Natural Gas Composition for NGVs

> William E. Liss
Gas Technology Institute

NGV Evolution

- NGV's have taken remarkable steps over past 15 years
  - NGV engine & vehicle manufacturers achieved very impressive emission levels
- Market can be segmented
  - Light duty (converted gasoline)
    - Closed-loop control with stoichiometric 3-way catalysts…very robust systems
  - Heavy duty (converted diesel)
    - Lean-burn technology…in recent years with advanced closed-loop controls

gti

NGV Evolution

- Medium/heavy-duty vehicles are industry workhorses
  - Potential to offer emission benefit and life cycle cost advantage over many diesel products
  - Largest fuel consumers
- Early M/H engines less sophisticated
- Since around 2001, new generation of heavy-duty engine technology introduced

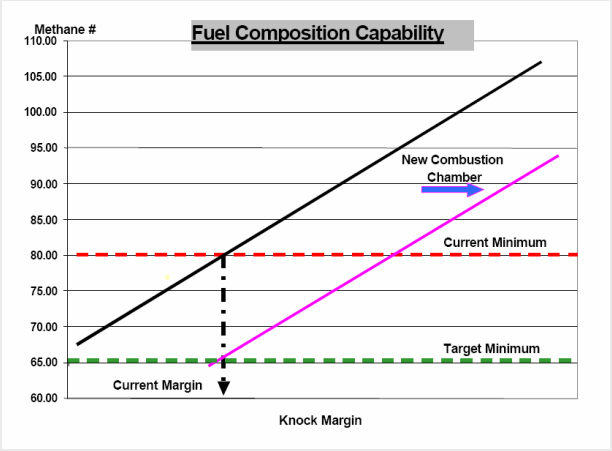
NGVs and Controls

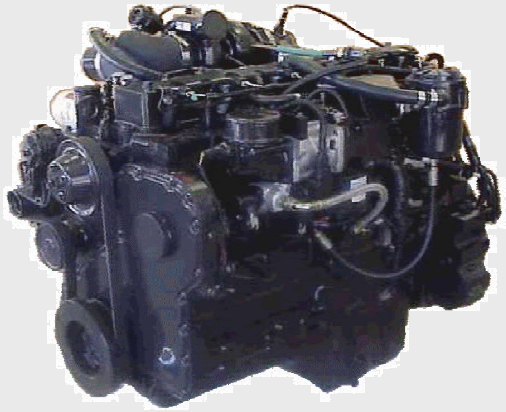
- Controls technology increasingly required to meet emissions & OBD requirements
  - Addresses host of variables: e.g., air temperature, barometric pressure, humidity, fuel composition, engine degradation, catalyst degradation, etc…
  - These controls help mitigate fuel composition as a knock or emissions concern
    - Most tests have identified small gas composition impact on emission

gti

Heavy Duty Natural Gas Engine Technology Advances

- Cummins “Plus” Technology
  - Improved fuel tolerance using sensors & controls
  - Improved combustion systems
  - Deere, Mack, others now have similar technology
  - Engines OK down to Methane Number 65 fuels





Cummins Knock Spec

Engineering Standards

Name	FUEL,NATURAL GAS (WIDE RANGE)	Engineering Standard Number
Identifier	PERFORMANCE SPECIFICATION (INTERFACE)	14608

4.3. Physical Properties

4.3.1. Methane Number

Methane Number shall not be below 65, when determined in accordance with the following equations.

a. Reactive Hydrogen to Carbon Ratio – (only use reactive hydro-carbons, see Section 3.1. Reactive Hydrogen to Carbon Ratio on page 2)

$$\text{Reactive } \frac{H}{C} = \left(\frac{\sum_{i=1}^{n} \left(\frac{\text{Volume \% of Component}_i}{100} \right) \text{x Number of Hydrogen Atoms in Component}_i}{\sum_{i=1}^{n} \left(\frac{\text{Volume \% of Component}_i}{100} \right) \text{x Number of Carbon Atoms in Component}_i} \right)$$

DDC Knock Spec

7.4.4 Compressed Natural Gas Fuel Specifications

The characteristics listed in Table 7–7 identify the minimum quality level recommended by Detroit Diesel for use in natural gas fueled engines. Users of this recommended specification are advised to review SAE J1616 "Compressed Natural Gas Vehicle Fuel Recommended Practice." Test method is provided in Title CCR section 94112.

Property	Limit	ASTM Test Method
Hydrocarbon	**Mole percent**	
Methane	88% min.	D 1945
Ethane	6% max.	
Propane	1.7% max	
Other		
C4 and Higher	0.3% max	
Other Gaseous Species	**Mole percent**	
Hydrogen	0.1% max	D 2650
Carbon dioxide + Nitrogen + Oxygen	4.5% max.	D 1945
Carbon Monoxide	0.1% max.	D 2650
Other Species		
Methanol	0% mass	No Test Method
Sulfur, total	23 ppm mol	D4468
Performance Related Properties		*
Motor Octane Number	115 min	D 2623
Wobbe Number	1290 - 1350 BTU/ft³	D 3588
Contaminants	†	
Pressure Water Dew Point Temperature, Max.	‡	D 1142
Pressure Hydrocarbon Dew Point Temperature, Max.	‡ Below which will form 1% condensate	D 1142
Odorant	§	

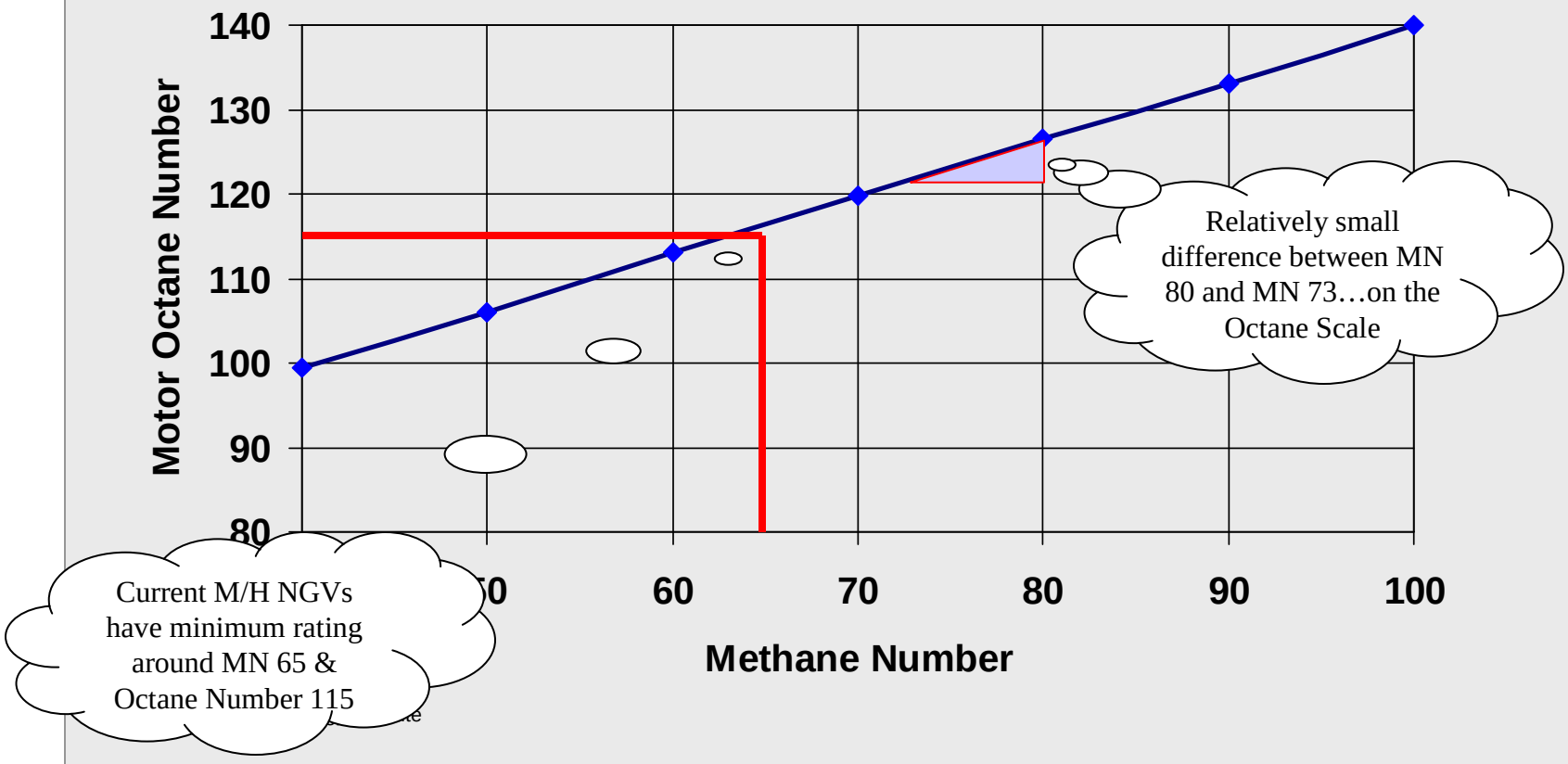
* Test method D 2623 was obsoleted by ASTM in 1991. Wobbe Index (WI), also known as Wobbe Number, is a measure of fuel energy flow rate through a fixed orifice under given inlet conditions. Numerically, WI = (dry, higher heating value)/(specific gravity)

† The compressed natural gas shall not contain dust, sand, dirt, gums, oils, or other substances in an amount sufficient to be injurious to the fuel station equipment or the vehicle being fueled.

‡ The dew point at vehicle fuel storage container pressure shall be at least 10°F (5.6°C) below the 99.0% winter design temperature listed in chapter 24, Table 1, Climatic Conditions for the United States, in *American Society of Heating, Refrigerating and Air conditioning Engineer's (ASHRAE) Handbook*, 1989 fundamentals volume. Testing for water vapor shall be in accordance with ASTM D 1142, utilizing the Bureau of mines apparatus.

§ The natural gas at ambient conditions *must* have a distinctive odor potent enough for its presence to be detected down to a concentration in air of 1% by volume.

Natural Gas Has Excellent Engine Knock Resistance



Methane Number measures a fuel's resistance to engine knock… analogous to Octane Number.

Next Generation M/H NGV Engines

- Future Medium/Heavy NGV products
  - Shifting to closed-loop control, stoichiometric 3-way catalysts, and cooled EGR
    - Cooled EGR & knock sensors will have increasing importance
  - Key issue is maximum engine BMEP and, thereby, power output rating

Bmep = brake mean effective pressure…a volume independent measure of engine specific power

Four-stroke engine power is:
P (kW) = k * (BMEP * Vd * N)
Where P (kW) is power output, BMEP is in psi, Vd is engine displacement in liters, N is engine speed (rpm), and k=5.75*10-5 for these units.

Engine Operating Limits

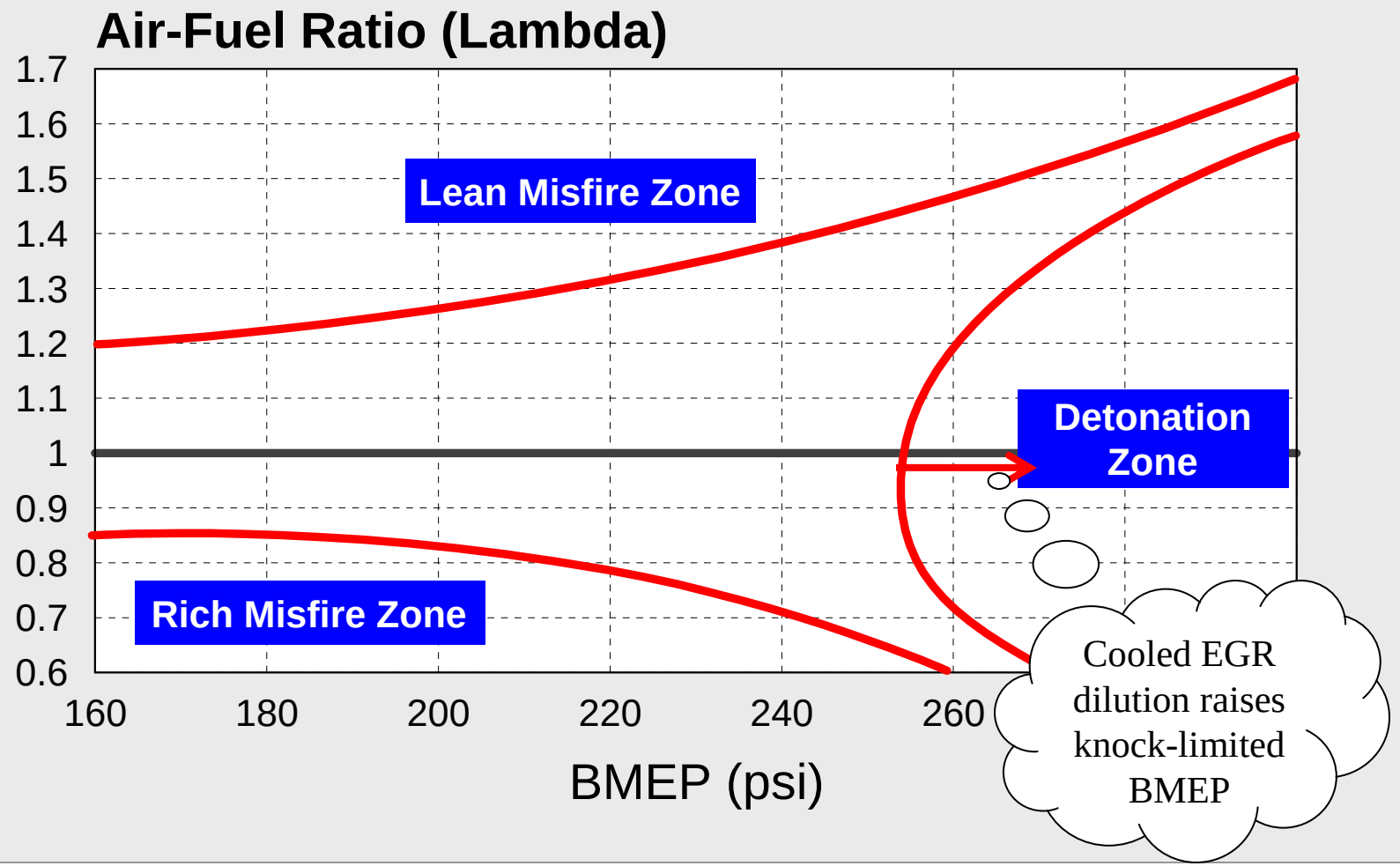


Figure is for illustrative purposes only

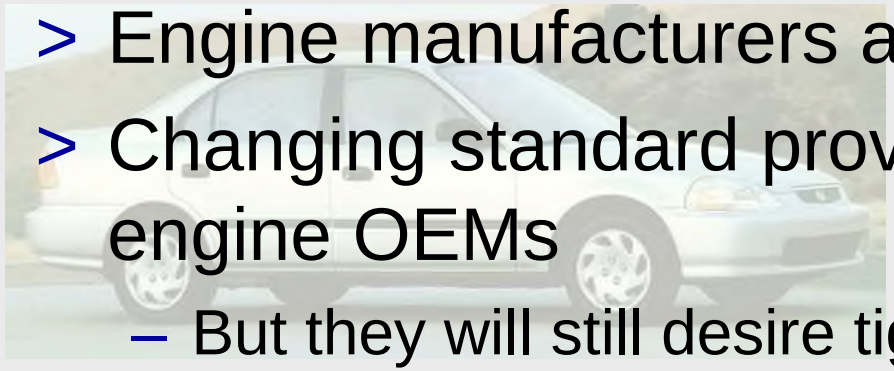
Next Generation M/H NGV Engines

- Many of today's gasoline engines operate near knock limit…this is not new stuff
  - Knock sensors monitor for knock in real time
  - When knock is detected, engine controller takes specific steps (e.g., retard timing)
  - Common effects of retarded timing:
    - Reduced peak bmep & power, decrease in efficiency, lower engine-out NOx emissions
    - Controls will continually adjust timing in attempt to return to optimal map

gti

CARB Fuel Specification

- Mods to CARB fuel spec appropriate
  - Reflect knowledge, experience, and technology development over past 15 years
  - Vast majority of NGVs can operate on proposed fuel
- Future engines will need to have capability to run on these fuels
- Engine manufacturers aware fuels exist
- Changing standard provides clarity for engine OEMs
  - But they will still desire tighter spec's



Proposed Changes

Methane Number	MN 80 MN73*	Regional MN 73 should require proper labeling and consumer awareness so users make appropriate fuel choices (modify footnote 2 to emphasize labeling and awareness…this is the best way to prevent misfueling)
Wobbe Number	TBD	Develop consensus that reflects in-state sources, future imported LNG, and NGC recommendations
C_4+	<= 1.5%	Adequately addressed in MN and Wobbe Number property limits…should consider removing from draft.
Inerts	<= 4%	Adequately addressed in MN and Wobbe Number property limits…should consider removing from draft.

* With regional limits

Summary

- Natural gas composition variations are common in California, US, and World
  - Policies should strike a balance…important to support ample supplies from various sources
    - Will help keep natural gas prices low and allow users and society to enjoy economic and environmental benefits
  - In-state producers, imported LNG, and future energy resources (e.g., bio-energy)
- Methane Number and Wobbe Number are satisfactory metrics
  - No clear need for specific composition limits such as C_4+, inerts

gti

Summary

- Most current engines can run on proposed Methane Number fuels
- Technology for next-generation NGV engines capable of addressing fuel variability
  - Engine rating is a consideration
  - Proposed changes will make engine manufacturers uncomfortable due to warranty concerns & unknowns
- Timely changes needed to give clarity to stakeholders

gti