Fuel Formulations

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Introduction

- Over 100 years of diesel engine lubricant development
- Engine, fuel, and lubricant development are interdependent
- Fuel/Engine/Lubricant system gradual continuous improvement
- Future systems could experience a step change

Interdependency

"... Satisfactory oil under one set of conditions may be unsatisfactory in the same engine under another set of conditions. This emphasizes the necessity for matching these four factors: oil, fuel, engine design, and conditions."

Development of CLR Oil Test Engine –
CRC Report No. 301, June 1955

Background

◇ Fuel composition impacts lubricant formulation
   - -Lubricant exposed to unburned fuel
   - -Lubricant exposed to fuel combustion products

◇ Future fuel composition uncertain

Presentation Overview

- Brief history of fuel development in last century
- Current research fuel formulations
- Future fuel composition

The first advanced fuel from last century -- 1903

- Fuel distilled from Pennsylvania crude oil
- Octane number estimated to be 38
- Half gallon, gravity feed fuel tank
- Wright brother's engine 4.4:1 CR; fixed 1200 rpm

Early Fuel Research

- Detonation discovered by Gibson 1915
- TEL discovered 1921 by Midgley & Boyd
- Ricardo explains detonation 1923
- Waukesha CFR engine 1929
- U.S. Army Air Corps Flight Testing 1935
  - 30% power increase
  - 40% increase in rate of climb
- British decide to modify all engines 1937

Results of Technical Cooperation -- The Battle of Britain*

"The RAF fighters, outnumbered almost three to one by the Luftwaffe, won the Battle of Britain by a narrow margin . . . Had the Luftwaffe gained control of the air . . . the then vastly superior German military forces could probably have invaded England successfully. With Britain occupied, it is difficult to conceive how a subsequent invasion of Europe could have been accomplished . . ." *Ogston, SAE 810848

A Century of Cooperative Research in Review

- Cooperative Fuel Research Comm., 1922
- War Dept. Comm. 100 Octane Fuel, 1935
- Coordinating Research Council, 1942
- CLR Oil Test Engine Group, 1950
- Octane race, ca. 1950s - 60s
- Cat. converters and unleaded, ca. 1970
- PFI deposit control, ca. 1985
- The Auto/Oil Program, 1989-1997

Selected Diesel Fuel Formulation Research

- CRC Report #120 "Investigation of High and Low Sulfur Diesel Fuels" 1945
- CRC Report #507 "Diesel Exhaust Odor Analysis System (DOAS)" 1979
- CRC Project #CAPE-32-80, "Effects of Fuels and Engine Variables on Light-Duty Diesel Engine Emissions" 1985
- CRC Project #VE-1, "Evaluation of Fuel and Engine Variables on Heavy-Duty Diesel Engine Emissions" 1990
- CRC Project #VE-10, "Effects of Fuel Oxygenates, Cetane Number, and Aromatic Content on Emissions from Low-Emission Heavy-Duty Diesel Engines" 1995
- SAE Paper #972966, "Influence of Future Fuel Formulations on Diesel Engine Emissions - A Joint European Study" 1997
- SAE Paper #981357, "Emissions Comparison of Alternative Fuels In an Advanced Automotive Diesel Engine" 1998

Recent PNGV Test Fuels Evaluated on a Daimler-Benz OM11 Engine

- 2D - EPA 2-D Certification Diesel Fuel
- CARB - "Pseudo"-CARB
- LS - Ultra Low Sulfur
- FT100 - Fischer Tropsch Synthetic Diesel
- FT20 - 20% FT Synthetic Diesel in LS
- B20 - 20% Biodiesel in LS
- DMM15 - 15% DMM in LS

Test Fuels

Fuel Code	Fuel
2D	EPA 2-D Certification Diesel
CARB	"Pseudo"-CARB
LS	Ultra Low Sulfur
FT100	Synthetic Diesel (Fischer-Tropsch Process)
FT20	20% Synthetic Diesel in LS
B20	20% Biodiesel in LS
DMM15	15% DMM in LS

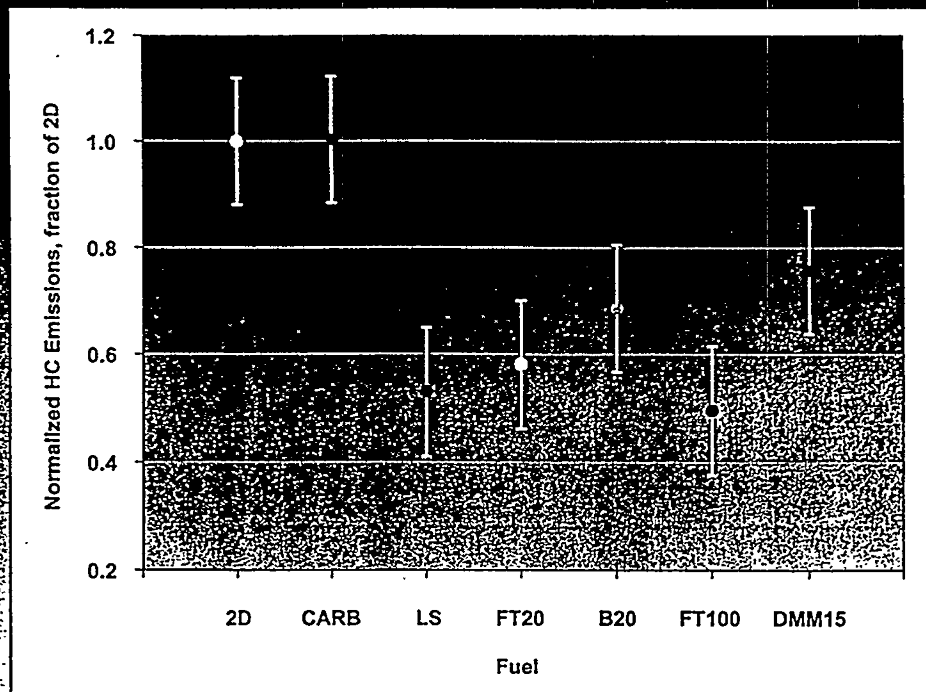
Fuel Properties

Property	Units	ASTM Method	Baseline Fuel (2D)	California Diesel (CARB)	Low-Sulfur Diesel (LS)	Synthetic Diesel (FT100)	Biodiesel Blend (B20)	Synthetic Diesel Blend (FT20)	DMM Blend (DMM15)
Density @ 15°C	g/mL	D 4052	0.849	0.831	0.811	0.781	0.826	0.806	0.817
Distillation		D 86							
IBP	°C		194	194	241	215	241	238	42
10%	°C		224	217	246	258	249	247	61
50%	°C		265	249	251	289	259	255	249
90%	°C		312	285	261	325	329	281	259
95%	°C		328	318	266	332	339	301	262
End Point	°C		344	344	285	337	347	322	281
Cetane Number		D 613	46	45	67	84	65	79	63
Aromatics	vol. %	D 5186	33.3	8.9	1.2	0.2	0.6	0.6	0.7
Flash Point	°C	D 93	74	69	101	98	104	100	< 9
Kin. Viscosity, 40°C	cSt	D 445	2.71	2.42	2.41	3.21	2.64	2.55	1.49
Carbon	mass %	D 5291	86.6	86	85.6	84.8	83.7	85.3	80.8
Hydrogen	mass %	D 5291	13.4	13.9	14.4	15.1	14.0	14.6	14.0
Oxygen	mass %	difference	0.0	0.1	0.0	0.1	2.3	0.1	5.2
Sulfur	ppm	D 2622	340	300	< 10	< 10	< 10	< 10	< 10
Nitrogen		D 4629	97.0	7.3	7.6	7.8	7.4	7.7	7.3
Net Heat of Comb.	MJ/kg	D 240	42.9	43.1	43.4	43.9	42.1	43.5	40.4

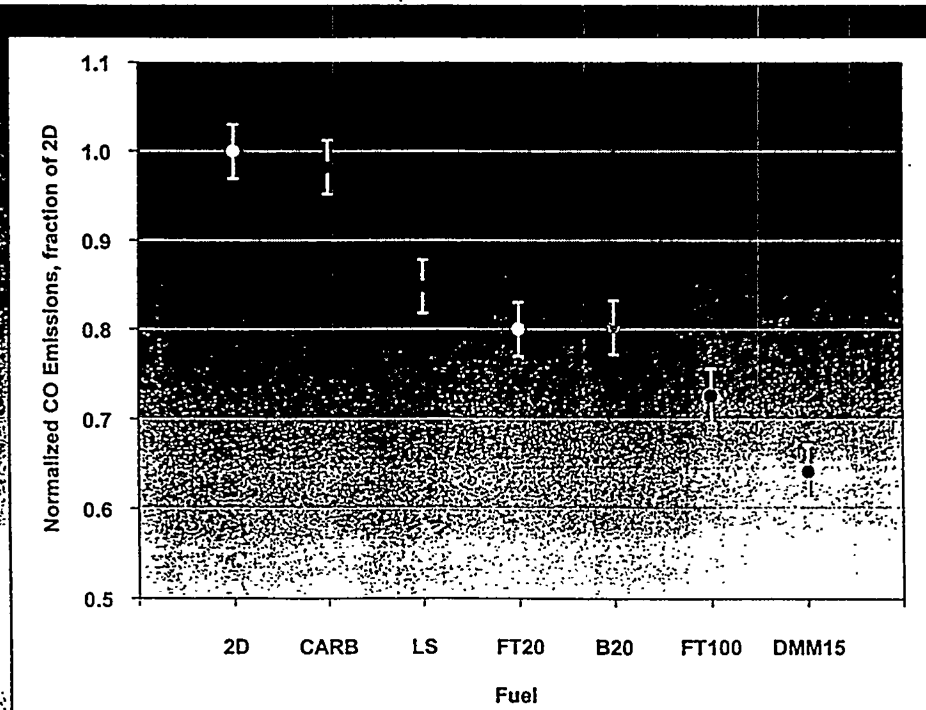
Range of Fuel Properties Tested

- Density, g/mL: 0.849 to 0.781
- IBP, deg C: 194 to 42 (241)
- EP, deg C: 344 to 281 (347)
- Cetane No.: 46 to 84 (45)
- Aromatics, vol%: 33 to 0.2
- Hydrogen, wt%: 13.4 to 15.1
- Oxygen, wt%: 0.0 to 5.2
- Sulfur, ppm: 340 to <10
- Net Heat of Combustion, MJ/kg: 42.9 to 40.4 (43.9)

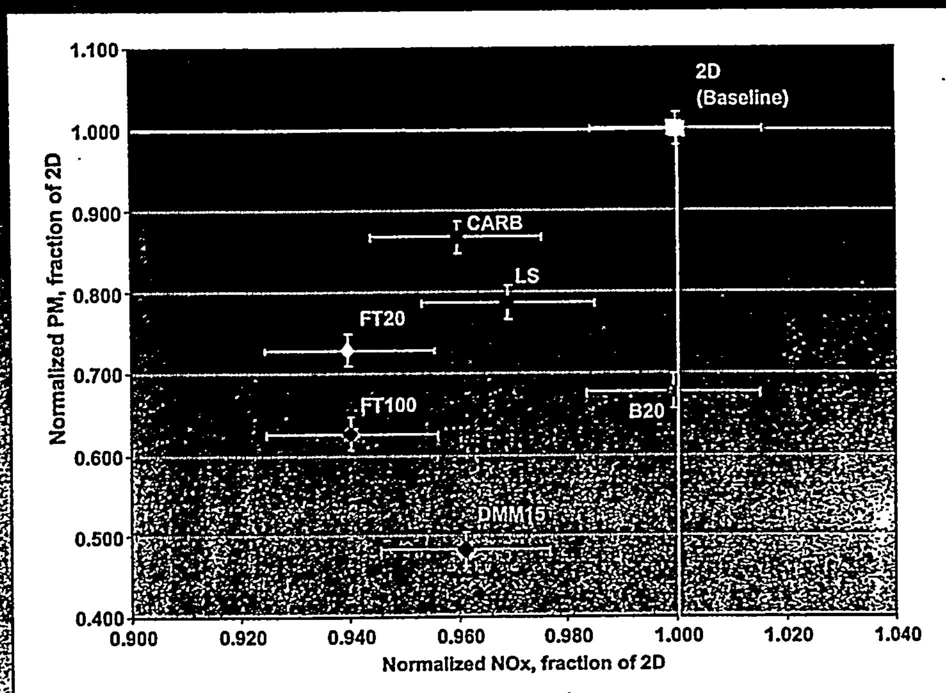
Comparison of Average HC Emissions



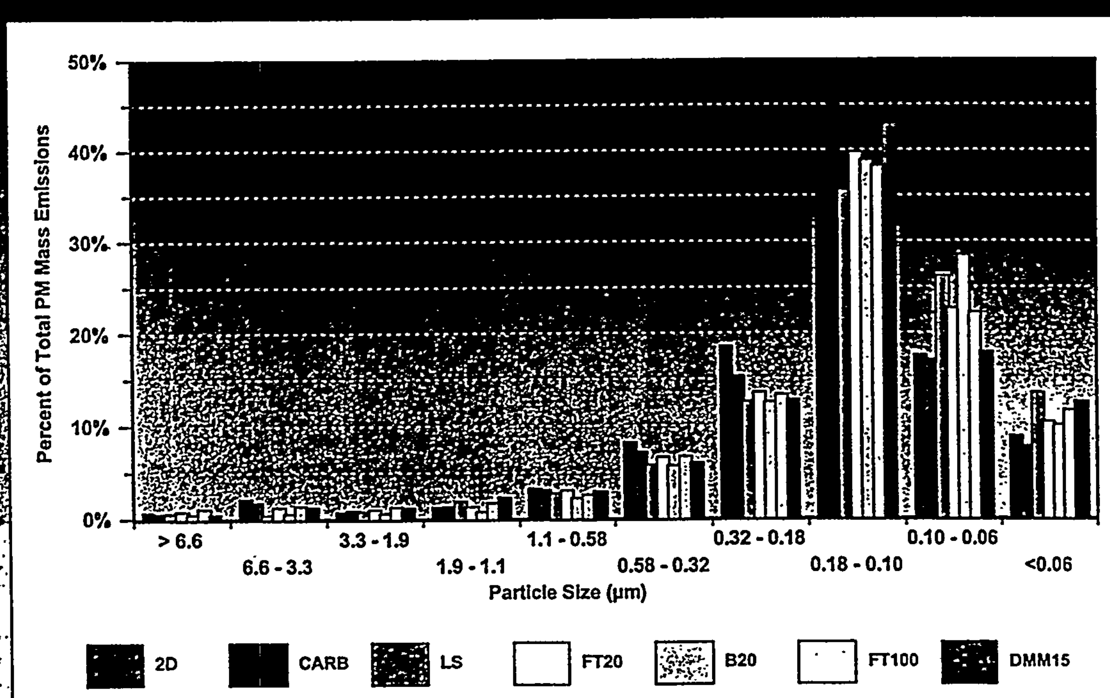
Comparison of Average CO Emissions



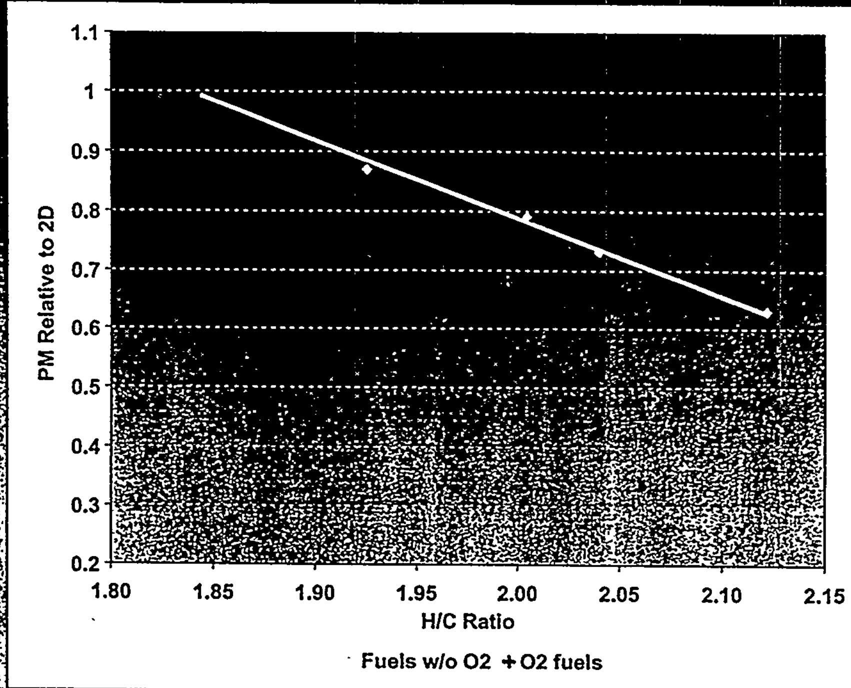
NO_x vs. PM
Equally weighted average of 13 modes



Average Particulate Size Distribution



Particulate Emissions Correlated with Hydrogen/Carbon Ratio



Fuel/Lubricant/Engine Interactions

- Significant differences in fuel composition
  - Fuel/lubricant compatibility
  - Lubricant performance requirements
- Emission benefits in unmodified engine
  - Lubricant benefits possible in formulation
  - Direct lubricant emissions become significant

New Drivers for Fuel Change

- EPA emissions standards
- Energy efficiency
- Resource availability
- New technology developments

The Process for Change Historically Established

- Continuous improvement path?
  - Engine and emission control systems modified
  - Fuels modified for improved systems
  - Lubricants modified for improved systems
- Step change in technology?
  - Coordinated industry/government development
  - Joint systems development for optimal performance