural gas. However, for NGVs, high levels of propane, elevated pressures and low temperatures can cause liquids to form. The condensation behavior of these mixtures is mostly dependent on (1) the amount of propane present and (2) the fuel temperature. Pressure has an impact, but only up to the critical point. To elaborate, Figure 10 is a phase diagram (or "envelope") of a natural gas/propane mixture (about 10.5% propane). Within the envelope, a distinct two-phase region of liquid and gas exists. Outside of this region, only one phase exists. The interpretation of this single fluid phase can be rather subjective. To the left of the envelope and below Pt. C, (the critical point) it can be called a liquid; to the right and below C it can be called a gas. Those points above Pt. C (and outside the phase envelope) are best referred to as highly compressed fluids of varying denisty. To reinforce the point, when NGV storage pressure goes above the critical point (typically ranging from 900-1500 psig depending on composition), the *gas* should really be considered a critical, high-density, single-phase fluid.

Adding propane to natural gas has the effect of extending the phase envelop to the right--i.e., raising the temperature at which condensation can occur. This increases the potential for liquids to form at typical winter conditions. To document this area, GRI has been undertaking modeling analysis with SwRI using an established commercial software package(16). The model is constructed to simulate the depressurization of a compressed gas storage tank--i.e., simulating engine fueling and dropping of pressure from a condition where the fluid is in a critical state. Nominally, the model goes from about 1800 psig to about 100 psig in 20 finite steps. Fuel temperature is held constant.

Figure 11 shows typical results. These data are a 75 mole% blend of natural gas with a 25% blend of P/A--overall, the propane level was about 13.5%. The figure shows that initially there is no change in gas-phase concentrations because the fuel is above the critical point. However, at a pressure of 1500-1600 psig there is a change in the concentrations of the gas-phase methane and propane. Effectively, the fluid has entered the two-phase region and a liquid phase has formed. The liquid is comprised mostly of propane and other heavy hydrocarbons. The transfer of mass from the gas phase to the liquid phase increases the methane concentration in the gas phase. As pressure is further

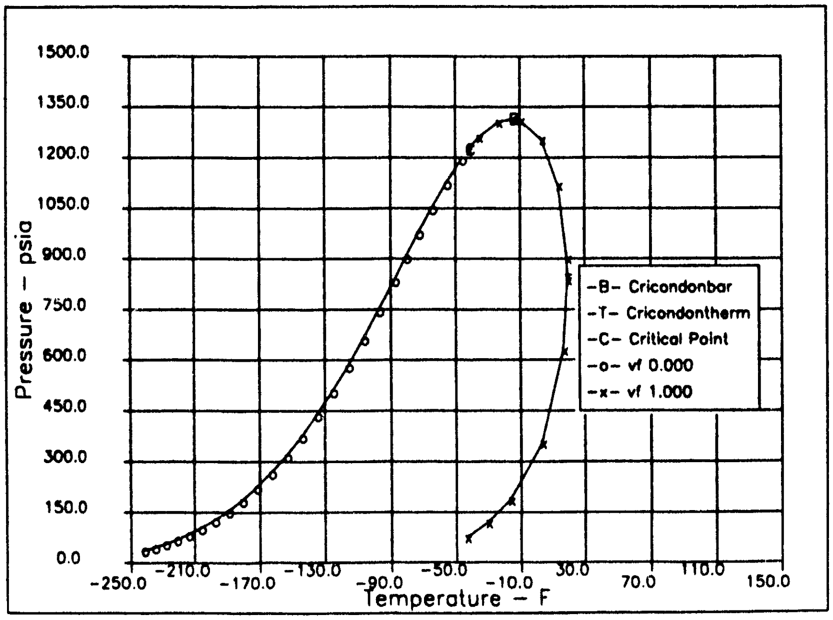
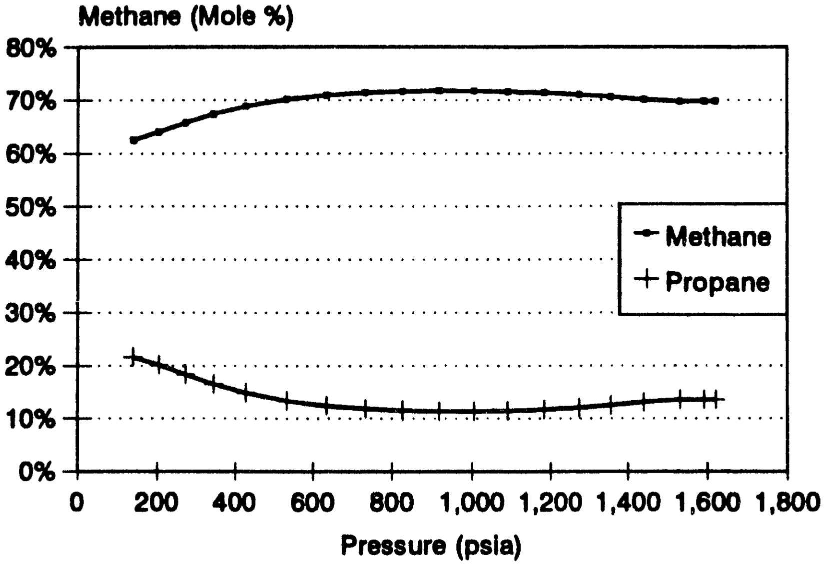


Figure 10: Pressure vs. Temperature Phase Envelope



Temp. = 20 deg. F

Figure 11: Depressurization Of A Natural Gas/Propane-Air Mixture

decreased, a minimum point is found at around 900 psig. Further drops in pressure are increasing the solubility of the liquid constituents in the gas as the mixture approachesw the right-most border of the envelope--i.e., the dewpoint curve. At low pressures, conditions exit the two-phase region and the revaporized liquid results in a final gas-phase propane concentration greater than the starting point. The greater the amount of liquid that forms initially, the greater the final propane concentration will be.

In closing, it should be recognized that P/A is not a widely used practice in the gas industry. However, for regions of the country where it is used, station operators and users should recognize that high levels of propane and low temperatures can result in liquid hydrocarbon condensation--which in turn can negatively impact station and vehicle operation.

Liquefied Natural Gas

Liquefied natural gas (LNG) is an attractive NGV fuel option because of its high energy density and lighter weight tanks (i.e., when compared to compressed gas). LNG seems to be especially attractive for use in heavy-duty engine and long-haul applications (e.g., locomotives, over-the-road trucks).

The primary fuel issue with LNG is its storability or *shelf life*. Testing and modeling work carried out by SwRI for GRI partially documented LNG NGV weathering and enrichment issues(17)(18). These data reveal that either limiting the flux of heat to LNG or quickly (e.g., within 4-7 days) using the fuel is of paramount importance. Either poorly insulated tanks (including those which loose their vacuum) or long storage periods can result in boil-off gas losses. The repeated withdrawal of these gases can result in a liquid which progressively becomes more concentrated with heavier hydrocarbons.

This phenomenon can become severe when the tank liquid level falls below ~1/4 full. This is shown if Figure 12, where the term "boil-off rate" refers to the proportion of system mass removed via the gas phase. At high liquid tank levels it is virtually impossible to alter the methane concentration (i.e., a high level of inertia exists). However, as the liquid level drops the amount of mass in the system

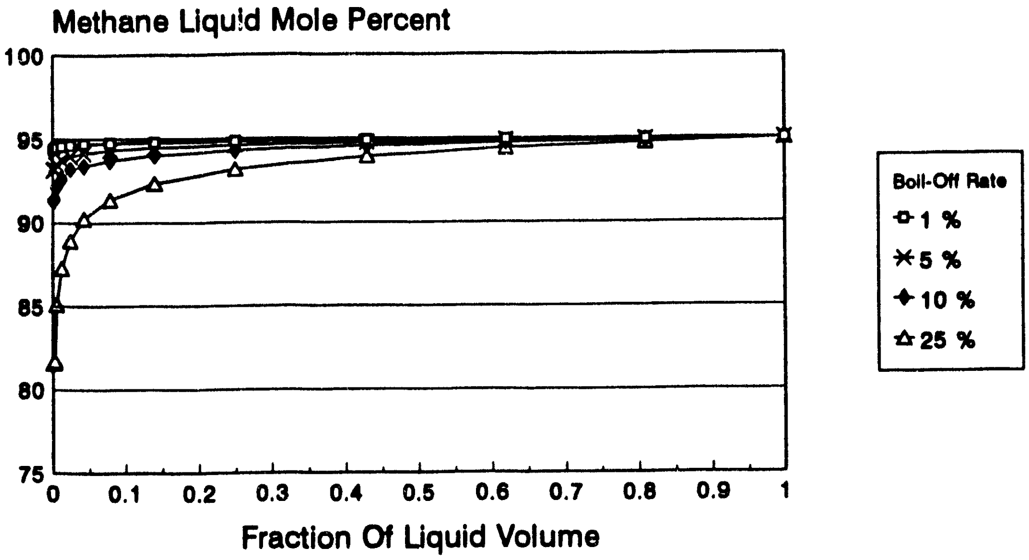


Figure 12: LNG Weathering Effects

decreases and the removal of boil-off gases can more meaningfully alter the liquid composition. For this reason, it is usually wise to keep LNG storage tanks filled. This helps increase the inertia (i.e., heat capacity) of the system. This latter point is believed to be important because the heat flux (or heat "leak") rate to the tank (BTU/hr) remains virtually constant regardless of the amount of liquid in the tank. That is, a tank containing small levels of liquids will have a higher specific rate of vaporization (i.e., moles vaporized/moles remaining) than a full tank--increasing the enrichment rate.. If LNG is left idle too long, it can effectively spoil (i.e., decrease in methane concentration). LNG has a finite shelf life.

SUMMARY

This discussion of fuel issues for NGVs goes into detail regarding potential cause/effect relations. An effort has been made to put these into context with other issues--such as sensitivities to measurement errors, requirement for advanced controls, etc. The reader should recognize that the practical reality is that NGVs are fully operational with the situation as it exists today. In most cases, equipment has a high level of tolerance to fuel changes. In fact, it should be a principal design challenge to incorporate such capabilities into refueling stations, vehicles, and engines.

By its nature, the discussion of issues and scientific phenomena on this subject tends to bring to light aspects of equipment operation for which even seasoned users are oblivious to and may appear as overly negative. In fact, many of these issues are more academic than practical. If minor effects occur, but are virtually undetectable by the user, do they really matter? From a practical standpoint, the answer is obviously no. However, as interested parties, it is in our collective interest to continue to expand our knowledge base on issues of various levels of importance--both minor or major. This is part of the evolutionary process that will make an already excellent vehicle fuel choice--natural gas--even better.

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SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

FUEL ISSUES FOR GAS ENGINES AND NGV'S

W.E. Liss, Gas Research Institute

Q. Matthew Bol, Sypher:Mueller International: What advice do you have for a utility company that wants NGV business but uses propane-air for peak shaving?

A. It depends on the amount of propane-air used. In low proportions, the mixture would not affect vehicle performance. If high levels of propane-air are needed, it would be preferable to use liquefied natural gas instead of propane-air for periods of peak demand. The utility company could import the LNG or produce it locally in off-peak periods.

Q. Vinod Duggal, Cummins Engine Co.: Do I understand that CNG from pipeline gas does not require a specification for NGV fuel?

A. The NGV market is small proportion of the natural gas market. Having a specification for vehicle fuel is a good idea because it makes the gas industry aware of what is desired. However, it may not accomplish the changes to make such fuel available at all times. It would be more practical to provide closed loop control on vehicles to accommodate fuel variations.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

MAINTAINING FUEL QUALITY: CALIFORNIA'S METHANOL EXPERIENCE

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California Energy Commission

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- Mitsubishi Motors
  Debbie Bakker
- Nissan Research and Development
  Robert Cassidy

Oil Company Support

- ARCO
  James White
- Chevron
  Greg Lyman
- Exxon
  Dave Allen
- Ultramar
  Rich Meissner
- Mobil
  J.J. Novack
- Shell
  Nancy Curry
- Texaco
  Richard Laughton

SUMMARY AND PURPOSE

* California Energy Commission Demonstration Program involving methanol (M85) fuel flexible vehicles and fuel storage and dispensing facilities.

* Determination of M85 fuel quality.

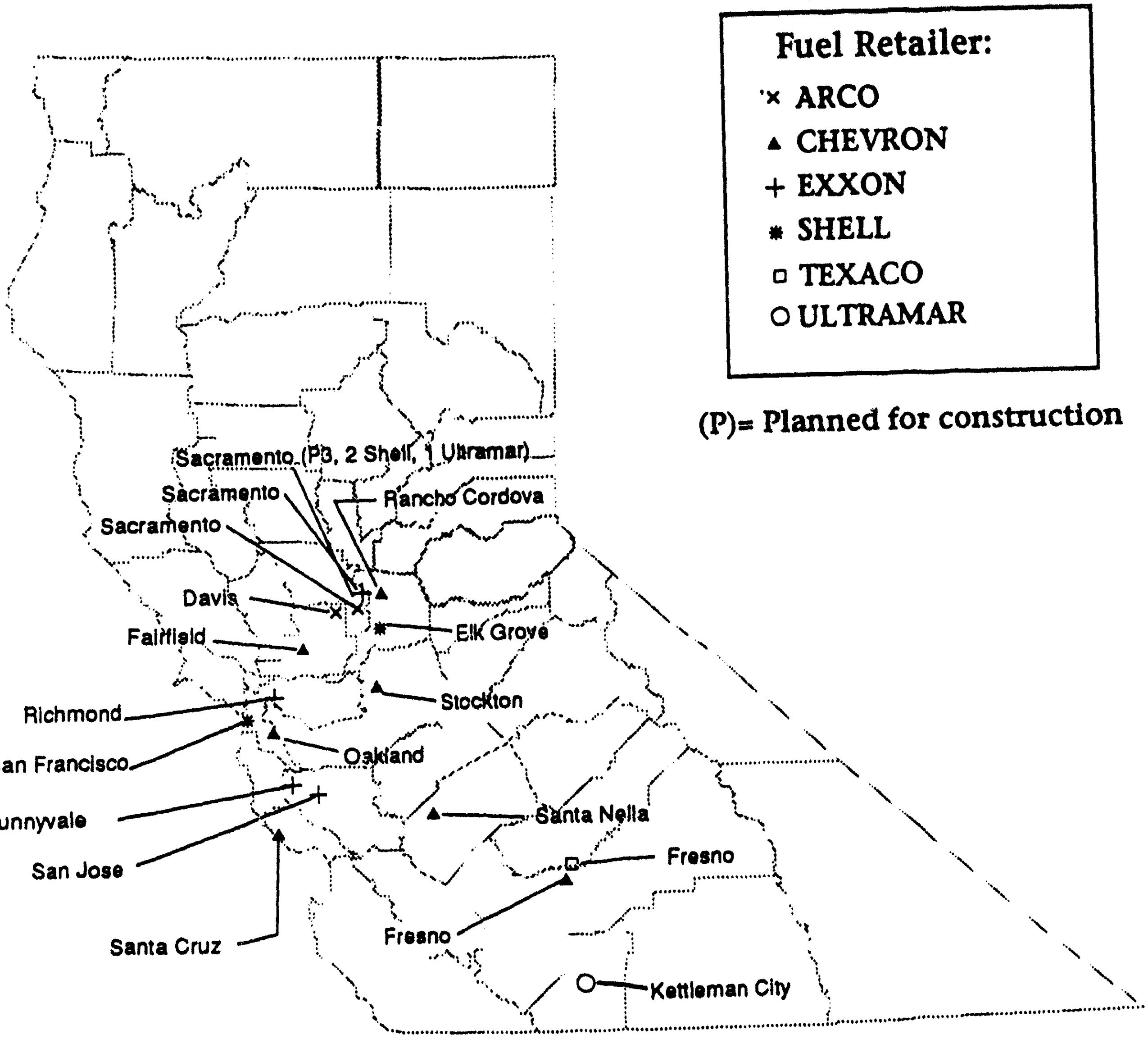
* Identify sources of possible fuel contamination.

* Suggestions for maintaining fuel quality.

CALIFORNIA M85 RETAIL NETWORK

Northern California

June 1993



(P)= Planned for construction

R. Jimenez 6/93

CALIFORNIA M85 RETAIL NETWORK

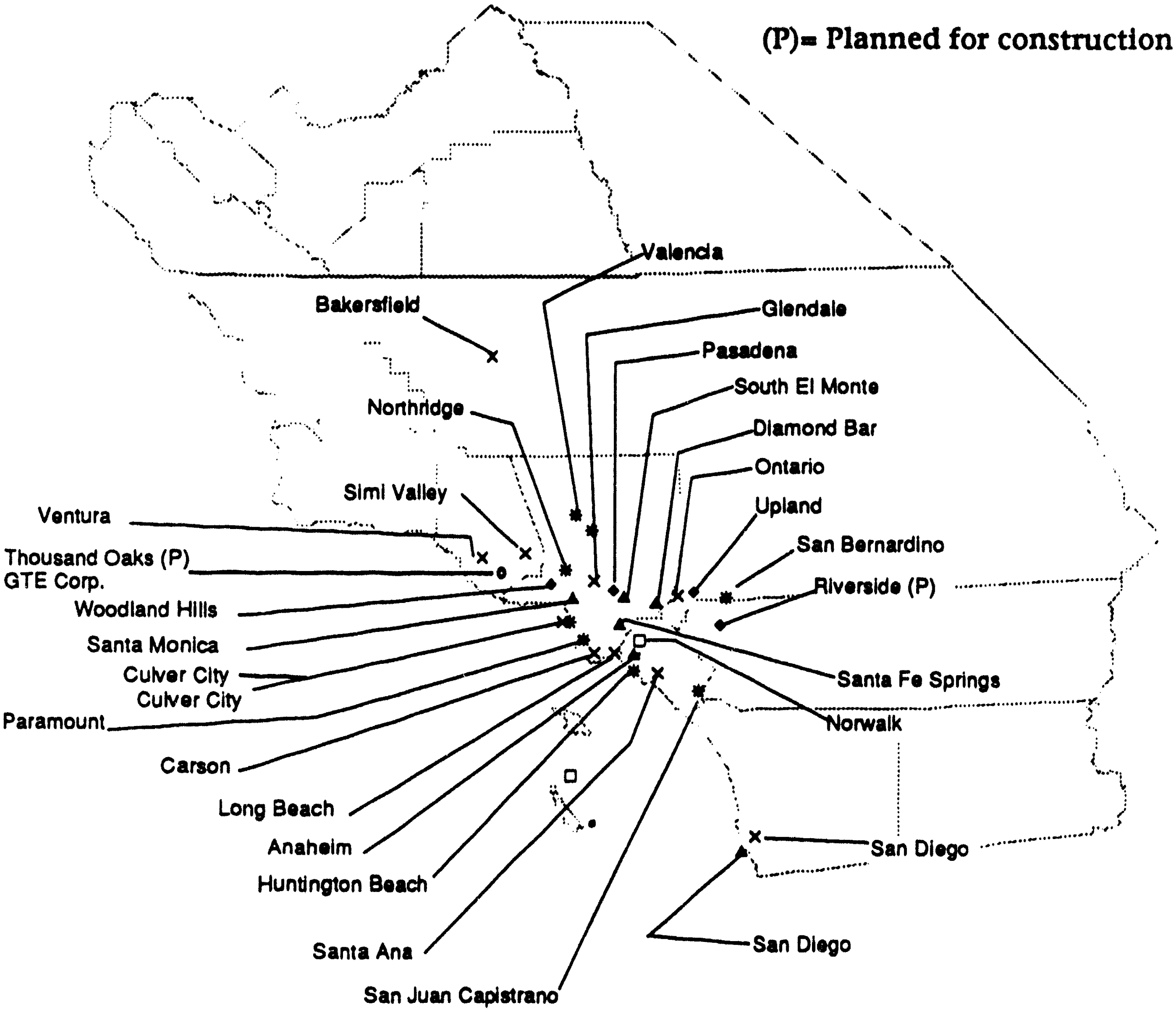
Southern California

June 1993

Fuel Retailer:

- × ARCO
- ▲ CHEVRON
- ◆ MOBIL
- ✱ SHELL
- □ TEXACO
- ○ ULTRAMAR

(P)= Planned for construction



R. Jimenez 8/93

THROUGHPUT IN SAMPLED STATIONS, GALLONS

	June 1992	May 1993
Northern California M85 Retail Total	20,595	23,909
High Sacramento	6,778	6,906
Average	1471	1708

	June 1992	May 1993
Southern California M85 Retail Total	26,322	39,461
High Ventura	5,455	7,461
Average	2025	3035

Air Resources Board M85 Specifications

Test Parameter	Test Method	Specification
Particulates, max.	ASTM D 2276-89	0.6 mg/l
Gum, washed, max.	ASTM D 381-86	5mg/100ml
Water, max.	ASTM E 203-75	0.5% by mass
Lead, max.	ASTM D 3329-88	2 mg/l
Vapor Pressure	Methods in Title 13, sec. 2262	7.0 - 13.1 psi (dependent upon geographic area)
Methanol, min.	ASTM D2 Proposal P-232, Draft 8-9-91 (Annex A-1)	84% by volume
Higher alcohols, max.	ASTM D 4815-89	2% by volume
Acidity as acetic acid, max.	ASTM D1613-85	0.005% by mass
Total chlorides, max.	ASTM D 3120-87	0.0002% by mass
Phosphorus max.	ASTM D 3231-89	0.2mg/l
Sulfur, max.	ASTM D 2622-87	0.004% by mass
Hydrocorbons + aliphatic ethers	ASTM D 4815-89	16% by volume
Luminosity	NA	Luminous flame
Appearance	ASTM D 4176-86	Free of turbidity, suspended matter and sedimant

Comparison of M85 Specifications

Test Parameter	ARB	Chrysler	Ford	GM	MVMA
Particulates, max.	●	●	●	○	●
Gum, washed, max.	●			●	
Water, max.	●	●	●	●	○
Lead, max.	●		●	●	○
Vapor pressure	●	●	○	●	●
Methanol, min.	○	●	○	○	●
Higher alcohols, max.	●			●	
Acidity as acetic acid, max.	●		○	●	○
Total chlorides, max.	●		●	○	○
Phosphorus, max.	●		●	●	○
Sulfur, max.	○		●	●	●
Hydrocarbons + aliphatic ethers	●	○		●	○
Luminosity	●				
Appearance	●				
Aromatics	●				
Gasoline (unleaded)			●		
Distillation residue, max.			●		●
Conductivity, max.				●	
Gum, unwashed, max.				●	

○ = Most stringent specification

● = Specification exists

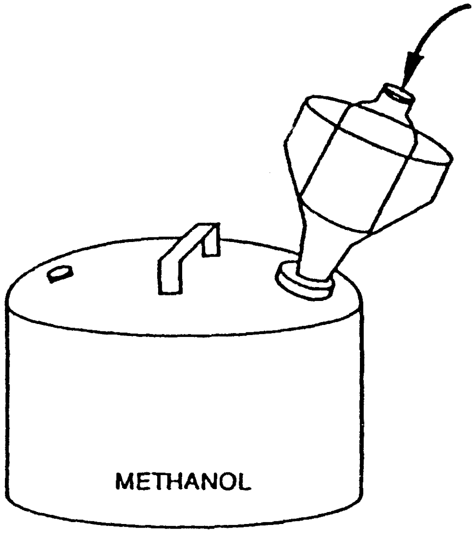
M85 ANALYSIS PROTOCOL

Property	Test Method
Electrical Conductivity	ASTM D 1125
Particulate contaminants, residue solids, and sediments	Modified EPA 160-2
Gum	ASTM 381
Water	ASTM D 1744
Lead content	ASTM D 3237
Sulfates	Ion Chromatography
Dry vapor pressure	ASTM D 4953
Aluminum	Atomic Absorption
Sodium content	Atomic Absorption
Calcium	Atomic Absorption
Iron content	Atomic Absorption
Aromatic content (vol. %)	Capillary Gas Chromatography
Methanol content	Modified ASTM D 4815
Other alcohols	Modified ASTM D 4815
Ethers	Modified ASTM D 4815
Specific gravity at 60 deg. F	ASTM D 1298
Acidity	ASTM D 1613
Total chlorides	Microcoulometry
Phosphorus content	ASTM D 3231
Sulfur content	ASTM D 3120
Refractive index	ASTM D 1218
Chlorinated hydrocarbons*	EPA 8010

*To be performed if total chlorides greater than 1ppm

FUEL SAMPLING METHOD

1. **SAMPLING EQUIPMENT**
   Amber Glass Sample Bottles with Teflon Caps, and Pre-cleaned to EPA Specifications, 5-Gallon Container, Funnel, Conductivity Meter (VWR Model 604, Serial No. 9109139), and Distilled Water



2. RINSE SAMPLE BOTTLES WITH REAGENT GRADE METHANOL

3. WITH 8 OZ BOTTLE IN THE FUNNEL IN THE 5-GALLON CONTAINER, ATTEMPT TO OBTAIN 4 OZ SAMPLE.

   -observe and record visual appearance
   -measure and record conductivity
   -seal and label bottle
   -rinse the conductivity meter cell with distilled water twice

4. OBTAIN A 1 LITER SAMP IN AN AMBER GLASS BOTTLE

FUEL SAMPLING METHOD CONT'D

5. **PUMP 4 TO 5 GALLONS INTO THE FFV (OR THE 5 GALLON CAN)**

   *Record the time
   *Record the amount of fuel

6. **OBTAIN FOUR 1 LITER SAMPLES IN AMBER GLASS BOTTLES**

   *Rinse the bottles
   *Discard the rinse into the 5 gallon can
   *Obtain four 1 liter samples
   *Seal and label the bottles

7. **STORE THE BOTTLES IN A COOLER WITH ICE**

8. **TRANSFER CONTENTS OF 5 GALLON CONTAINER TO FFV**

Summary of Analytical Results - M85 Retail

Fuel Property	ARB SPEC	Low	High	Mean
Particulates, max. (mg/l)	0.6	0.1	0.8	0.5
Gum, washed, max. (mg/100ml)	5	0.1	4.6	0.9
Water, max. (mass%)	0.5	0.0029	0.1990	0.0204
Lead, max. (mg/l)	2	<1	<1	<1
Vapor pressure (psi)	7.0-13.1	7.0	9.3	7.8
Methanol, min. (vol%)	84	80	87.2	84.6
Acidity as acetic acid, max. (mass%)	0.005	0.002	0.005	0.004
Total chlorides, max. (mass%)	0.0002	<0.0001	0.0003	0.0001
Phosphorus, max. (mg/l)	0.2	<0.03	<0.2	<0.05
Sulfur, max. (mass%)	0.004	0.0004	0.0033	0.0017

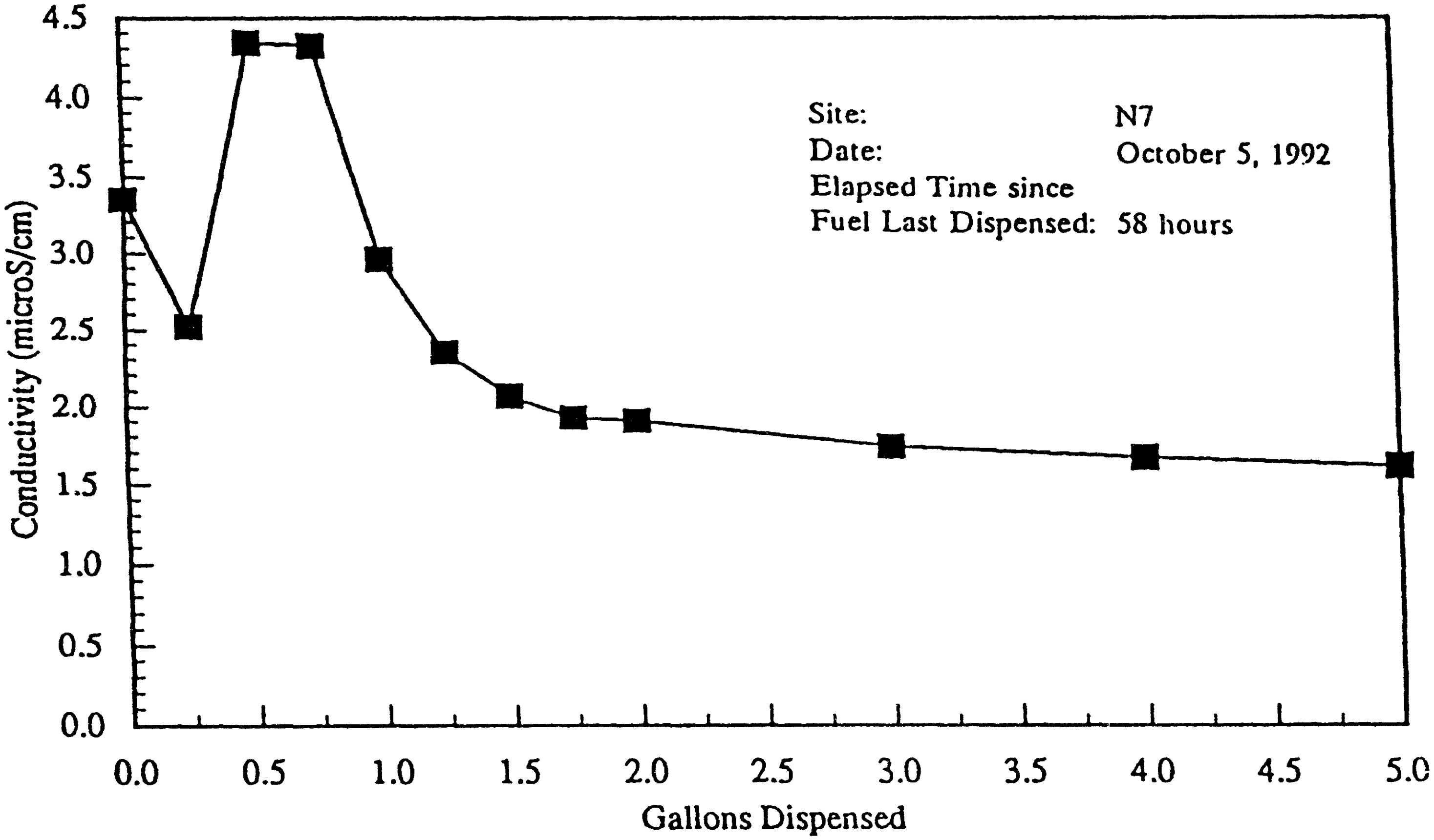
Summary of Analytical Results - M85 Non Retail

Fuel Property	ARB SPEC	Low	High	Mean
Particulates, max. (mg/l)	0.6	0.2	0.5	0.3
Gum, washed, max. (mg/100ml)	5	<0.1	0.6	0.2
Water, max. (mass%)	0.5	0.0022	0.61	0.097
Lead, max. (mg/l)	2	<1	<1	<1
Vapor pressure (psi)	7.0-13.1	7.3	9.3	7.7
Methanol, min. (vol%)	84	73.6	87.1	84.36
Acidity as acetic acid, max. (mass%)	0.005	0.003	0.010	0.004
Total chlorides, max. (mass%)	0.0002	<0.0001	<0.0001	<0.0001
Phosphorus, max. (mg/l)	0.2	<0.003	<0.2	<0.1
Sulfur, max. (mass%)	0.004	0.0004	0.0046	0.0023

ARB Specification Exceedances

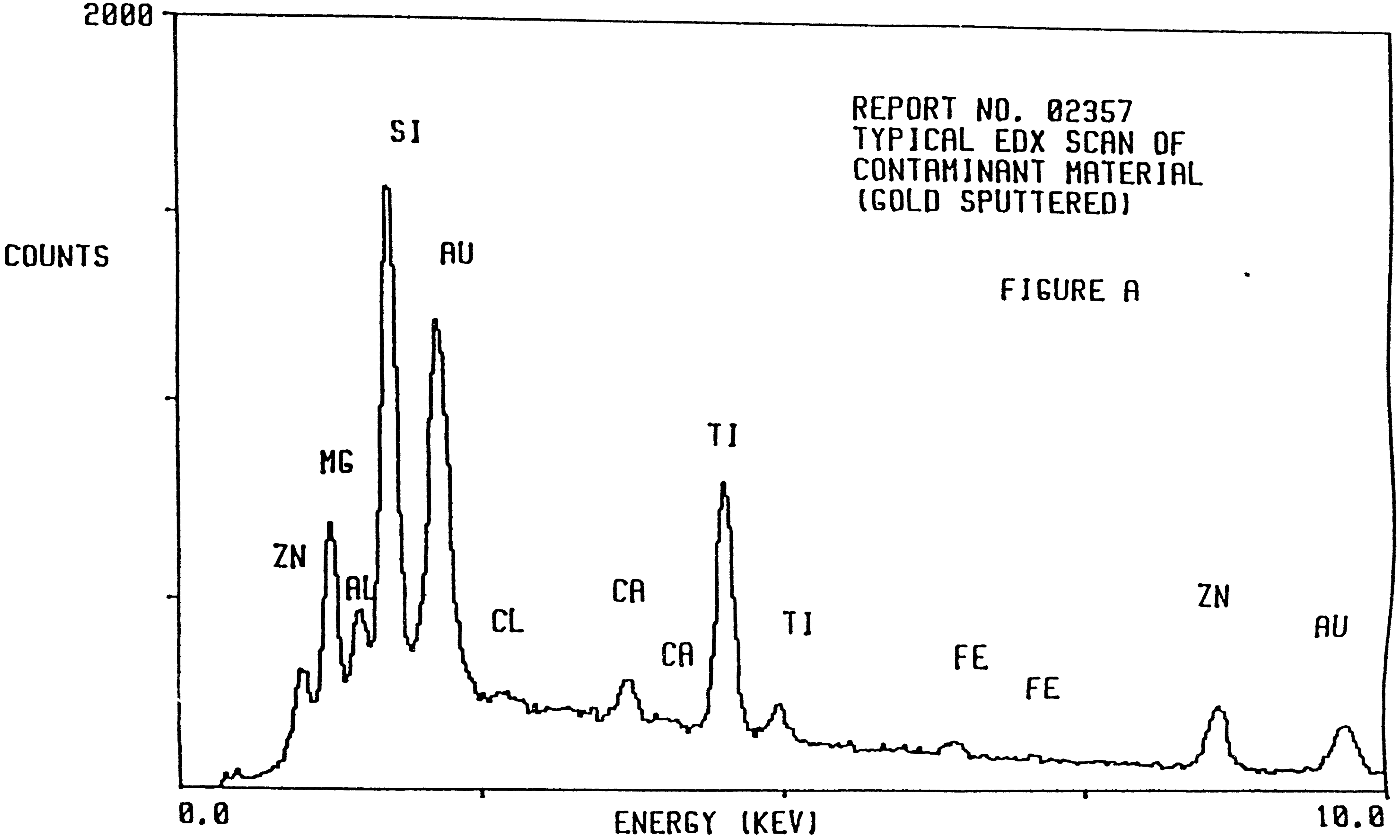
				Range to Exceedances	
Test Parameter	ARB Std.	M85 Retail	M85 Non-Retail	M85 Retail	M85 Non-Retail
Particulates, max. (mg/l)	0.6	11	—	0.7-0.8	—
Water, max. (mass%)	0.5	—	1	—	0.61
Methanol, min. (vol%)	84	6	1	80.0-83.6	73.6
Acidity as acetic acid, max. (w%)	0.005	—	1	—	0.010
Chlorides (mass%)	0.0002	1	—	0.0003	—
Sulfur, max. (mass%)	0.004	—	1	—	0.0046

Fuel Conductivity

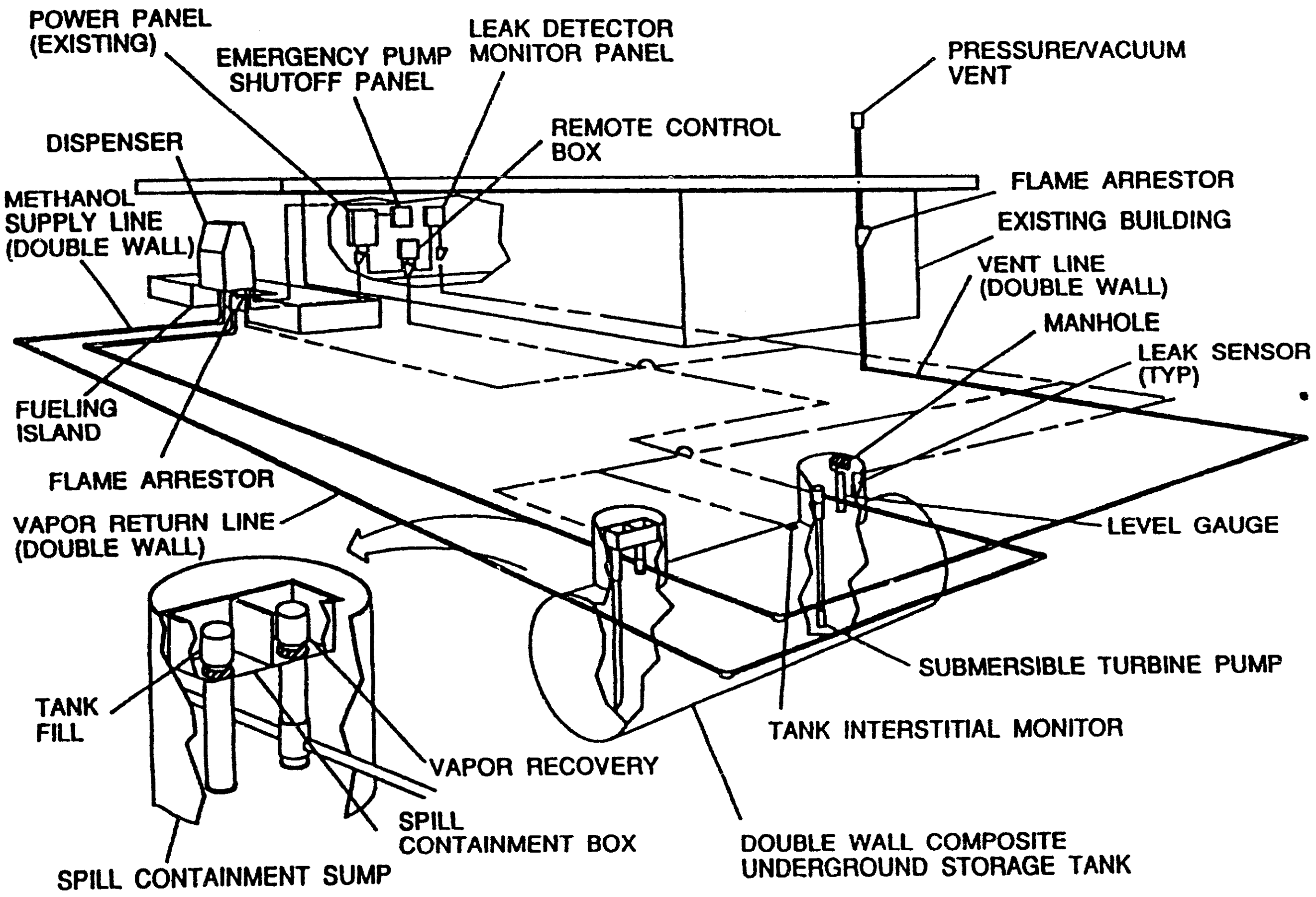


Site: N7
Date: October 5, 1992
Elapsed Time since
Fuel Last Dispensed: 58 hours

Fuel Precipitate



Generic M85 Fuel Station Design



Major Equipment Items

ITEM	MANUFACTURER	DESCRIPTION
UNDERGROUND STORAGE TANKS	OWENS-CORNING	Double-wall Fiberglass
	XERXES	Double-wall Fiberglass
	JOOR	Double-wall steel W/Fiberglass wrap
	MODERN WELDING	Double-wall Glass-steel
	TRUSCO	Double-wall steel
FILL TUBES	OPW	Model 61SOM with 1/500" annodizing
	EBW	Duratube Model No. 782-207-02
DISPENSERS	TOKHEIM	Models 1250 & 262RC Modified for M85 use
	GILBARCO	Salesmaker II modifed for M85 use
	DRESSER WAYNE	Modified for M85 use
SUBMERSIBLES TURBINE PUMPS	RED JACKET	Model A/G 75S1 3/4 HP
	TOKHEIM	Model 535-13
PIPING	AMERON	Dualloy fiberglass piping (UL listed for alcohol services)
	A.O. SMITH	Red Thread II
FLEX CONNECTORS	TITEFLEX	Stainless steel

MAJOR EQUIPMENT ITEMS CONT'D

ITEM	MANUFACTURER	DESCRIPTION
ENVIRONMENTAL MONITORING SYSTEM	API/RONAN POLLULERT CEI TIDEL	Miscellaneous Tank, sump, and image probes, line pressure sensors, etc.
IN-LINE FLAME ARRESTORS	PROTECTOSEAL	Models C4951F & C4952F
VAPOR RECOVERY NOZZLES	EMCO WHEATON	Electroless nickel plated A4001 & A4005
	OPW	Electroless nickel plated 11VF-4297
BREAK-A-WAY	EMCO WHEATON	Electroless nickel plated A4019-003
	OPW	66CL-0250
PRODUCT HOSE	GOODYEAR	Maxxim coaxial hose with RC58P602 tube compound
JUMPER HOSE	GOODYEAR	24" XLPE Fabchem hose with MxM roster fittings
FILTER HOUSING	AMF CUNO	Model 1B1 & 1B2 (Stainless or carbon steel)
FILTER MOUNTS	CIM-TEK	Models 50016, 50017 & 50018
FILTERS	CIM-TEK	1 Micron microglass inserts for 1B1 & 1B2 1 Micron microglass 70025-B
CARD READER	NBCS	GCII reader, dosc & pedestal

POTENTIAL SOURCES OF PROBLEMS

1. **ALUMINUM EQUIPMENT**
    - * DISPENSER FITTINGS
    - * NOZZLES
    - * COAXIAL ADAPTERS/VAPOR VALVES
    - * DROP FILL TUBE
    - * FILTER HOUSING OR FITTINGS
2. **INCOMPATIBLE SUBMERSIBLE TURBINE PUMPS**
3. **GALVANIZED METAL PIPING**
4. **INCOMPATIBLE HOSES**
    - * PRODUCT HOSE
    - * JUMPER HOSE
5. **INCOMPATIBLE SEALANT/PIPE DOPE**

COMPONENT UPGRADES

NOZZLES

EMCO WHEATON A4001, A4005, AND OPW 11VF-4297 VAPOR RECOVERY NOZZLES TO BE REPLACED BY ELECTROLESS NICKEL PLATED VERSIONS OF THE SAME MODEL NOZZLES.

VAPOR VALVES/COAXIAL ADAPTERS

EMCO WHEATON A226 AND A227 VAPOR VALVES TO BE REPLACED WITH EITHER EMCO WHEATON A4041-003, A4041-004, OR A4042-002 ELECTROLESS NICKEL PLATED COAXIAL ADAPTERS.

OPW 38CS-0380 COAXIAL ADAPTER TO BE RELACED WITH ELECTROLESS NICKEL PLATED VERSIONS OF THE SAME MODEL ADAPTER.

BREAKAWAYS

EMCO WHEATON A4019-003 AND OPW 66CL-0250 BREAKAWAYS TO BE REPLACED WITH ELECTROLESS NICKEL PLATED VERSION OF THE SAME MODEL BREAKAWAYS.

DISPENSER FILTER HOUSINGS/MOUNTS

ENSURE THAT THE FOLLOWING FILTER HOUSINGS OR SPIN-ON MOUNTS ARE USED:

FILTER HOUSINGS
AMF CUNO 1B1
AMF CUNO 1B2

SPIN-ON FILTER MOUNTS
CIM-TEK 50016
CIM-TEK 50017
CIM-TEK 50018

DISPENSER FILTERS

CIM-TEK 70025B (SPIN-ON)
CIM-TEK (1B1 & 1B2 INSERTS)

PRODUCT HOSE

PRODUCT HOSES TO BE GOODYEAR MAXXIM M85 COMPATIBLE HOSE (W/RC58P602 TUBE COMPOUND)

JUMPER HOSE

HARD PIPE W/BLACK IRON OR USE GOODYEAR 24" XLPE FABCHEM HOSE WITH MxM ROSTER FITTINGS

CONSTRUCTION QUALITY ASSURANCE

- M85 FUELING EQUIPMENT LIST SHOULD BE REVIEWED BY THE CALIFORNIA ENERGY COMMISSION FOR APPROVAL PRIOR TO PROCUREMENT

- EQUIPMENT SHOULD BE INSPECTED UPON RECEIPT TO ENSURE THAT IT'S THE SPECIFIC EQUIPMENT THAT WAS ORDERED

- PRIOR TO ASSEMBLY OF THE SYSTEM THE SEALANT FOR THE FITTINGS SHOULD BE VERIFIED FOR M85 COMPATIBILITY

- AFTER INSTALLATION, FUELING EQUIPMENT SHOULD BE VISUALLY AND PRESSURE TESTED FOR POSSIBLE LINE LEAKS

- PRODUCT HOSE SHOULD BE SOAKED FOR A MINIMUM OF TWENTY-FOUR HOURS IN M85 TO LEACH OUT PLASTISIZERS PRIOR TO INSTALLATION

- FUEL SAMPLES SHOULD BE TAKEN FOR VISUAL INSPECTION OF POSSIBLE PARTICULATE MATTER

CONCLUSIONS

- BASED UPON AVERAGE TEST RESULTS, M85 FUEL QUALITY MEETS ARB SPECIFICATIONS.
- HOWEVER, PARTICULATE LEVELS NEED TO BE REDUCED.
- THERE MAY BE A CORROSION-TYPE PHENOMENA THAT MAY BE OCCURRING BOTH IN THE NOZZLE AND IN THE DISPENSER.
- CONDUCTIVITY MAY BE A USEFUL INDICATOR OF POTENTIAL CONTAMINATION.
- PROTECTING OR ISOLATING ALUMINUM PARTS THAT ARE IN CONTACT WITH M85 AND THE USE OF M85 COMPATIBLE HOSES ARE REQUIRED.
- RESEARCH NEEDS TO BE DONE ON THE SEALANT WHICH SHOULD BE USED ON THE DISPENSER AND PRODUCT LINE FITTINGS. THIS INFORMATION SHOULD BE DISTRIBUTED TO THE MAINTENANCE STAFF IN THE FIELD.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

MAINTAINING FUEL QUALITY CALIFORNIA METHANOL EXPERIENCE

D. Fong, California Energy Commission

Q. Norval Horner, Amoco Canada: What is the cost of a methanol filling station?

A. CEC contributes 35 to 40 thousand dollars for the equipment that goes into a station. The oil company adds another 30 to 40 thousand dollars in engineering, design, and construction, and they are committed to operate and maintain the facility for ten years.

Q. Anonymous: Could you comment on the plan to have 2,500 new methanol outlets across the U.S.?

A. I do not have all the details, but a major supplier is ready to make methanol available where needed, on their own or through other marketers. The fleet operators are asking for more M85 stations. The oil companies should be glad to hear this if there will be more vehicles to increase fuel demand and station throughput.

We believe that there could be 20,000 flexible fuel vehicles in California in the next 2 to 3 years. A regulation by CARB would require additional fueling sites in California with emphasis in the South Coast Air Basin.

SESSION 4: INFRASTRUCTURE ISSUES

Chair: Paul Wuebben, SCAQMD

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

MICROPROCESSOR CONTROL OF NATURAL GAS VEHICLE FAST FILLS

J.Y. Guttman
Canadian Gas Research Institute

Objective of CGRI Work

- To provide fast fills to NGVs
  - Refueling in two minutes or less
  - Operation analogous to gasoline refueling

Conventional Technology

- Mechanical dome load valve stops fill by creating zero pressure drop between dispenser and vehicle fuel tank toward end of fill
  - Prolonged fills
  - Very large range of flow rates during the fill
  - Difficulty in accurate metering

Fundamentals of CGRI Approach

- Mechanical dome load valve replaced using microprocessor technology
- Utilizes a mathematical algorithm developed by CGRI
- Sensors are placed entirely in the dispenser cabinet
- No sensors are attached to the vehicle since no vehicle information is required
- Automatic compensation for different flow path properties and different vehicle storage volumes

G 9320

How Does It Work?

- Microprocessor receives sensor inputs and utilizes algorithm to estimate current vehicle fuel tank pressure 60 times per second
  - Flow of gas monitored by micro motion meter
  - Gas pressure in dispenser
  - Gas and ambient temperatures
- Microprocessor contains pre-programmed information on maximum allowable vehicle fuel pressure
- Microprocessor instantaneously closes main valve to stop fill when estimated vehicle pressure reaches allowable maximum

Test Conditions

- All mechanical dome load valves must be removed from the system in order to observe and evaluate the CGRI technology
- Ten fills correctly stopped out of twelve documented test fills
- Mathematical algorithm confirmed since random stopping of fill would unlikely be correct ten time out of twelve
- Failures related to human error

G 9322

Field Use

- Field tested by CGRI for one year, filling gas utility company vehicles at a company depot
- Extensive laboratory testing and field use by a second gas utility company in Canada
- Brief opportunity to test at a public filling station
- Installed at a public filling station in the U.S.
- Technology licensed to a manufacturer and is commercially available

Benefits of CGRI Technology

- Better protection against overfills
- Eliminates restrictions to obtain faster fills
- More accurate fills for greater travel range
- Eliminates maintenance of mechanical valves

Summary

- Based on the available data, the CGRI technology works well
- Mechanical dome load valves can be completely eliminated from the dispensing system
- The CGRI technology can provide control of all storage and dispenser functions

G 9325

MICROPROCESSOR CONTROL OF NATURAL GAS VEHICLE FAST FILLS

J.Y. Guttman and E.J. Farkas

Canadian Gas Research Institute
55 Scarsdale Road
Don Mills, Ontario
Canada M3B 2R3

Tel: (416) 447-6661
Fax: (416) 447-6757

Full consumer acceptance of natural gas as a motor vehicle fuel requires availability of a convenient and efficient "fast fill" procedure at public filling stations. Therefore, the natural gas fast fill time must be no greater than the gasoline refuelling time, i.e., less than two minutes for the typical passenger car or light truck. The natural gas vehicle must receive the maximum safe amount of fuel, for maximum range, without danger of overfilling.

The Fast Fill

Mass of fuel dispensed is not a direct indicator of the correct point at which to stop the fill. Mass of fuel is proportional to volume of on-board storage, which varies from vehicle to vehicle.

The maximum safe amount of fuel in the on-board storage is typically defined by regulatory agencies in terms of a maximum allowable pressure at a given temperature. In Canada, the maximum allowable pressure is 20.8 MPa absolute (3,000 psig) at 21.1°C (70°F). Over the year, outdoor temperatures in various parts of Canada range from -50°C to +40°C. The vehicle has been filled correctly if the pressure in the fuel tank would "settle" at 20.8 MPa if the vehicle were held indefinitely in a 21.1°C environment.

The primary factor in knowing when to stop the fill is vehicle fuel tank pressure. Temperature is less clear-cut; the temperature in the tank at the end of the fill is a function of initial and final tank pressures, as well as outdoor temperature, gas supply temperature, and fill time.

The requirement to fill in under two minutes means that flow rate must be high throughout the fill. For flow rate to be high, the driving force for flow must be high. Therefore, the pressure drop between the dispenser and the interior of the vehicle fuel tank must be significant throughout the fill. The pressure in the vehicle fuel tank during the fill is not known, complicating determination of when to stop the fill.

Drawbacks of Current Technology

Many dispensers utilize the dome load valve with a reference cylinder in order to stop fills at approximately the correct point. The dome load valve is located in the dispenser and can only sense the dispenser pressure rather than the vehicle fuel tank pressure. With the dome load valve, the correct final vehicle pressure is achieved essentially by equalization between the dispenser and the vehicle fuel tank. The result is very low flow rates toward the end of the fill.

The dome load valve is generally restrictive and, as a result, flow rates are lower than necessary throughout the fill. The dome load system is not readily able to account for the temperature increase in the vehicle tank during the fill. To ensure safety, most vehicles are, therefore, underfilled and driving range is reduced.

CGRI Microprocessor System

Canadian Gas Research Institute (CGRI) has developed a microprocessor-based system which resolves these problems. The CGRI system has been field-tested with excellent results and is available commercially.

The main points concerning the CGRI technology are the following:

- The system utilizes a proprietary mathematical algorithm developed by CGRI. The mathematical model is programmed into the microprocessor which is installed within the dispenser cabinet.

- The microprocessor receives inputs from the flow meter, from flowing gas pressure, and temperature sensors installed within the dispenser cabinet. There is also an input related to outdoor temperature.

- The CGRI system can be installed in new dispensers during manufacture or can be retrofitted to existing dispensers after removal of the dome load valve.

- The CGRI system does not require knowledge of the total volume of on-board storage. The CGRI system automatically compensates for different values of flow resistance due to different types of fittings and different tubing sizes on different vehicles.

- There is no mechanical equipment in the flow path, other than the main on-off valve within the dispenser cabinet. On the basis of the mathematical model, and using initial and current flow information, the microprocessor, typically 60 times per minute during the fill, prepares an estimate of current vehicle fuel tank pressure. When the estimated pressure reaches a pre-programmed value, the microprocessor instantaneously closes the on-off valve to stop the fill. The preprogrammed pressure values take account of the temperature increase in the tank during the fill.

Test Results

Consider a vehicle tank which contains 10 kg of fuel when the fuel tank internal pressure and temperature are 20.8 MPa and 21.1°C. On a cold day the correct final vehicle fuel tank pressure may be only 18 MPa in order to have 10 kg of fuel in the tank at the end of the fill.

The most straightforward test of the CGRI system is carried out during cold weather, when the correct final vehicle fuel tank pressure is well below the supply pressure. Under these conditions, observers can readily satisfy themselves that fills are stopped by the action of the CGRI system, rather than by equalization.

Also, the dome load valve must be removed from a dispenser in which the CGRI system is installed for test purposes. Otherwise, it is impossible to determine whether the CGRI system is working properly or not.

Two typical tests were carried out on January 16, 1990. These tests were performed with the commercial version of the CGRI system, installed at a public filling station in Mississauga, Ontario. The outdoor temperature was 4°C and at this temperature the pre-programmed pressure at which the CGRI system is supposed to stop the fill is 19.50 MPa (2815 psig).

In both fills, vehicle fuel tank pressure immediately after cessation of flow was 19.40 MPa (2800 psig). The dispenser pressure was observed continuously during the fills. The dispenser pressure toward the end of the fill was 21.47 MPa (3100 psig). in the first case and 20.78 MPa (3000 psig) in the second. Therefore the fills were correctly stopped by the CGRI microprocessor-based system, rather than by pressure equalization between the supply and the vehicle fuel tank. Flow rate was also observed to be substantial right up to the instant of the closing of the ball valve.

A further twelve documented fills resulted in ten correct fills and two underfills due most likely to human error. The mathematical algorithm is therefore confirmed since random stopping of fill would unlikely be correct ten times out of twelve.

The CGRI fast fill technology was field tested for one year at a gas utility company fuelling station for company vehicles. Extensive laboratory testing and field use of the system was carried out by a second gas utility company in Canada. There was also a brief opportunity to test the technology at a public filling station in Canada and another is installed in the U.S. The technology is licensed to a Canadian manufacturer and is commercially available.

Summary

The CGRI fast fill technology can completely eliminate the mechanical dome load valves, provide better protection against overfills, and obtain significantly faster and more complete fills of natural gas vehicles.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

MICROPROCESSOR CONTROL OF NATURAL GAS VEHICLE FAST FILLS

J.Y. Guttman, Canadian Gas Research Institute

Q. Anonymous: Will the system overpressure a tank slightly to compensate for cooling to 70°F after the tank is filled?

A. The microprocessor is temperature compensated so that calculations will predict the final pressure and temperature.

Q. William Liss, Gas Research Institute: Do Canadian regulations allow electronic replacement for mechanical devices?

A. Yes, the microprocessor-based technology has been accepted and eliminated the need for dome load valves.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

INFRASTRUCTURE ISSUES FROM THE RETAILERS' PERSPECTIVE - PANEL DISCUSSION

Panel Moderator: Paul Wuebben

ALTERNATIVE TRANSPORTATION FUEL IMPLEMENTATION ISSUES - CALIFORNIA PERSPECTIVE

D. Fong
California Energy Commission

TECHNOLOGY DEVELOPMENT

- ENGINE AND COMPONENT DURABILITY
    - Fuel Systems
    - Emission Control Systems
- FUEL STORAGE AND DISPENSING SYSTEMS
    - Materials Compatibility
    - Vehicle/Fueling System Interface
- LUBRICANTS/ADDITIVES
    - Oils
    - Fuel Additives

INFRASTRUCTURE DEVELOPMENT

- FUEL AVAILABILITY
    - Number of Fueling Sites
    - Location
    - Supply and Distribution
- FUEL TRANSACTIONS
    - Access Control
    - Payment
- REGULATORY CONSTRAINTS
    - Local Authorizations (Permits)
    - State Certifications for Equipment
- MAINTENANCE SUPPORT
    - Vehicles
    - Fuel Distribution Systems
- SPECIFICATIONS
    - Fuel
    - Equipment

MARKET DEVELOPMENT

- EDUCATION
  - Consumers
  - Retailers
  - Mass Media
- PRODUCT AVAILABILITY
  - Vehicle Types/Models
- MARKET PENETRATION
  - Consumer Targets
  - Timing

COST REDUCTION

- **INCENTIVES**
  - Technology Development
  - Regulatory
  - Marketing

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

INFRASTRUCTURE ISSUES FROM THE RETAILERS' PERSPECTIVE - PANEL DISCUSSION

Panel Moderator: Paul Wuebben

METHONAL FUEL INFRASTRUCTURE OVERVIEW

J. Spacek
Canadian Oxygenated Fuels Association

Canadian Oxygenated Fuels Association

COFA is a Methanol Fuel Industry Association.

Formed in 1984 by:

- Celanese Canada Inc.;
- Methanex Corporation; and
- Novacor Chemicals Ltd.

COFA's Objective is to Promote the Responsible Use of Methanol as a Transportation Fuel.

Light Duty Vehicle Program

(to March 31, 1993)

Program initiated in February 1991

- 11 vehicles (pre-production)
- 4 service stations

Program amended in January 1992

- 136 vehicle (production)
- 11 pre-production LH vehicles
- 5 service stations
- 6 portable stations

Amendment No. 2 August 1992

- dedicated project manager
- additional marketing resources

Proposed MLDVP
(to March 31, 1994)

Program Activities

- continue dedicated project manager
- fuel quality monitoring program
- vehicle marketing and promotions program
- station program

Targets

# of stations

	Current	New	Total
Toronto	2	6	8
Vancouver	1	3	4
Calgary	1	2	3
Kitimat	-	1	1
Medicine Hat	-	1	1
Kamloops	1	-	1
TOTAL	5	13	18

Refuelling Infrastructure Summary

Transit Installations

- Medicine Hat Transit;
- Winnipeg Transit; and
- Transit Windsor.

Service Station Installations

- Toronto, Ontario (Sunoco)
- Calgary, Alberta (Robertson/Mohawk)
- Kamloops, B.C. (Mohawk)
- Burnaby, B.C. (Mohawk)

Portable Refuelling Stations

- Clemmer Steel Tank Assemblies

Transit Installations

Overview

- Typically a Red Jacket submersible pump;
- 10,000 gallon steel double-walled under-ground tank;
- GasBoy island dispenser rated at 40 gallon/minute;
- Emco-Wheaton dry-brake nozzle;
- RPCO 559N hose;
- 5 micron Micro-Wind cartridge filters; and
- vacuum monitoring with alarm system.

Transit Installations

Cost (Based on Transit Windsor 1991)

Equipment		
Tankage	$ 18,700	
Card Tool	$ 1,750	
Pump/Dispenser	$ 13,200	
	$ 33,750	$33,750
Installation		
Installation Contract*	$22,500	
Inspection	$ 1,000	
Insurance	$ 1,250	
Freight	$ 1,000	
Engineering Fees	$10,000	
	$35,750	$35,750
Other		
Engineering Mark-Up	$ 6,000	
Goods & Services Tax	$ 6,000	
	$12,000	$12,000
TOTAL		$81,500

* Includes contractor supplied materials

Service Station Installations

Two Approaches:
1. M85 Installation
2. M100 With Pump Blending

M85 Installations

- Various dispenser/pump brands used including:
  - Red Jacket
  - GasBoy; and
  - Bennett
- Both steel and fibreglass tankage used;
- Hoses now standardized to cross-linked polyethylene with nickel plated swivels;
- Nozzles are OPW nickel-plated aluminum;
- 1 micron Cim-tek spin-on filters; and
- Vacuum monitoring with alarm system.

M85 Installation

Cost (Based on Calgary 1992)

Equipment		
Tankage	$ 8,000	
Dispenser	$ 3,600	
Other	$ 7,000	
	$18,600	$18,600
Installation		
Contractor*	$17,300	$17,300
Permits/Engineering/ Signage**	$14,100	$14,100
TOTAL		$50,000

* Includes submersible pump, cardlock and contractor supplied materials.

** Estimate.

Service Station Installations

M85 Pump Blending

- Wayne/Dresser electronic blending dispenser;
- Red Jacket submersible pump;
- Cross-linked polythylene with nickel-plated swivels;
- OPW nickel-plated nozzle;
- 1 micron Cim-tek spin-on filters; and
- Vacuum monitoring with alarm system.

M85 Pump Blending Installation

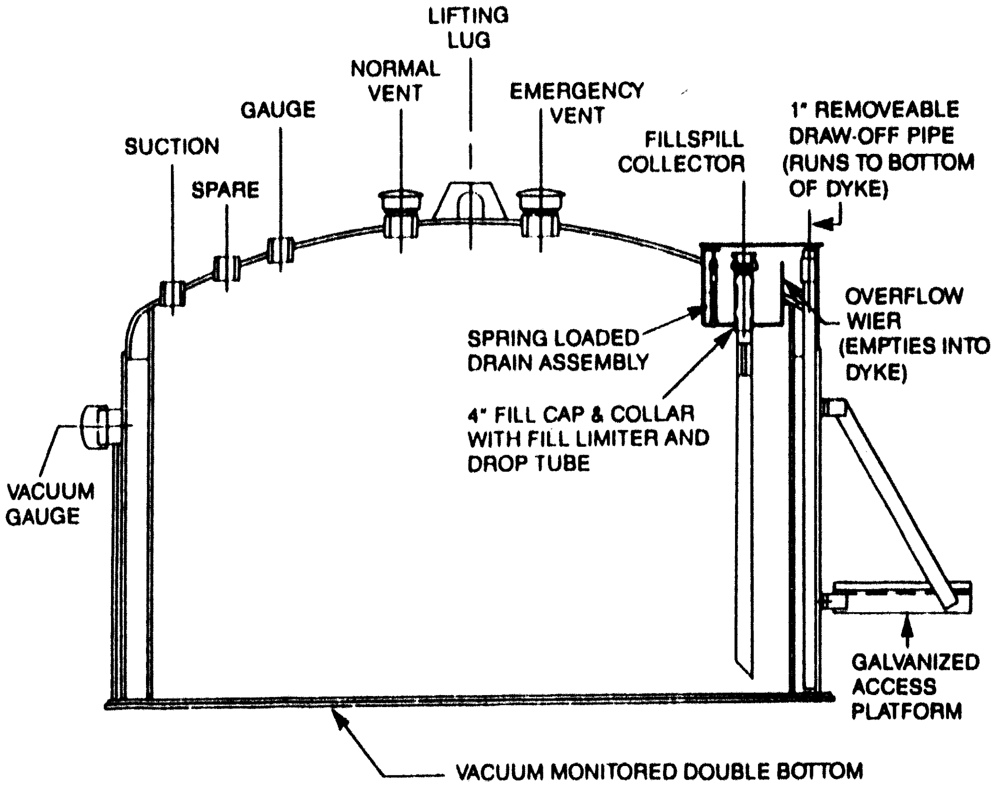
Cost (Based on Toronto 1992)

Equipment		
Tankage	$11,700	
Dispenser	$10,000	
Submersible Pump	$ 1,800	
Other	$ 6,850	
	$30,350	$30,350
Installation		
Contractor*	$23,150	$23,150
Permits/Engineering/Signage**		$16,500
		$70,000

* Includes contractor supplied materials.
** Estimate.

Fleet Installations

Clemmer Tank Diagram



- Methanol fuel portable station designed by Clemmer Industries;
- GasBoy commercial-use pump included; and
- Cost approximately $6,000.

Field Experience: Regulatory Environment

"The only thing worse than a regulation is no regulation"

Fuel Safety Organizations

- not familiar with methanol fuel;
- deviation approach typically used; and
- more stringent requirements than gasoline.

Fire Code/Practice Organizations

- not familiar with methanol fuel;
- methanol fuel not in fire codes; and
- substantial education required to obtain permits.

Weights and Measures Organizations

- not familiar with methanol fuel; and
- pumps installed under "demonstration" approval.

Field Experience: Fuel Quality

Early installations provided steep learning curve:

- "Methanol compatible" hoses were not M85 compatible;
- "Methanol compatible" nozzles were not M85 compatible; and
- "Methanol compatible" pumps/dispensers were not M85 compatible;

COFA published Methanol Fuelling Systems Guide:

- recommends installation procedures; and
- lists infrastructure manufacturers offering/claiming methanol compatible equipment.

Continued

Fuel retailers involvement critical in:

- "auditing" methanol installations to ensure methanol compatible components used; and
- Monitoring fuel Quality.

Other:

- Stations with low fuel through-put exhibit higher levels of fuel contamination;
- Aluminum contamination highest priority.

Transit:

- Fuel quality not a concern
- Vehicle fuel system design pro-active

Lessons Learned

Be Pro-active

- methanol fuel education of regulatory bodies a must;
- network to ensure access to latest fuel infrastructure knowledge.

Be Specific

- identify specific methanol compatible components and manufacturers.

Be Patient

- allow for long regulatory approval period;
- be prepared to educate fuel retailers.

Be Watchful

- ensure aggressive fuel quality monitoring;
- ensure fuel installation is "audited" for methanol compatible materials.

Recommendations

Infrastructure

- Immediate Requirements For:
    - dispensing nozzle;
    - dispenser; and
    - hose.

- Investigate Temporary Refuelling Infrastructure:
    - above ground tankage with island pump
    - estimate $15,000 - $20,000

- Investigate Station Retrofit
    - clean steel tank;
    - replace components with methanol compatible; and
    - replace dispensing pump.
    - estimate $15,000-$20,00.

Continued

Government:Regulatory

- Accelerated Methanol Fuel Education of Regulatory Officials

- High Priority Needed on Placing Methanol Fuel into Regulatory Regime:

    - fuel specification
    - fire code
    - fuel safety

Government:Policy

- Government Leadership to Encourage Flexible Fuel Infrastructure;

    - development of service station infrastructure compatible with all liquid fuels;

    - encourage all tankage to be methanol compatible; and

    - encourage competition in market place.

Continued

- M85 Service Station Financial Assistance:
  - should be provided after evidence of quality fuel performance; and
  - should reward pump blending approach on strategic and cost effectiveness objectives.

<u>Other Stakeholders:</u>

- Vehicle Manufacturers Address Accessible and Enhanced Fuel Filtering on Vehicles.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

INFRASTRUCTURE ISSUES FROM THE RETAILERS' PERSPECTIVE - PANEL DISCUSSION

Panel Moderator: Paul Wuebben

PROPANE - INFRASTRUCTURE ISSUES FROM THE RETAILERS' PERSPECTIVE

N. Horner
Amoco Canada

(Other presentations made during this Panel Discussion were unavailable at time of printing)

PROPANE - INFRASTRUCTURE ISSUES FROM THE RETAILERS PERSPECTIVE

PRESENTED TO THE
1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS
TORONTO, JUNE 15, 1993

NORVAL HORNER - MGR. OF ENGINEERING, AMOCO CANADA

ASSISTANCE FROM ICG & SUPERIOR
2 LARGE CAN. DISTRIBUTORS.

1. INTRODUCTION AND HISTORY
2. TYPICAL AUTO PROPANE FILL STATION
3. DESIGN AND PERMITS
4. CONSTRUCTION AND OPERATION
5. MAINTENANCE AND PRODUCT QUALITY
6. OEM PRESENCE IN VEHICLES
7. SUPPLY
8. TRANSPORTATION/WHOLESALE INFRASTRUCTURE
9. PRICE AND CONCLUSIONS

NOTATIONS BASED ON
ACTUAL DELIVERED VERSION
NVH

1. INTRODUCTION AND HISTORY

- CINDERELLA FUEL - MOST POPULAR ALTERNATIVE FUEL IN CANADA AND U.S.

- RAPID GROWTH IN CANADA IN THE 1980 TO 1993 PERIOD.
  - INCENTIVES ON CONVERSIONS (TO '84)
  - INCENTIVES ON ROAD TAXES (DECLINING)

- IN 13 YEARS WE HAVE ACHIEVED:
  - 5000 AUTO PROPANE STATIONS IN CANADA

    MORE STATIONS THAN DIESEL
  - 170,000 PROPANE POWERED VEHICLES
  - 1.3 BILLION LITRES/YR SALES TO VEHICLES
  - ABOUT 4% OF GASOLINE'S SALES:
    - o NOTE HOLLAND HAS PROPANE AT 13.5% OF TOTAL TRANSPORT FUEL

- GROWTH DUE TO PROPANES ADVANTAGES
  - ENERGY DENSITY 3/4 OF GASOLINE
  - OCTANE RATING OF 100+
  - NATIONAL PRODUCTION & PIPELINE INFRASTRUCTURE

NOTE: CANADA IS A SIMILAR SIZE MARKET TO CALIFORNIA.

2. TYPICAL PROPANE AUTO FILL STATION

- ADD-ON TO A GASOLINE STATION
- USUALLY FULL SERVICE
  - SELF SERVE REQUIRES TRAINING
  - CARD LOCK OR KEY LOCK ALSO USED
- TYPICAL TANK VOLUME, 2000 GAL.
- SKID MOUNTED SELF CONTAINED DISPENSER
- PROPANE IS STORED AND DISPENSED AS A LIQUID
- SAFETY SYSTEMS AND TRAINED PERSONNEL
- COST $40,000 ALL-IN
- DISTRIBUTOR USUALLY PROVIDES THE FACILITY AND THE PRODUCT. THE STATION OWNER GETS A GALLONAGE FIGURE.
- CURRENT AVERAGE SALES = 200,000 LITRES/YR
- COULD SELL 5 TIMES AS MUCH PER STATION (1,000,000 LITRES/YR)

PROPANE COULD BE WORKING HARDER YET

3. DESIGN

- STANDARDIZED DESIGNS ← MODEST PRESSURE PROPANE STORES AT UNDER 200 PSIA.
- CGA B149 CODE
- PROPER TRAFFIC FLOW
- DECIDE ON ATTENDED VS CARDLOCK APPROACH
- USUAL LIGHTING/SIGNAGE ISSUES
- USUALLY SKID MOUNTED - SIMPLE EQUIPMENT STEEL TANK, STORAGE PUMP, CONTROLS AND POWER
  - 45 LPM DISPENSING RATE ← SAME FILLING TIME AS GASOLINE.
- SAFETY ASPECTS - COLLISION PROTECTION
  - INTERNAL SAFETY CONTROL VALVE
  - HIGH FLOW SHUT OFF
  - AUTOMATIC SHUT OFF ON HEAT

PERMITS

- TANK AND OTHER EQUIPMENT MUST MEET A VARIETY OF STANDARDS AND CODES
  - IE. ASME, ELECTRICAL
- VARIOUS APPROVALS REQUIRED (ZONING, BUILDING PERMIT, FIRE DEPARTMENT)
- IN ONTARIO - REQUIRE A PROVINCIAL PROPANE TRANSFER FACILITY LICENCE
- TYPICALLY REQUIRES 4 - 6 WEEKS OF TIME

4. CONSTRUCTION

- SIMPLIFIED DUE TO STANDARDIZATION - SKID MOUNTED - ABOVE GROUND
- REQUIRES ONLY POWER CONNECTIONS, FOUNDATIONS AND COLLISION PROTECTION
- CONSTRUCTION NORMALLY TAKES 2 WEEKS
- SITE INSPECTIONS - ELECTRICAL & FUEL SAFETY

OPERATION

- NORMALLY ATTENDED VEHICLE INSPECTION STICKER REQUIRED
- ALL ATTENDANTS RECEIVE PGAC 100-1 TRAINING
  - 900 CERTIFIED INSTRUCTORS IN CANADA
  - 14,000 PER YEAR ARE TRAINED
- UNATTENDED, IE. CARDLOCK OPERATION, WE REQUIRE VEHICLE OPERATOR TO BE TRAINED
- FILL TO 80% OF TANK TO ALLOW EXPANSION
  - HISTORICALLY USED A LIQUID LEVEL VALVE
  - NOW HAVE AN APPROVED AUTOMATIC "STOP FILL"
- VAPOURS MINIMIZED DUE TO CLOSED SYSTEM
- MINIMAL OPERATING COSTS - LOW POWER REQUIREMENTS

5. MAINTENANCE

- PROPANE IS DELIVERED BY BULK VEHICLES
- DISPENSING NOZZLES AND HOSE NEED THE MOST MAINTENANCE
- PREVENTATIVE MAINTENANCE SCHEDULES ON BREAKAWAY COUPLERS, FILTERS, METERS AND PUMPS - SEMI ANNUAL OR ANNUAL

PRODUCT QUALITY

- AUTO PROPANE, HD5 - NATIONAL STD OF CANADA
- ALL PROPANE IN CANADA MADE TO THIS (SO IS ALL RETAIL PROPANE IN THE U.S.)
- LIMITS ETHANE, BUTANE, SULPHUR, WATER AND OIL STAIN
- POLYPROPYLENE LIMITED TO 5% (HURTS OCTANE RATING)
- ODORANT ADDED
- NO OXYGEN, INHERENTLY NON-CORROSIVE
- CONSISTENT ACROSS NORTH AMERICA

SLIDES ON PROPANE LINE HAUL CARRIERS
DISTRIBUTION CENTRES, DELIVERY TRUCKS
RETAIL AND WHOLESALE STATIONS.

6. OEM PRESENCE

- BUSINESS HISTORICALLY BASED ON CONVERSION FROM GASOLINE TO PROPANE.
- DOING BETWEEN 15-20,000 CONVERSIONS/YR IN CANADA.
- COST $1800 BASIC PLUS $400 TO ADAPT TO A CURRENT ENGINE FEEDBACK CONTROL.
- GM AND FORD MAKE FACTORY PREPARED ENGINES DESIGNED FOR AFTERMARKET CONVERSION TO PROPANE.
- FORD MEDIUM DUTY TRUCKS AVAILABLE FOR PROPANE FROM MANUFACTURER.
- CHRYSLER $4.25 MM JOINT INDUSTRY/GOV'T PROJECT TO BUILD A PROPANE AFV. GOAL IS VANS AND/OR LIGHT TRUCKS AVAILABLE IN 1995.

7. SUPPLY

- PROPANE IS IN SURPLUS IN CANADA
    - CDN PRODUCTION IS 190,000 BBL/DAY
    - EXPORTS ARE APPROXIMATELY 50%

- PROPANE IS IN BALANCE IN NORTH AMERICA
    - U.S. PRODUCTION OVER 900,000 BBL/DAY
    - PETCHEM DEMAND

- FOR COMPARISON (U.S. PRODUCTION):

METHANOL - 78,000 BBL/DAY (8.5%)
ETHANOL - 52,000 BBL/DAY (6%)

WORLD METHANOL PRODUCTION = 460,000 BBL/DAY.

IE: THE U.S. PRODUCES 12 TIMES AS MUCH PROPANE AS IT DOES METHANOL!

THE U.S. ALONE PRODUCES 2 TIMES AS MUCH PROPANE AS THE ENTIRE WORLD PRODUCTION OF METHANOL!

PROPANE IS NOT THE WHOLE SOLUTION SEE A LARGER ROLE FOR NATURAL GAS AS WELL.

8. TRANSPORTATION & WHOLESALE INFRASTRUCTURE

- THERE IS A NORTH AMERICAN WIDE PROPANE STORAGE AND DELIVERY STRUCTURE ALREADY IN PLACE.

- IN CANADA:
  - MAJOR TRANSCONTINENTAL PIPELINES IN PLACE FROM THE WEST TO ONTARIO. TARIFFS OF 1 - 2.4 CENTS/LITRE.
  - PRODUCTION AT REFINERIES
  - THE STORAGE, DISTRIBUTION TERMINALS, THE BULK TRUCKS ARE ALL IN PLACE.

- IN THE U.S.A.:
  - OVER 800 GAS PLANTS PRODUCE PROPANE
  - THERE ARE 31 FRACTIONATORS
  - 150 MILLION BARRELS OF STORAGE (C3)
  - TWENTY FIVE STATES SERVED BY PIPELINE
  - OTHERS SERVED BY INTERNAL REFINERY OR GAS PLANT PRODUCTION

OTHER LIQUID FUELS WOULD HAVE TO SPEND A STAGGERING SUM TO REPEAT THIS INFRASTRUCTURE

9. PRICE

- CURRENT SARNIA WHOLESALE PROPANE PRICE IS 11.6 CENTS/LITRE FOR PROPANE.
- CURRENT TORONTO PROPANE PUMP PRICE IS 29.9 CENTS/LITRE INCLUDING TAXES (APRIL 27, 1993).
- CURRENT TORONTO GASOLINE PUMP PRICE IS 53.6 CENTS/LITRE INCLUDING TAXES.
- CHECK FINANCIAL PAGES FOR PROPANE FUTURES AND UNLEADED GASOLINE FUTURES.
- ON A LEVEL PLAYING FIELD PROPANE CAN WIN ON ECONOMICS ALONE VS GASOLINE.
- ENERGY COMPARISON

$$\frac{\text{PROPANE LHV}}{\text{GASOLINE LHV}} = \frac{82{,}500}{114{,}000} - 72.4\%.$$

(PER GALLON)

- ADJUSTED PRICE COMPARISON.

$$\frac{1.38\ \ell\ \text{PROPANE}}{1.0\ \ell\ \text{GASOLINE}} = \frac{41.2¢}{53.6¢}.$$

- PROPANE ACTUALLY GETS BETTER MILEAGE THAN A STRAIGHT ENERGY CONVERSION WOULD IMPLY.

CONCLUSIONS

- PROPANE SUPPLY AND INFRASTRUCTURE WOULD ALLOW CANADA TO TRIPLE EXISTING AUTO PROPANE USE WITH VIRTUALLY NO INVESTMENT.
  - SAME IS TRUE IN THE U.S.
- OTHER LIQUID FUEL ALTERNATES REQUIRE:
  - MASSIVE INFRASTRUCTURE INVESTMENT
  - MASSIVE INVESTMENT TO EXPAND SUPPLY
- PROPANE IS INEXPENSIVELY RETAILED
- MORE OEM INVOLVEMENT COMING

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

PANEL DISCUSSION: INFRASTRUCTURE ISSUES FROM THE RETAILERS' PERSPECTIVE

Moderator: Paul Wuebben, SCAQMD

Panel Members:
Dan Fong, California Energy Commission
John Spacek, Canadian Oxygenated Fuels Association
Herbert Burnett, Southern California Gas Co.
Norval Horner, Amoco Canada

After short presentation by each panel member, questions were permitted. Panel member replies are identified by name below.

Q. Paul Weubben, SCAQMD: What materials are used for methanol dispensing nozzles?

A. John Spacek, We have been through several iterations with nozzle materials. Nickel plated aluminum has been used for M85. Another choice for M100 was nickel plated brass or stainless steel. An all-steel version will also be tested this year.

Q. Paul Weubben, SCAQMD: Is there a concern for moisture in natural gas, especially in cold weather?

A. Herbert Burnett: There have been problems with freezing where water content has been above 0.5 pound per million SCF. We recommend filter-coalescers and dryers on the suction side of compressors and non-lubricated compressors to avoid oil contamination of the gas. We also encourage a vigorous testing program for contaminants.

Q. Joe Wagner, NYSERDA: What is the largest transit bus fueling facility?

A. Herbert Burnett: We have two facilities for buses that have 80 gallon equivalent tanks on board. Fueling time allowed is 10 minutes per bus. We deliver about 10 gallons per minute per hose to a temperature-compensated fill point of 3000 psi and 70oF within plus or minus 2 percent. Building the facility is about a 12-month process. Market development may take 2 to 3 months minimum. Design, procurement, and construction require 8 to 9 months. Permits can add another 2 to 3 months.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

PANEL DISCUSSION: INFRASTRUCTURE ISSUES FROM THE RETAILERS' PERSPECTIVE

Q. Anonymous: What type of drivers are used on natural gas compressors? And what are compression costs?

A. Herbert Burnett: All of our compressors are electric-driven. Compression costs are about 30 cents per gallon, including power cost and other operating expenses.

Q. Anonymous: What type of card system is used for access to methanol dispensing stations? Will this change in the future?

A. Dan Fong: The oil companies each have their own cards. There may be a move to a single card for all seven companies. That would depend on increased demand to justify software development to use bank-type cards.

Q. Anonymous: What use is made of mobile natural gas dispensing equipment?

A. Herbert Burnett: We use mobile refueling systems as means to start a developing station. Customers typically start with a small portion of their fleet dedicated to natural gas. We can provide a cost effective systems with a portable trailer and a lower cost station without compression to provide up to 250 gallons per day.

Q. Lois Bennett, General Motors: What actions are in progress to adopt standard connectors for refueling natural gas vehicles?

A. Herbert Burnett: The American Gas Association committees are working on this subject. A draft document is expected by the end of 1993 that will incorporate overpressure protection for various type of fittings.