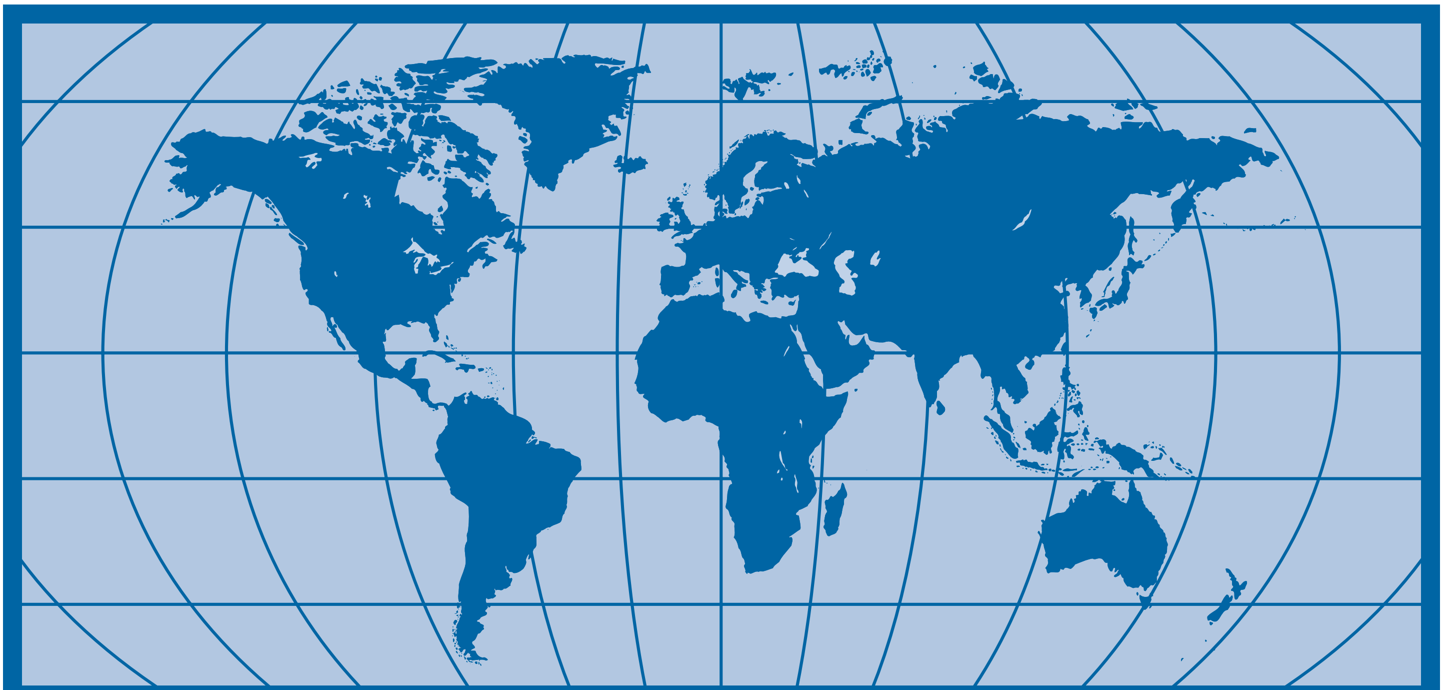

Fourth Edition

WORLDWIDE FUEL CHARTER

SEPTEMBER 2006

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For copies, please contact ACEA, Alliance, EMA or JAMA or visit their web sites.

Worldwide Fuel Charter, Fourth Edition, September 2006

Errata Sheet

Page 21, first paragraph, 5th sentence, should read:

“Figure 10 provides visual evidence of MMT’s impact on parts used in Tier 1 or LEV vehicles; the spark plug and oxygen sensor came from vehicles used in the 2002 joint automaker study, and the catalytic converters came from market vehicles, one driven in Canada and the other driven in California.”

2-Apr-07

ACEA
European Automobile
Manufacturers Association

Alliance OF AUTOMOBILE MANUFACTURERS
Alliance of Automobile
Manufacturers

ema
Engine Manufacturers
Association

JAMA
Japan Automobile Manufacturers
Association

September 2006

Dear Worldwide Fuel Charter Recipient:

Subject: **Worldwide Fuels Harmonisation**

On behalf of automobile and engine manufacturers from around the world, we are pleased to present the Fourth Edition of the Worldwide Fuel Charter. The Charter was first established in 1998 to promote greater understanding of the fuel quality needs of motor vehicle technologies and to harmonise fuel quality worldwide in accordance with engine and vehicle needs. Importantly, it matches fuel specifications to the needs and capabilities of engine and vehicle technologies designed for various markets around the world.

This edition realigns the fuel specification categories to more accurately reflect market conditions and engine and vehicle requirements. In addition, it updates and expands the listed test methods and adds information to the technical background. Advanced ultra-clean engine and vehicle technologies have begun to be introduced in some markets and will continue to be used in increasing numbers. These new technologies require the best fuel quality- as represented in Category 4- to achieve their emissions and performance potential. Their exhaust aftertreatment systems, including particulate matter and NOx aftertreatment systems, are being designed to enable compliance with various new emission regulations. Fuels that are sulphur-free and metals-free are prerequisites to effective use of these ultraclean technologies.

As with previous editions, the Worldwide Fuel Charter Committee invited interested parties to comment on the proposed changes to the document. We are pleased to report that this edition has generated considerably more comments from more interested parties than ever before, which the Committee carefully considered before finalizing this edition. We appreciate the time people took to review the document and share their reactions, and we are especially grateful to those organizations that expressed support for this endeavor.

We look forward to working with you to support these harmonised specifications for the continued benefit of consumers and the environment around the globe.

Ivan Hodac Jed R. Mandel Yoshiyasu Nao

Ivan Hodac
Secretary General
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Frederick L. Webber
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- Association of International Automobile Manufacturers (AIAM)
- Association of International Automotive Manufacturers of Canada (AIAMC)
- Associacion Mexicana de la Industria Automotriz, A.C. (AMIA)
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- Canadian Vehicle Manufacturers' Association (CVMA)
- Chamber of Automotive Manufacturers of the Philippines, Inc. (CAMPI)
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- Indonesia Automotive Federation (IAF)
- Korean Automobile Manufacturers Association (KAMA)
- National Association of Automobile Manufacturers of South Africa (NAAMSA)
- Malaysian Automotive Association (MAA)
- Thai Automotive Industry Association (TAIA)
- Vietnam Automobile Manufacturers Association (VAMA)

Supporting organisations:
- Organisation Internationale des Constructeurs d'Automobiles (OICA)

ACRONYM LIST

AAMA	American Automobile Manufacturers Association, whose members were Chrysler, Ford and GM, ceased to exist after 31 December 1998.
ACEA	Association des Constructeurs Européens d'Automobiles (European automotive manufacturers association)
AIAM	Association of International Automobile Manufacturers
Alliance	Alliance of Automobile Manufacturers
AMA	Accelerated Mileage Accumulation
AQIRP	Air Quality Improvement Research Programme (part of the US Auto Oil programme, 1989-1992)
ASTM	ASTM International (formerly American Society for Testing and Materials)
CCD	Combustion Chamber Deposits
CDPF	Catalysed Diesel Particulate Filter
CEC	Coordinating European Council for the Development of Performance Tests for Transportation Fuels, Lubricants and Other Fluids
CFPP	Cold Filter Plugging Point
CI	Cetane Index
CN	Cetane Number
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CP	Cloud Point
CRC	Coordinating Research Council (US)
CR-DPF	Continuously Regenerating Diesel Particulate Filter
DECSE	Diesel Emission Control – Sulfur Effects, research program of the US Department of Energy
DI	Distillation Index
DIN	Deutsches Institut für Normung (German Institute of Standardisation)
DPF	Diesel Particulate Filter
DVPE	Dry Vapour Pressure Equivalence
EMA	Engine Manufacturers Association
EN	European Norm
EPA	Environmental Protection Agency (US)
EPEFE	European Programme on Emissions, Fuels and Engine Technology (part of the European Auto-Oil 1 programme, 1993-1995)
FAEE	Fatty Acid Ethyl Esters
FAME	Fatty Acid Methyl Esters
FBP	Final Boiling Point
FLTM	Ford Laboratory Test Method
HC	Hydrocarbons
HFRR	High Frequency Reciprocating Rig
ICP-AES	Inductively Coupled Plasma - Atomic Emission Spectrometry
IP	The Institute of Petroleum
ISO	International Organisation for Standardization
IVD	Intake Valve Deposits
JAMA	Japan Automobile Manufacturers Association
JARI	Japan Automobile Research Institute
JIS	Japanese Industrial Standards
LEV	Low Emission Vehicle
LTFT	Low Temperature Flow Test
MECA	Manufacturers of Emission Controls Association
MMT	Methylcyclopentadienyl Manganese Tricarbonyl
MtBE	Methyl tertiary Butyl Ether
MON	Motor Octane Number
NF M	Norme Française - Industrie du Pétrole (French Norm - Petroleum Industry)
NF T	Norme Française - Industrie Chimique (French Norm - Chemical Industry)
NOx	Oxides of Nitrogen
OBD	On-Board Diagnostics
OFP	Ozone Forming Potential
Oxy	Oxygen
PAH	Polycyclic Aromatic Hydrocarbons
pHe	Acidity of ethanol
PM	Particulate Matter
ppm	Parts per million
RON	Research Octane Number
SULEV	Super-Ultra-Low Emission Vehicle
TGA	Thermal Gravimetric Analysis
THC	Total Hydrocarbons
TLEV	Transitional Low Emission Vehicle
TWD	Total Weighted Demerits
ULEV	Ultra-Low Emission Vehicle
VDE	Vegetable Derived Esters

The objective of the global fuels harmonisation effort is to develop common, worldwide recommendations for "quality fuels," taking into consideration customer requirements and vehicle emission technologies, which, in turn, will benefit our customers and all other affected parties. These recommendations allow automotive and engine manufacturers to provide consistent fuel quality advice worldwide.

Implementation of the recommendations will:
- Reduce the impact of motor vehicles on the environment through reduced vehicle fleet emissions;
- Minimise vehicle equipment complexities with optimised fuels for each emission control category, which will reduce customer costs (purchase and operation); and,
- Increase customer satisfaction with vehicle performance.

Four different categories of fuel quality have been established for both unleaded gasoline and diesel fuel. These are described below.

Category 1:
Markets with no or first level of emission control; based primarily on fundamental vehicle/engine performance and protection of emission control systems. For example, markets requiring US Tier 0 and EURO 1 emission standards.

Category 2:
Markets with stringent requirements for emission control or other market demands. For example, markets requiring US Tier 1, EURO 2 or 3, or equivalent emission standards.

Category 3:
Markets with advanced requirements for emission control or other market demands. For example, markets requiring US/California LEV or ULEV, EURO 3, JP 2005, or equivalent emission standards.

Category 4:
Markets with further advanced requirements for emission control to enable sophisticated NOx and particulate matter after-treatment technologies. For example, markets requiring US EPA Tier 2 or 2007 / 2010 Heavy Duty On-Highway, US EPA Non-Road Tier 4, US California LEV-II, EURO 4, EURO 5 Heavy Duty, or equivalent emission standards.

Engine and vehicle technologies normally achieve improved performance and lower emissions with higher category fuels. These fuel quality recommendations are for the properties of the finished fuel as provided to the end user. Internal quality control methods are not dictated or restricted, as long as the fuel meets these specifications. Where national requirements are more severe than these recommendations, those national limits have to be met.

To meet future customer, environmental and energy challenges, the automotive and engine industries worldwide are exploring advanced propulsion technologies. While Category 3 has been defined as those requirements needed by advanced technologies as they exist today, Category 4 has been defined as an ultra-low sulphur fuel to meet the needs of advanced and future vehicle technologies.

All the Categories will be reviewed and revised as appropriate to reflect changes in engine and vehicle technologies, petroleum refining, and test methods.

Markets with no or first level of emission controls; based primarily on fundamental vehicle/engine performance and protection of emission control system.

PROPERTIES		**UNITS**	**LIMIT**	
			Min.	Max.
'91 RON' (1)	Research Octane Number	-	91.0	
	Motor Octane Number	-	82.0	
'95 RON' (1)	Research Octane Number	-	95.0	
	Motor Octane Number	-	85.0	
'98 RON' (1)	Research Octane Number	-	98.0	
	Motor Octane Number	-	88.0	
Oxidation stability		minutes	360	
Sulphur content		mg/kg(2)		1000
Metal content (Fe, Mn, Pb(3), other)		mg/l		Non-detectable (4)
Oxygen content		% m/m		2.7 (5)
Aromatics content		% v/v		50.0
Benzene content		% v/v		5.0
Volatility			See Tables, page 7	
Unwashed gums		mg/100 ml		70
Washed gums		mg/100 ml		5
Density		kg/m^3	715	780
Copper corrosion		merit	Class 1	
Appearance			Clear and Bright; no free water or particulates	
Carburettor cleanliness		merit	8.0 (6)	
Fuel injector cleanliness, Method 1		% flow loss		10 (6)
Fuel injector cleanliness, Method 2		% flow loss		10 (6)
Intake valve cleanliness		merit	9.0 (6)	

General Notes:

N.B. # 1: Additives must be compatible with engine oils (no increase in engine sludge/varnish deposits). Addition of ash-forming components is not allowed.

N.B. # 2: Good housekeeping practices to reduce contamination (dust, water, other fuels, etc.).

Footnotes:

(1) Adequate labeling of pumps must be defined and used; fuel should be dispensed through nozzles meeting SAE J285, 'Recommended Practice Gasoline Dispenser Nozzle Spouts.' Three octane grades defined for maximum market flexibility. Availability of all three not needed.

(2) The unit mg/kg is often expressed as ppm. Lower sulphur content preferred for catalyst-equipped vehicles.

(3) No intentional lead addition. Maximum level of 10 mg/kg is acceptable during the transitional period.

(4) Metal-containing additives are accepted for valve seat protection in non-catalyst cars only. In this case, potassium-based additives are recommended.

(5) Where oxygenates are used, ethers are preferred. Where up to 10% by volume ethanol (meeting ASTM D 4806) is permitted by existing regulation, the blended fuel must meet all other Category 1 requirements, and fuel pump labelling is recommended. Higher ($C > 2$) alcohols are limited to 0.1% maximum by volume. Methanol is not permitted.

(6) Compliance with this requirement can be demonstrated by the use of proper detergent additives in comparable-base gasolines.

Markets with stringent requirements for emission controls or other market demands.

PROPERTIES		**UNITS**	**LIMIT**	
			Min.	Max.
'91 RON' (1)	Research Octane Number	-	91.0	
	Motor Octane Number	-	82.5	
'95 RON' (1)	Research Octane Number	-	95.0	
	Motor Octane Number	-	85.0	
'98 RON' (1)	Research Octane Number	-	98.0	
	Motor Octane Number	-	88.0	
Oxidation stability		minutes	480	
Sulphur content		mg/kg (2)		150
Metal content (Fe, Mn, Pb, Others)		mg/l	Non-detectable (3)	
Phosphorus content		mg/l	Non-detectable (3)	
Silicon content		mg/kg	Non-detectable (3)	
Oxygen content		% m/m		2.7 (4)
Olefins content		% v/v		18.0
Aromatics content		% v/v		40.0
Benzene content		% v/v		2.5
Volatility			See Tables, page 12	
Sediment		mg/l		1
Unwashed gums (5)		mg/100 ml		70
Washed gums		mg/100 ml		5
Density		kg/m^3	715	770
Copper corrosion		merit	Class 1	
Appearance			Clear and Bright; no free water or particulates	
Fuel injector cleanliness, Method 1		% flow loss		5
Fuel injector cleanliness, Method 2		% flow loss		10
Intake-valve sticking		pass/fail	Pass	
Intake valve cleanliness II				
Method 1 (CEC F-05-A-93), or		avg. mg/valve		50
Method 2 (ASTM D 5500), or		avg. mg/valve		100
Method 3 (ASTM D 6201)		avg. mg/valve		90
Combustion chamber deposits (5)				
Method 1 (ASTM D 6201), or		% of base fuel		140
Method 2 (CEC-F-20-A-98), or		mg/engine		3500
Method 3 (TGA - FLTM BZ154-01)		% mass.@ 450° C		20

General Notes:

N.B. # 1: Additives must be compatible with engine oils (no increase in engine sludge/varnish deposits). Addition of ash-forming components is not allowed.

N.B. # 2: Good housekeeping practices to reduce contamination (dust, water, other fuels, etc.).

Footnotes:

(1) Adequate labeling of pumps must be defined and used; fuel should be dispensed through nozzles meeting SAE J285, 'Recommended Practice Gasoline Dispenser Nozzle Spouts'. Three octane grades defined for maximum market flexibility. Availability of all three not needed.

(2) The unit mg/kg is often expressed as ppm.

(3) At or below limit of quantitation of test method used. No intentional addition of metal-based additives.

(4) Where oxygenates are used, ethers are preferred. Where up to 10% by volume ethanol (meeting ASTM D 4806) is permitted by existing regulation, the blended fuel must meet all other Category 2 requirements, and fuel pump labelling is recommended. Higher (C > 2) alcohols are limited to 0.1% maximum by volume. Methanol is not permitted.

(5) To provide flexibility (for example, to enable the use of detergency additives that increase unwashed gum levels), the fuel may comply with either the Unwashed Gum limit or the Combustion Chamber Deposits limit.

Markets with advanced requirements for emission controls or other market demands.

PROPERTIES		**UNITS**	**LIMIT**	
			Min.	Max.
'91 RON' (1)	Research Octane Number	-	91.0	
	Motor Octane Number	-	82.5	
'95 RON' (1)	Research Octane Number	-	95.0	
	Motor Octane Number	-	85.0	
'98 RON' (1)	Research Octane Number	-	98.0	
	Motor Octane Number	-	88.0	
Oxidation stability		minutes	480	
Sulphur content		mg/kg (2)		30
Metal content (Fe, Mn, Pb, Other)		mg/l	Non-detectable (3)	
Phosphorus content		mg/l	Non-detectable (3)	
Silicon content		mg/kg	Non-detectable (3)	
Oxygen content		% m/m		2.7 (4)
Olefins content		% v/v		10.0
Aromatics content		% v/v		35.0
Benzene content		% v/v		1.0
Volatility			See Tables, page 12	
Sediment		mg/l		1
Unwashed gums (5)		mg/100 ml		30
Washed gums		mg/100 ml		5
Density		kg/m^3	715	770
Copper corrosion		merit	Class 1	
Appearance			Clear and Bright; no free water or particulates	
Fuel injector cleanliness, Method 1		% flow loss		5
Fuel injector cleanliness, Method 2		% flow loss		10
Particulate contamination, size distribution		Code rating	18/16/13 per ISO 4406	
Intake-valve sticking		pass/fail	Pass	
Intake valve cleanliness II				
Method 1 (CEC F-05-A-93), or		avg. mg/valve		30
Method 2 (ASTM D 5500), or		avg. mg/valve		50
Method 3 (ASTM D 6201)		avg. mg/valve		50
Combustion chamber deposits (5)				
Method 1 (ASTM D 6201), or		% of base fuel		140
Method 2 (CEC-F-20-A-98), or		mg/engine		2500
Method 3 (TGA FLTM BZ154-01)		% mass. @ 450° C		20

General Notes:

N.B. # 1: Additives must be compatible with engine oils (no increase in engine sludge/varnish deposits). Addition of ash forming components is not allowed.

N.B. # 2: Good housekeeping practices to reduce contamination (dust, water, other fuels, etc.).

Footnotes:

(1) Adequate labeling of pumps must be defined and used; fuel should be dispensed through nozzles meeting SAE J285, 'Recommended Practice Gasoline Dispenser Nozzle Spouts'. Three octane grades defined for maximum market flexibility. Availability of all three not needed.

(2) The unit mg/kg is often expressed as ppm.

(3) At or below limit of quantitation of test method used. No intentional addition of metal-based additives.

(4) Where oxygenates are used, ethers are preferred. Where up to 10% by volume ethanol (meeting ASTM D 4806) is permitted by existing regulation, the blended fuel must meet all other Category 3 requirements, and fuel pump labelling is recommended. Higher (C > 2) alcohols are limited to 0.1 % maximum by volume. Methanol is not permitted.

(5) To provide flexibility (for example, to enable the use of detergency additives that increase unwashed gum levels), the fuel may comply with either the Unwashed Gum limit or the Combustion Chamber Deposits limit.

Markets with further advanced requirements for emission control, to enable sophisticated NOx after-treatment technologies.

PROPERTIES		**UNITS**	**LIMIT**	
			Min.	Max.
'91 RON' (1)	Research Octane Number	-	91.0	
	Motor Octane Number	-	82.5	
'95 RON' (1)	Research Octane Number	-	95.0	
	Motor Octane Number	-	85.0	
'98 RON' (1)	Research Octane Number	-	98.0	
	Motor Octane Number	-	88.0	
Oxidation stability		minutes	480	
Sulphur content		mg/kg (2)		10
Metal content (Fe, Mn, Pb, other)		mg/l	Non-detectable (3)	
Phosphorus content		mg/l	Non-detectable (3)	
Silicon content		mg/kg	Non-detectable (3)	
Oxygen content		% m/m		2.7 (4)
Olefins content		% v/v		10.0
Aromatics content		% v/v		35.0
Benzene content		% v/v		1.0
Volatility			See Tables, page 12	
Sediment		mg/l		1
Unwashed gums (5)		mg/100 ml		30
Washed gums		mg/100 ml		5
Density		kg/m^3	715	770
Copper corrosion		merit	Class 1	
Appearance			Clear and Bright; no free water or particulates	
Fuel injector cleanliness, Method 1		% flow loss		5
Fuel injector cleanliness, Method 2		% flow loss		10
Particulate contamination, size distribution		Code rating	18/16/13 per ISO 4406	
Intake-valve sticking		pass/fail	Pass	
Intake valve cleanliness II				
Method 1 (CEC F-05-A-93), or		avg. mg/valve		30
Method 2 (ASTM D 5500), or		avg. mg/valve		50
Method 3 (ASTM D 6201)		avg. mg/valve		50
Combustion chamber deposits (5)				
Method 1 (ASTM D 6201), or		% of base fuel		140
Method 2 (CEC-F-20-A-98), or		mg/engine		2500
Method 3 (TGA FLTM BZ154-01)		% mass. @ 450° C		20

General Notes:

N.B. # 1: Additives must be compatible with engine oils (no increase in engine sludge/varnish deposits). Addition of ash forming components is not allowed.

N.B. # 2: Good housekeeping practices to reduce contamination (dust, water, other fuels, etc.).

Footnotes:

(1) Adequate labeling of pumps must be defined and used; fuel should be dispensed through nozzles meeting SAE J285, 'Recommended Practice Gasoline Dispenser Nozzle Spouts'. Three octane grades defined for maximum market flexibility. Availability of all three not needed.

(2) The unit mg/kg is often expressed as ppm.

(3) At or below limit of quantitation of test method used. No intentional addition of metal-based additives.

(4) Where oxygenates are used, ethers are preferred. Where up to 10% by volume ethanol (meeting ASTM D 4806) is permitted by existing regulation, the blended fuel must meet all other Category 4 requirements, and fuel pump labelling is recommended. Higher (C > 2) alcohols are limited to 0.1 % maximum by volume. Methanol is not permitted.

(5) To provide flexibility (for example, to enable the use of detergency additives that increase unwashed gum levels), the fuel may comply with either the Unwashed Gum limit or the Combustion Chamber Deposits limit.

VOLATILITY CLASSES FOR HARMONISED GASOLINE SPECIFICATIONS

CATEGORY 1

Class *	A	B	C	D	E
Ambient Temp. Range, °C	> 15	5 to 15	-5 to +5	-5 to -15	< -15
Vapour Pressure, kPa	45 - 60	55 - 70	65 - 80	75 - 90	85 - 105
T10, °C, max	70	70	65	60	55
T50, °C	77 - 110	77 - 110	77 - 110	77 - 110	77 - 110
T90, °C	130 - 190	130 - 190	130 - 190	130 - 190	130 - 190
EP, °C max.	215	215	215	215	215
E70, %	15 - 45	15 - 45	25 - 45	25 - 47	25 - 47
E100, %	50 - 60	50 - 65	50 - 65	55 - 70	55 - 70
E180, % min	85	85	85	85	85

* 'Class' is based on the minimum expected ambient temperatures of the market and will vary by season.

CATEGORY 2, 3 and 4

Class *	A	B	C	D	E
Ambient Temp. Range, °C	> 15	5 to 15	-5 to +5	-5 to -15	< -15
Vapour Pressure, kPa	45 - 60	55 - 70	65 - 80	75 - 90	85 - 105
T10, °C, max	65	60	55	50	45
T50, °C	77 - 100	77 - 100	77 - 100	77 - 100	77 - 100
T90, °C	130 - 175	130 - 175	130 - 175	130 - 175	130 - 175
EP, °C max.	195	195	195	195	195
E70, %	20 - 45	20 - 45	25 - 45	25 - 47	25 - 47
E100, %	50 - 65	50 - 65	50 - 65	55 - 70	55 - 70
E180, % min	90	90	90	90	90
D.I., max	570	565	560	555	550

* 'Class' is based on the minimum expected ambient temperatures of the market and will vary by season.

Notes:

Ambient temperature ranges listed represent the condition the vehicle operator will encounter. Local regulations/standards may define classes based on expected temperatures from varying historical or statistical information sources applicable to their locale.

D.I. (Distillation Index) = (1.5 * T10) + (3 * T50) + T90 + (11 * mass % of oxygen); temperatures are in degrees Celsius.

Oxygenate correction does not apply to ethers. Limited data on LEV/ULEV vehicles suggest that a similar oxygenate correction may be needed for ethers. The need for and the magnitude of the correction will be determined as more data become available. Preliminary data indicate that vehicles may need further volatility controls beyond what is currently specified.

VAPOUR / LIQUID RATIO (V/L), $T_{V/L}$=20

CATEGORY 1, 2, 3 and 4

Class	Test Temperature, °C, min.	Applicable Temperature, °C
1	60	≥43
2	56	< 43
3	51	< 36
4	47	< 29
5	41	< 21
6	35	< 14

Vapour lock class is determined based on the 90th percentile maximum (applicable) daily temperature. The minimum test temperature of the gasoline for V/L=20 is provided for each vapour lock class. Additional information is provided in ASTM D 4814.

The latest test methods should be used unless otherwise indicated by specific method year. On those parameters where "non-detectable" is listed, the lowest possible levels are expected with no intentional additions of this additive or contaminant. Where multiple methods are indicated, the manufacturer should assure the product conforms to the most precise method listed.

PROPERTIES	**UNITS**	**ISO**	**ASTM**	**JIS**	**Other**
Research Octane Number	-	EN 5164	D 2699	K 2280	
Motor Octane Number	-	EN 5163	D 2700	K 2280-96	
Oxidation stability	minutes	7536	D 525	K 2287	
Sulphur content	mg/kg	20846 20884	D 2622 D 5453	K 2541	
Lead content	mg/l		D 3237	K 2255	EN 237
Potassium (K) content	mg/l				NF M 07065 EN 14538
Metal content	mg/l				ICP (1)
Phosphorus content	mg/l		D 3231		
Manganese content	mg/l		D 3831		
Silicon content	mg/kg				ICP-AES (Reference in-house methods with detection limit = 1 mg/kg)
Oxygen content	% m/m		D 4815	K 2536	EN 13132
Olefins content (2)	% v/v	3837	D 1319	K 2536	
Aromatics content (2)	% v/v	3837	D 1319	K 2536	EN 14517
Benzene content	% v/v		D 5580 D 3606	K 2536	EN 238 EN 14517
Vapour Pressure	kPa		D 5191	K 2258	EN 13016/1 DVPE
Distillation: T10/T50/T90, E70/E100/E180, End Point, residue		3405	D 86	K 2254	
Vapour/liquid ratio (V/L)	°C		D 5188		
Sediment	mg/l		D 5452		
Unwashed gums	mg/100 ml	6246	D 381	K 2261	May be replaced with CCD test
Washed gums	mg/100 ml	6246	D 381	K 2261	
Density	kg/m^3	3675 12185	D 4052	K 2249	
Copper corrosion	merit	2160	D 130	K 2513	
Appearance			D 4176		Visual inspection
Carburettor cleanliness	merit				CEC F-03-T
Fuel injector cleanliness, Method 1	% flow loss		D 5598		
Fuel injector cleanliness, Method 2	% flow loss		D 6421		
Particulate contamination,	code rating	4406			
size distribution	no of particles/ml	4407 & 11500			
Intake-valve sticking	pass/fail				CEC F-16-T
Intake valve cleanliness I	merit				CEC F-04-A
Intake valve cleanliness II	avg. mg/valve				
Method 1, 4 valve avg.					CEC F-05-A
Method 2, BMW test			D 5500		
Method 3, Ford 2.3L			D 6201		
Combustion chamber deposits					
Method 1	% of base fuel		D 6201		
Method 2	mg/engine			CEC F-20- A	
Method 3	% mass @ 450 °C			FLTM-BZ154 (3)	

(1) ASTM D 5185 may be used as a guide for developing a test method for metals and other inorganic elements in fuel. The lower limit of quantitation for various elements in lubricating oil may provide an estimate of the values expected for fuels. See Table 1.

(2) Some methods for olefin and aromatic content are used in legal documents; more precise methods are available and may be used.

(3) This method is available at www.autoalliance.org

Table 1 : Limits of Quantitation for ASTM D 5185 (Element Limit of quantitation (mg/kg))

Ag = 0.5	Al = 6	B = 4	Ba = 0.5	Ca = 40	Cr = 1	Cu = 2	Fe = 2	K = 40	Mg = 5	Mn = 5
Mo = 5	Na = 7	Ni = 5	P = 10	Pb = 10	Si = 8	Sn = 10	Ti = 5	V = 1	Zn = 60	

Markets with no or first level of emission controls; based primarily on fundamental vehicle/engine performance and protection of emission control systems.

PROPERTIES	UNITS	LIMIT	
		Min.	Max.
Cetane Number	-	48.0	
Cetane Index (1)	-	48.0 (45.0) (1)	
Density @ 15°C	kg/m3	820 (2)	860
Viscosity @ 40°C	mm2/s	2.0 (3)	4.5
Sulphur content	mg/kg (4)		2000 (5)
T95	°C		370
Flash point	°C	55 (6)	
Carbon residue	% m/m		0.30
CFPP (7) or LTFT or CP	°C	Maximum must be equal to or lower than the lowest expected ambient temperature.	
Water content	mg/kg		500
Oxidation stability, Method 1	g/m3		25
Oxidation stability, Method 2	induction time	(8)	
FAME content	% v/v		5% (9)
Copper corrosion	merit		Class 1
Ethanol/Methanol content	% v/v	Non-detectable (10)	
Ash content	% m/m		0.01
Particulate Contamination, total	mg/kg		10 (11)
Appearance		Clear and bright; no free water or particulates	
Lubricity (HFRR wear scar dia. @ 60°C)	micron	--	400

General Notes:

N.B. # 1: Additives must be compatible with engine oils. Addition of ash-forming components is not allowed.

N.B. # 2: Good housekeeping practices to reduce contamination (dust, water, other fuels, etc.).

N.B. # 3: Adequate labeling of pumps must be defined and used.

Footnotes:

(1) Cetane Index is acceptable instead of Cetane Number if a standardized engine to determine the Cetane Number is unavailable and cetane improvers are not used. When cetane improvers are used, the estimated Cetane Number must be greater than or equal to the specified value and the Cetane Index must be greater than or equal to the number in parentheses.

(2) The minimum limit can be relaxed to 800 kg/m3 when ambient temperatures are below -30°C.

(3) The minimum limit can be relaxed to 1.5 mm2/s when ambient temperatures are below -30°C, and to 1.3 mm2/s when ambient temperatures are below -40°C.

(4) The unit mg/kg is often expressed as ppm.

(5) 3000 mg/kg is allowed as a transitional limit.

(6) The minimum limit can be relaxed to 38°C when ambient temperatures are below -30°C.

(7) If compliance is demonstrated by meeting CFPP, then it must be no more than 10°C less than cloud point.

(8) Limit and test method are under review.

(9) For FAME (Fatty Acid Methyl Esters), both EN14214 and ASTM D6751, or equivalent standards, should be considered. Where FAME is used, it is recommended that fuel pumps be marked accordingly.

(10) At or below detection limit of the test method used.

(11) Limit and test method are under further review.

Markets with stringent requirements for emission controls or other market demands.

PROPERTIES	**UNITS**	**LIMIT**	
		Min.	Max.
Cetane Number	-	51.0	
Cetane Index (1)	-	51.0 (48.0)(1)	
Density @ 15°C	kg/m^3	820 (2)	850
Viscosity @ 40°C	Mm^2/s	2.0 (3)	4.0
Sulphur content	mg/kg (4)		300
Metal content (Zn, Cu, Mn, Ca, Na, other)	g/l	Non-detectable (5)	
Total aromatics content	% m/m		25
PAH content (di+, tri+)	% m/m		5
T90 (6)	°C		340
T95 (6)	°C		355
Final Boiling Point	°C		365
Flash point	°C	55	--
Carbon residue	% m/m		0.30
CFPP (7) or LTFT or CP	°C	Maximum must be equal to or lower than the lowest expected ambient temperature.	
Water content	mg/kg		200
Oxidation stability, Method 1	g/m^3		25
Oxidation stability, Method 2	induction time	(8)	
Biological growth		'Zero' content	
FAME content	% v/v		5 (9)
Ethanol/Methanol content	% v/v	Non-detectable (10)	
Total acid number	mg KOH/g		0.08
Ferrous corrosion	-	--	Light rusting
Copper corrosion	merit	Class 1	
Ash content	% m/m		0.01
Particulate contamination, total	mg/kg		10 (11)
Particulate contamination, size distribution	code rating	18/16/13 per ISO 4406	
Appearance		Clear and Bright; no free water or particulates	
Injector cleanliness	% air flow loss		85
Lubricity (HFRR wear scar dia. @ 60°C)	micron	--	400

General Notes:

N.B. # 1: Additives must be compatible with engine oils. Addition of ash-forming components is not allowed.
N.B. # 2: Good housekeeping practices to reduce contamination (dust, water, other fuels, etc.).
N.B. # 3: Adequate labeling of pumps must be defined and used.

Footnotes:

(1) Cetane Index is acceptable instead of Cetane Number if a standardized engine to determine the Cetane Number is unavailable and cetane improvers are not used. When cetane improvers are used, the estimated Cetane Number must be greater than or equal to the specified value and the Cetane Index must be greater than or equal to the number in parentheses.

(2) The minimum limit can be relaxed to 800 kg/m^3 when ambient temperatures are below -30°C. For environmental purposes, a minimum of 815 kg/m^3 can be adopted.

(3) The minimum limit can be relaxed to 1.5 mm^2/s when ambient temperatures are below -30°C, and to 1.3 mm^2/s when ambient temperatures are below -40°C.

(4) The unit mg/kg is often expressed as ppm.

(5) At or below the limit of quantitation of the test method used. No intentional addition of metal-based additives.

(6) Compliance with either T90 or T95 is required.

(7) If compliance is demonstrated by meeting CFPP, then it must be no more than 10°C less than cloud point.

(8) Limit and test method are under review.

(9) For FAME (Fatty Acid Methyl Esters), both EN14214 and ASTM D6751, or equivalent standards, should be considered. Where FAME is used, it is recommended that fuel pumps be marked accordingly.

(10) At or below detection limit of the test method used.

(11) Limit and test method are under review.

Markets with advanced requirements for emission controls or other market demands.

PROPERTIES	**UNITS**	**LIMIT**	
		Min.	Max.
Cetane Number	-	53.0	
Cetane Index (1)	-	53.0 (50.0)(1)	
Density @ 15°C	kg/m^3	820 (2)	840
Viscosity @ 40°C	mm^2/s	2.0 (3)	4.0
Sulphur content	mg/kg (4)		50
Metal content (Zn, Cu, Mn, Ca, Na, other)	g/l	Non-detectable (5)	
Total aromatics content	% m/m		20
PAH content (di+, tri+)	% m/m		3.0
T90 (6)	°C		320
T95 (6)	°C		340
Final Boiling Point	°C		350
Flash point	°C	55	--
Carbon residue	% m/m		0.20
CFPP (7) or LTFT or CP	°C	Maximum must be equal to or lower than the lowest expected ambient temperature.	
Water content	mg/kg		200
Oxidation stability, Method 1	g/m^3		25
Oxidation stability, Method 2	induction time	(8)	
Foam volume	ml		100
Foam vanishing time	sec.		15
Biological growth		'Zero' content	
FAME content	% v/v		5 (9)
Ethanol/Methanol content	% v/v	Non-detectable (10)	
Total acid number	mg KOH/g		0.08
Ferrous corrosion	-	--	Light rusting
Copper corrosion	merit	Class 1	
Ash content	% m/m		0.01
Particulate contamination, total	mg/kg		10 (11)
Particulate contamination, size distribution	code rating	18/16/13 per ISO 4406	
Appearance		Clear and bright; no free water or particulates	
Injector cleanliness	% air flow loss		85
Lubricity (HFRR wear scar dia. @ 60°C)	micron	--	400

General Notes:

N.B. # 1: Additives must be compatible with engine oils. Addition of ash-forming components is not allowed.
N.B. # 2: Good housekeeping practices to reduce contamination (dust, water, other fuels, etc.).
N.B. # 3: Adequate labeling of pumps must be defined and used.

Footnotes:

(1) Cetane Index is acceptable instead of Cetane Number if a standardized engine to determine the Cetane Number is unavailable and cetane improvers are not used. When cetane improvers are used, the estimated Cetane Number must be greater than or equal to the specified value and the Cetane Index must be greater than or equal to the number in parentheses.

(2) The minimum limit can be relaxed to 800 kg/m^3 when ambient temperatures are below -30°C. For environmental purposes, a minimum of 815 kg/m^3 can be adopted.

(3) The minimum limit can be relaxed to 1.5 mm^2/s when ambient temperatures are below -30°C, and to 1.3 mm^2/s when ambient temperatures are below -40°C.

(4) The unit mg/kg is often expressed as ppm.

(5) At or below the limit of quantitation of the test method used. No intentional addition of metal-based additives

(6) Compliance with either T90 or T95 is required.

(7) If compliance is demonstrated by meeting CFPP, then it must be no more than 10°C less than cloud point.

(8) Limit and test method are under review.

(9) For FAME (Fatty Acid Methyl Esters), both EN14214 and ASTM D6751, or equivalent standards, should be considered. Where FAME is used, it is recommended that fuel pumps be marked accordingly.

(10) At or below detection limit of the test method used.

(11) Limit and test method are under review.

Markets with further advanced requirements for emission control, to enable sophisticated NOx and PM after-treatment technologies.

PROPERTIES	UNITS	LIMIT	
		Min.	Max.
Cetane Number	-	55.0	
Cetane Index (1)	-	55.0 (52.0) (1)	
Density @ 15°C	kg/m^3	820 (2)	840
Viscosity @ 40°C	mm^2/s	2.0 (3)	4.0
Sulphur content	mg/kg (4)		10
Metal content (Zn, Cu, Mn, Ca, Na, other)	g/l	Non-detectable (5)	
Total aromatics content	% m/m		15
PAH content (di+, tri+)	% m/m		2.0
T90 (6)	°C		320
T95 (6)	°C		340
Final Boiling Point	°C		350
Flash point	°C	55	--
Carbon residue	% m/m		0.20
CFPP (7) or LTFT or CP	°C	Maximum must be equal to or lower than the lowest expected ambient temperature.	
Water content	mg/kg		200
Oxidation stability, Method 1	g/m^3		25
Oxidation stability, Method 2	induction time	(8)	
Foam volume	ml		100
Foam vanishing time	sec.		15
Biological growth		'Zero' content	
FAME content	% v/v	Non-detectable (9)	
Ethanol/Methanol content	% v/v	Non-detectable (9)	
Total acid number	mg KOH/g		0.08
Ferrous corrosion	-	--	Light rusting
Copper corrosion	merit	Class 1	
Ash content	% m/m		0.001 (10)
Particulate contamination, total	mg/kg		10 (8)
Particulate contamination, size distribution	code rating	18/16/13 per ISO 4406	
Appearance		Clear and bright; no free water or particulates	
Injector cleanliness	% air flow loss		85
Lubricity (HFRR wear scar dia. @ 60°C)	micron	--	400

General Notes:

N.B. # 1: Additives must be compatible with engine oils. Addition of ash-forming components is not allowed.
N.B. # 2: Good housekeeping practices to reduce contamination (dust, water, other fuels, etc.).
N.B. # 3: Adequate labeling of pumps must be defined and used.

Footnotes:

(1) Cetane Index is acceptable instead of Cetane Number if a standardized engine to determine the Cetane Number is unavailable and cetane improvers are not used. When cetane improvers are used, the estimated Cetane Number must be greater than or equal to the specified value and the Cetane Index must be greater than or equal to the number in parentheses.

(2) The minimum limit can be relaxed to 800 kg/m^3 when ambient temperatures are below -30°C. For environmental purposes, a minimum of 815 kg/m^3 can be adopted.

(3) The minimum limit can be relaxed to 1.5 mm^2/s when ambient temperatures are below -30°C, and to 1.3 mm^2/s when ambient temperatures are below -40°C.

(4) The unit mg/kg is often expressed as ppm.

(5) At or below the limit of quantitation of the test method used. No intentional addition of metal-based additives.

(6) Compliance with either T90 or T95 is required.

(7) If compliance is demonstrated by meeting CFPP, then it must be no more than 10°C less than cloud point.

(8) Limit and test method are under review.

(9) At or below detection limit of the test method used. FAME limit is under review.

(10) Limit and test method for DPF endurance are under review.

The latest test methods should be used unless otherwise indicated by specific method year. On those parameters where "no detectable" is listed, the lowest possible levels are expected with no intentional additions of this additive or contaminant. Where multiple test methods are indicated, the product should conform to the most precise method listed.

PROPERTIES	**UNITS**	**ISO**	**ASTM**	**JIS**	**Other**
Cetane Number	-	5165	D 613	K 2280	
Cetane Index	-	4264	D 4737	K 2280	
Density @ 15°C	kg/m^3	3675 12185	D 4052	K 2249	
Viscosity @ 40°C	mm^2/s	3104	D 445	K 2283	
Sulphur content	mg/kg	20846 20884	D 5453 D 2622	K 2541	
Total aromatics content	% m/m		D 5186	EN 12916	
PAH content (di+, tri+)	% m/m		D 2425	EN 12916	
T90, T95, FBP	°C	3405	D 86	K 2254	
Flash point	°C	2719	D 93	K 2265	
Carbon residue	% m/m	10370	D 4530	K 2270	
Cold Filter Plugging Point (CFPP)	°C		D 6371	K 2288	EN 116, IP 309
Low Temperature Flow Test (LTFT)	°C		D 4539		
Cloud Point (CP)	°C	3015	D 2500	K 2269	
Water content	mg/kg	12937	D 6304	K 2275	
Oxidation stability, Method 1	g/m^3	12205	D 2274		
Oxidation stability, Method 2	induction time				(1)
Foam volume	ml				NF M 07-075
Foam vanishing time	sec.				NF M 07-075
Biological growth	-				NF M 07 070
FAME content	% v/v				EN 14078
Ethanol/Methanol content	% v/v		D 4815 (modified)		
Total acid number	mg KOH/g	6618	D 664		
Ferrous corrosion	-		D 665 (2)		
Copper corrosion	merit	2160	D 130	K 2513	
Appearance			D 4176		Visual inspection
Ash content	% m/m	6245	D 482 (3)	K 2272	
Particulate contamination, total	mg/kg		D 5452		DIN 51419 EN 12662 (4)
Particulate contamination, size distribution	code rating	4406			
	no of particles/ml	4407, 11500			
Injector cleanliness	% air flow loss				CEC (PF-023) TBA
Lubricity (HFRR wear scar diameter @ 60°C)	micron	12156-1.3	D 6079		CEC F-06-A
Metal content					ICP (5)

(1) A new test method based on the Rancimat method is under development.

(2) Procedure A, run at 38°C for five hours.

(3) Minimum 100 g sample size.

(4) Method under review

(5) ASTM D 5185 may be used as a guide for developing a test method for metals and other inorganic elements in fuel. The lower limit of quantitation for various elements in lubricating oil may provide an estimate of the values expected for fuels. See Table 2 (supra).

TECHNICAL BACKGROUND
FOR HARMONISED
FUEL RECOMMENDATIONS **GASOLINE**

OCTANE

Octane is a measure of a gasoline's ability to resist auto-ignition; auto-ignition can cause engine knock. There are two laboratory test methods to measure gasoline octane numbers: one determines the Research octane number (RON) and the other the Motor octane number (MON). RON correlates best with low speed, mild-knocking conditions and MON correlates with high-temperature knocking conditions and with part-throttle operation. RON values are typically higher than MON and the difference between these values is the sensitivity, which should not exceed 10.

Vehicles are designed and calibrated for a certain octane value. When a customer uses gasoline with an octane level lower than that required, knocking may result which could lead to severe engine damage. Engines equipped with knock sensors can handle lower octane levels by retarding the spark timing; however, fuel consumption, driveability and power will suffer and at low octane levels, knock may still occur. Using gasoline with an octane rating higher than that recommended may not improve the vehicle's performance.

Historically, lower octanes at high altitude have provided the same anti-knock performance as higher octanes at sea level in older-model engines. Since 1984, however, most vehicles have been equipped with sophisticated electronic control systems that adjust to changes in air temperature and barometric pressure. These vehicles require the same octane levels at all altitudes. Thus, gasoline octane levels should not be lower at higher altitudes.

This Fuel Charter specifies three octane grades in each gasoline Category. It is not intended to require all three grades in all markets. One or more of the octane grades should be made available consistent with market requirements. In North America, (RON + MON)/2 is typically used to specify the octane rating.

Ash-forming (metal-containing) additives sometimes used for boosting octane are not recommended (see Ash-Forming Additives discussion, page 25).

SULPHUR

Sulphur naturally occurs in crude oil. If the sulphur is not removed during the refining process it will contaminate vehicle fuel. Sulphur has a significant impact on vehicle emissions by reducing the efficiency of catalysts. Sulphur also adversely affects heated exhaust gas oxygen sensors. Reductions in sulphur will provide immediate reductions of emissions from all catalyst-equipped vehicles on the road.

There has been extensive testing done on the impact of sulphur on vehicle emissions. The following studies (see table) indicate the emission reductions that occur with different vehicle technologies as sulphur is reduced from the 'high' sulphur gasoline to the 'low':

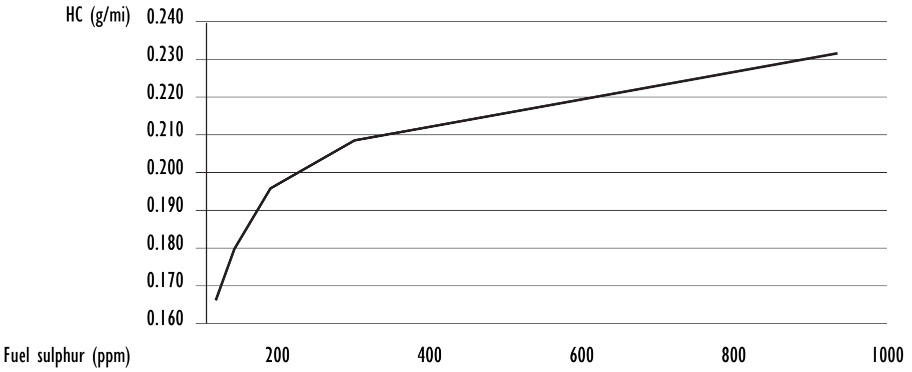
Table 2: Impact of sulphur on emissions

Study	Vehicle Technology	Sulphur Range (ppm)		Emission Reduction, % (high to low sulphur)		
		high	low	HC	CO	NOx
AQIRP	Tier 0	450	50	18	19	8
EPEFE	EURO 2+	382	18	9 (43*)	9 (52*)	10 (20*)
AAMA/AIAM	LEV & ULEV	600	30	32	55	48
CRC	LEV	630	30	32	46	61
JARI	1978 Regulations	197	21	55	51	77
Alliance/AIAM	LEV/ULEV	100	30	21	34	27
	LEV/ULEV	30	1	7	12	16
JCAP	DI/NOx cat.	25	2			37

* Reduction achieved during hot EUDC (extra-urban) portion of test.

This Figure (Figure 1) depicting the HC reductions from the US AQIRP study indicates the typical emission reduction for the different studies as the sulphur level changes, including the significant reduction when sulphur is reduced from about 100 ppm to 'low' sulphur fuel. This suggests the importance of a very low sulphur limit for advanced technology vehicles.

Figure 1: Sulphur Effects on Tier 0 Technology



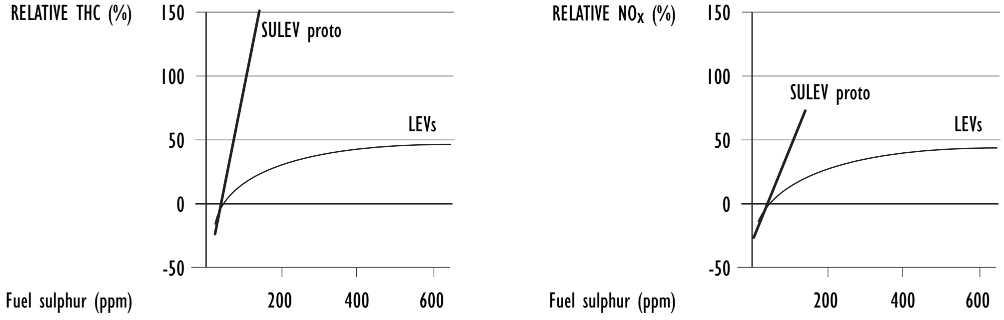
In addition, laboratory research of catalysts has demonstrated delays in light-off time, increases in light-off temperature and reductions in efficiency resulting from higher sulphur fuels across a full range of air/fuel ratios. Studies have also demonstrated that sulphur slows the rich to lean transition, thereby introducing an unintended rich bias into the emission calibration.

Stringent Emission Standard Challenges

Stringent emission requirements, combined with long-life compliance, demand extremely efficient, and durable, after-treatment systems. For example, it is generally recognised that catalyst hydrocarbon efficiency at 100,000 miles must be at least 93% for a vehicle meeting Low Emission Vehicle (LEV)/EURO 3 standards, and about 97% for a vehicle meeting Ultra-LEV/EURO 4 standards. Studies on LEVs indicate that warmed-up catalyst HC efficiency (i.e., excluding the start-up portion) must be 98% or better for 120,000 miles to ensure that new US Tier 2 emission limits are met. These standards represent significant technological hurdles, even in markets with high quality (Category 3) gasoline.

Figure 2 indicates the significant HC and NOx sensitivity to sulphur content. Advanced technologies indicate an even higher response to sulphur.

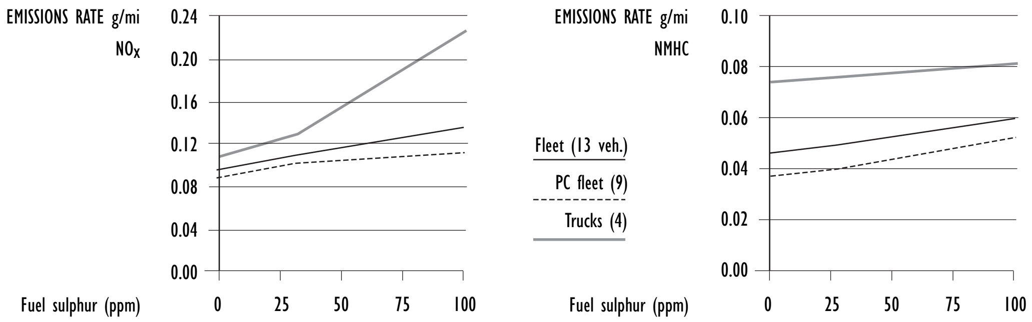
Figure 2: Effects of Fuel Sulphur on Emissions (relative to 30 ppm sulphur fuels)



In 2001, the Alliance and AIAM completed a joint test program to evaluate the emission effects of decreasing fuel sulphur levels ranging from 100 to 30 to 1 ppm S in a California Phase 2 reformulated gasoline containing 11% MtBE. The test fleet consisted of 13 vehicles with LEV and ULEV technology, including nine passenger cars and four light trucks. Vehicles were tested using the U.S. EPA Federal Test Procedure (FTP). The relative rate of emissions reduction in the 30 to 1 ppm S range may have been due to a sulphur contribution from the engine lubricant.

Figure 3 shows how the emissions of NOx and non-methane hydrocarbon (NMHC) continue to decline significantly at ultra-low sulphur levels for advanced technology vehicles.

Figure 3: Effects of ultra-low sulphur levels on emissions of NOx and NMHC



Sulphur will also affect the feasibility of advanced on-board diagnostic system requirements. Existing California on-board diagnostic (OBD II) regulations require vehicles to be equipped with catalyst monitors to determine when catalyst efficiency changes and tailpipe emissions increase by 1.5 times the standard. There is concern that the loss of catalyst efficiency resulting from high sulphur fuels will cause some catalyst monitors to indicate a problem code resulting in the illumination of a malfunction indicator light to signal the driver. Data on other LEVs demonstrate that the impact on the system is such that the catalyst monitor fails to properly identify a failed catalyst when operated on high sulphur fuel.

Advanced and Future Technology

Manufacturers are working toward ambitious goals for improved fuel consumption/reduced CO_2 emissions. Operation at lean air-fuel ratio is the most promising means to achieve these reductions in gasoline-powered vehicles. However, lean operation introduces a new challenge for exhaust emission control. While existing catalysts effectively remove unburned HC and CO during lean operation, they remove NOx only during stoichiometric or rich operation.

Many manufacturers are developing and introducing lean-burn engines that have the potential to reduce fuel consumption by up to 15 to 20%. These engines, however, require NOx control technologies that can function under lean conditions. These technologies are very sensitive to fuel sulphur.

Figures 4 and 5 provide examples of the adverse effect of sulphur on storage type NOx reduction catalyst needed in lean burn vehicles. With increased exposure time, the lower sulphur gasolines allow the catalysts to retain a higher NOx conversion efficiency. Further tests in vehicles (Figures 6 and 7) confirm the critical need for very low sulphur gasolines. Sulphur-free gasolines are required to achieve and maintain high NOx conversion efficiencies.

Figure 4: Sulphur effect on Low emission vehicles – Direct Fuel injection engines (Japan Clean Air Program)

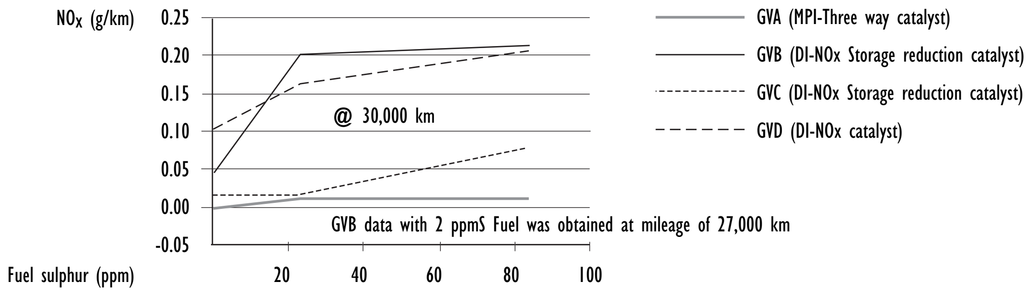


Figure 5: Effect of Fuel Sulphur on Lean NOx Traps Flow Reactor Study

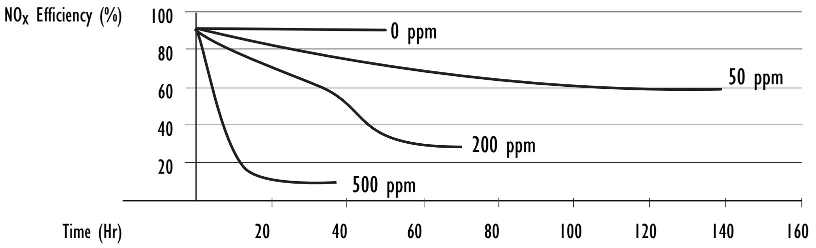


Figure 6: Influence of Sulphur Concentration in Gasoline on Vehicle Aftertreatment System Durability

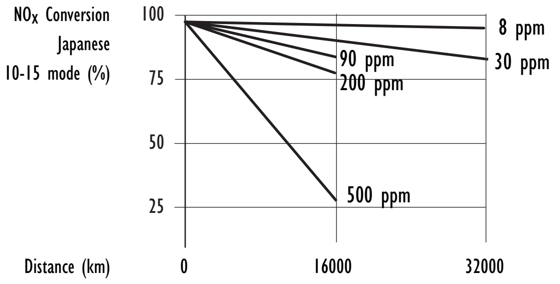
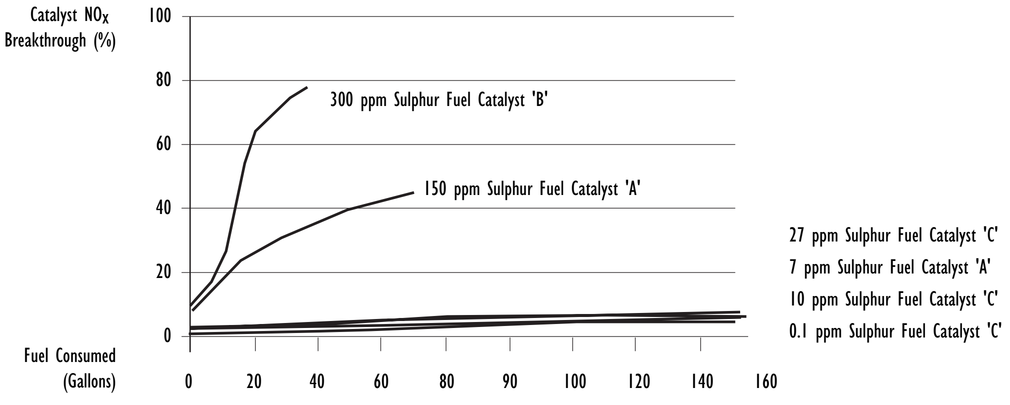
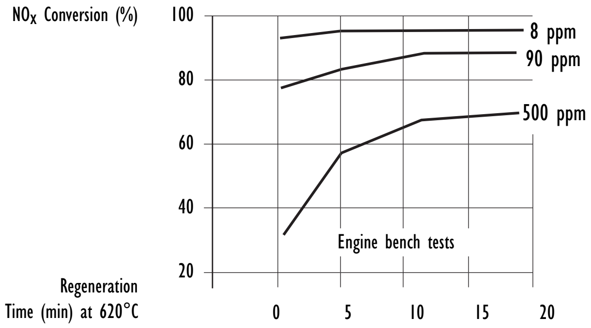


Figure 7: Lean NOx Adsorber Catalyst Data – Catalyst NOx Breakthrough vs. Fuel Consumed & Fuel Sulphur Content



Lean NOx adsorber catalysts function by trapping NOx chemically during lean burning conditions. NOx can then be released and destroyed over a catalyst by a few seconds of rich operation. However, sulphur oxides are more strongly trapped, and as a competitor to NOx, they reduce the NOx capacity of the adsorber. Sulphur removal requires a more prolonged rich operating condition, but the original efficiency level can never be fully recovered. Also, allowing any rich operation significantly negates the fuel efficiency benefits of the lean burn engine technologies used with these catalysts. Sulphur-free gasolines, however, will maintain the necessary NOx conversion efficiency (Figure 8). Sulphur-free gasoline is therefore necessary to maximise the benefits of lean-burn, fuel-efficient technology.

Figure 8: Regeneration of Sulphur Poisoning



ASH-FORMING (METAL-CONTAINING) ADDITIVES

Today's vehicles employ sophisticated emission control equipment such as three-way catalysts and exhaust gas oxygen sensors to provide precise closed-loop control. These systems must be kept in optimal condition to maintain low emissions for the lifetime of the vehicle. Ash-forming additives can adversely affect the operation of catalysts and other components, such as oxygen sensors, in an irreversible way that increases emissions. Thus, high-quality gasoline should be used and ash-forming additives must be avoided.

Lead

Lead alkyl additives have been used historically as inexpensive octane enhancers for gasoline. Concerns over health effects associated with the use of these additives, and the need for unleaded gasoline to support vehicle emission control technologies such as catalytic converters and oxygen sensors, have resulted in the elimination of leaded gasoline from many markets. As vehicle catalyst efficiencies have improved, tolerance to lead contamination is very low, so that even slight lead contamination can poison a catalyst. As catalyst-equipped vehicles are introduced into developing areas, unleaded gasoline must be available. Removal of lead compounds from gasoline reduces vehicle hydrocarbon emissions, even from vehicles without catalytic converters. A lead-free market worldwide is therefore essential, not only for emission control compatibility, but also because of the well-known adverse health effects of lead. Leaded gasoline should be eliminated as soon as possible.

Manganese (MMT)

MMT (methylcyclopentadienyl manganese tricarbonyl) is a manganese-based compound marketed as an octane-enhancing fuel additive for gasoline. It has also been suggested for use in diesel fuel as a smoke reducing additive.

Studies have shown that only a small percentage of the MMT-derived manganese from the fuel is emitted from the tailpipe – the majority remains within the engine, catalyst and exhaust system.

- The combustion products of MMT coat internal engine components such as spark plugs, potentially causing misfire which leads to increased emissions, increased fuel consumption and poor engine performance. These conditions result in increased owner dissatisfaction and expense for consumers and vehicle manufacturers.

- The combustion products of MMT also accumulate on the catalyst. In some cases, the front face of the catalyst can become plugged with deposits, causing poor vehicle operation and increased fuel consumption in addition to reduced emission control.

In 2002, automobile manufacturers jointly completed a multi-year study of the impact of MMT on Low Emission Vehicles (LEVs). At 100,000 miles (Figure 9), MMT significantly increased non-methane organic gases (NMOG), CO and NOx emissions from the fleet. MMT also significantly decreased EPA City fuel economy, and on-road fuel economy through 100,000 miles was, on average, about 0.5 miles per gallon (mpg) lower. In another part of the study with earlier model vehicles equipped with Tier 1 emission control technology, HC emissions also increased through 50,000 miles. Figure 10 provides visual evidence of MMT's impact that was obtained from the LEV vehicles used in this study. The reddish-brown deposits have been identified as oxidized manganese.

Figure 9: Emission and Fuel Economy Effect of MMT – 1998-99 LEVs

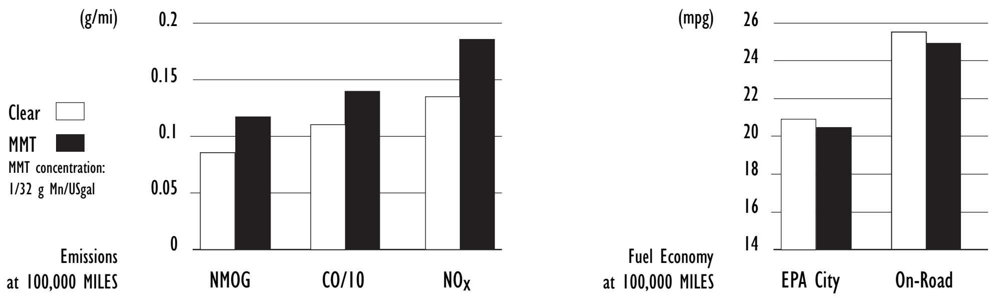
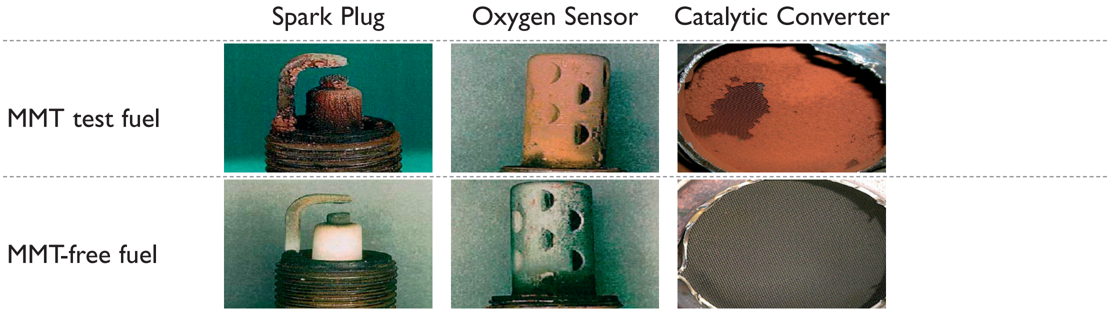


Figure 10: Impact of MMT on Tier 1/LEV Parts at 50,000 miles



Given this body of information, automobile manufacturers are extremely concerned with MMT's impact on the highly sensitive technologies that will be required to meet Tier-2 emission standards in the U.S. and Canada.

Many countries have been debating whether to allow the use of this gasoline additive while the real-world evidence of adverse impacts continues to grow. PSA and VW have reported on failed emission components in China and Argentina. Emission component failures, including catalyst plugging on advanced low emission vehicles, also have been reported in Canada where MMT was used in most of the gasoline until 2005, when most oil companies voluntarily stopped using it. South African vehicles, which have less advanced control systems than in Canada but use fuel with higher levels of MMT, also have been adversely affected (Figure 11). In spite of its approval for use in non-reformulated gasoline in the U.S. since 1995, it is used in very few gasolines sold in the U.S. Most major auto manufacturers state in their Owner Guides that they recommend against the use of MMT, advising further that any damage caused by MMT may not be covered by the warranty.

Figure 11: Evidence of MMT's Impact on Canadian and South African Vehicles

A: Canada

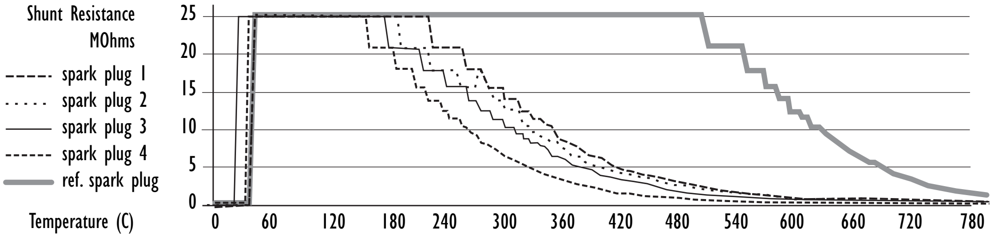
B: South Africa

Iron (Ferrocene)

Ferrocene has been used to replace lead as an octane enhancer for unleaded fuels in some markets. It contains iron, which deposits on spark plugs, catalysts and other exhaust system parts as iron oxide, and may also affect other engine components. The deposits will cause premature failure of the spark plugs, with plug life being reduced by up to 90% compared to normal service expectations. Failing spark plugs will short-circuit and cause misfiring when hot, such as under high load condition. This may cause thermal damage to the exhaust catalyst.

Figure 12 shows the reduction in spark plug insulator resistance as a function of temperature. The results compare plugs using fuel with a ferrocene additive after only 32 hours of testing, with a reference plug using conventional gasoline after 300 hours of testing.

Figure 12: Insulator resistance at temperature test results for spark plugs taken from test engine after 32 hours



Iron oxide also acts as a physical barrier between the catalyst/oxygen sensor and the exhaust gases, and also leads to erosion and plugging of the catalyst. As a result the emission control system is not able to function as designed, causing emissions to increase. Additionally, premature wear of critical engine components such as the pistons and rings can occur due to the presence of iron oxide in the vehicle lubrication system.

SILICON

Silicon is not a natural component of gasoline. However, in several instances silicon has appeared in commercial gasolines, usually as a result of waste solvents containing silicon compounds being used as a gasoline-blending component after the fuel has left the refinery. Such contamination has significant adverse effects on emission control systems. Silicon, even in low concentrations, can cause failure of oxygen sensors and high levels of deposits in engines and catalytic converters. This can lead to catastrophic engine failures in less than one tankful of contaminated fuel. Therefore, no detectable level of silicon should exist in gasoline nor should it be used as a component of any fuel additive package to improve gasoline and engine performance.

OXYGENATES

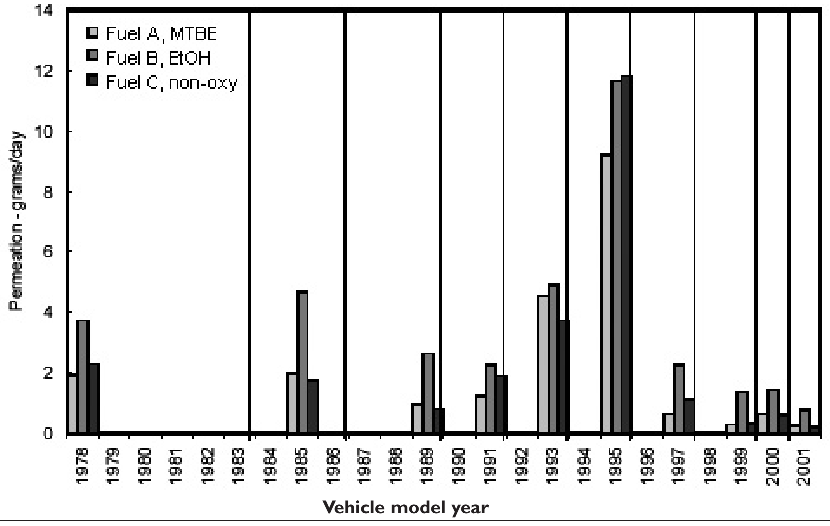
Oxygenated organic compounds, such as MtBE and ethanol, often are added to gasoline to increase octane or extend gasoline supplies. Oxygenating the fuel also may affect vehicle emissions (tailpipe, evaporative or both), performance and/or durability.

Adding oxygenates to gasoline will induce a lean shift in engine stoichiometry, which, in turn, will reduce carbon monoxide (CO) emissions, especially from carburetted vehicles without electronic feedback controlled fuel systems. These emission benefits are smaller in modern electronic feedback controlled vehicles, however, because the leaning effect only occurs during cold operation or during rapid accelerations. In fact, fuel-leaning caused by oxygenates can cause tailpipe emissions to increase, depending on the leanness of the engine's base calibration with non-oxygenated gasoline. The California Air Resources Board (CARB) found in emission tests on 14 1990-1995 model year vehicles that a gasoline containing 10% ethanol by volume decreased toxic emissions by 2% and CO by 10% but increased NOx by 14%, total HC by 10% and Ozone Forming Potential by 9%, relative to a gasoline containing 11% MtBE by volume. More recent testing by the Coordinating Research Council (CRC) on newer vehicles has produced similar results (CRC E-67).

This over-leaning also can degrade driveability, and it is well documented that ethanol-blended gasoline, in particular, can cause an offset in driveability performance. Increased exhaust hydrocarbon emissions are likely to accompany this offset in driveability performance. Because ethanol has a higher heat of vaporisation than ethers, some of the driveability and emissions degradation of gasoline-ethanol blends can be attributed to the additional heat needed to vaporise the gasoline.

The use of ethanol-blended gasoline also may affect evaporative emissions. LEV vehicles, for example, have been found to emit approximately 12 percent more evaporative emissions when using 10% ethanol-blended gasoline than when using a hydrocarbon-only fuel (General Motors, 2000). This emissions impact may be due, in part, to the permeation of fuel molecules through elastomeric materials (rubber and plastic parts) used in the vehicle's fuel and fuel vapor handling systems. In a study conducted from January 2003 to June 2004, the CRC in cooperation with CARB found that permeation emissions increased on all 10 vehicle-fuel systems in the study when ethanol replaced MtBE as the test fuel oxygenate (both oxygenated fuels contained 2% oxygen by weight). The ethanol-blended fuel increased the average diurnal permeation emissions by 1.4 g/day compared to the MtBE fuel and by 1.1 g/day compared to the non-oxygenated fuel (see Figure 13). The study also confirmed previous estimates that permeation of these gasoline-ethanol blends doubles for each 10 C rise in temperature.

Figure 13: Average Diurnal Permeation of Day 1 & Day 2 (CRC E65 Fleet)



The study further examined specific ozone reactivity and found the non-oxygenated fuel to have a statistically higher reactivity than either the MtBE- or ethanol-containing fuels. The average specific reactivities of the two oxygenated fuel permeates were not statistically different. The data support the hypothesis that ethanol-blends tend to increase the permeation of other hydrocarbon species in addition to ethanol. The study is continuing with 2004 model year vehicles, which have to meet more stringent emission standards than those used in the first part of the study.

Based on past experience with impurities in ethanol that have led to degradation of fuel systems, fuel ethanol must have a specification to control pHe and its blending properties (ASTM D 4806). Also, the limits and restriction on the oxygenates permitted in each Category were developed on the basis of emission benefits, vehicle performance and existing regulations. Based on these criteria, when oxygenates are used, ethers are preferred. Also, the use of ethanol-blended gasoline may require other fuel changes to mitigate evaporative and exhaust emission impacts.

Methanol is not permitted. Methanol is an aggressive material that can cause corrosion of metallic components of fuel systems and the degradation of plastics and elastomers.

OLEFINS

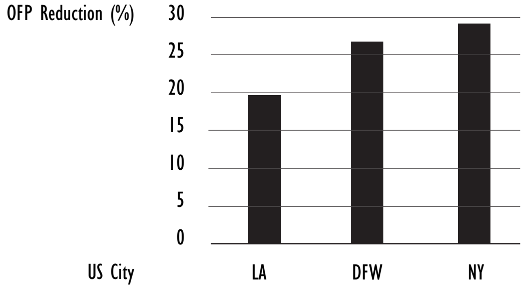
Olefins are unsaturated hydrocarbons and, in many cases, are also good octane components of gasoline. However, olefins in gasoline can lead to deposit formation and increased emissions of reactive (i.e., ozone-forming) hydrocarbons and toxic compounds.

Effect of Olefins on Emissions

Olefins are thermally unstable and may lead to gum formation and deposits in an engine's intake system. Furthermore, their evaporation into the atmosphere as chemically reactive species contributes to ozone formation and their combustion products form toxic dienes.

The effect on ozone-forming potential was clearly demonstrated by the US Auto/Oil programme. The programme concluded that reducing total olefins from 20% to 5% would significantly decrease ozone-forming potential in three critical cities: Los Angeles, Dallas-Fort Worth, and New York (Figure 14).

Figure 14: Reduction in Ozone-Forming Potential with Reduction in Fuel Olefins (20%-5%)



The model also showed that the same reduction in gasoline olefin level would reduce the light-duty vehicle contribution to peak ozone by 13% to 25% in future years for the cities shown in Figure 11. About 70% of this effect was due to reducing low molecular weight olefins.

AROMATICS

Aromatics are fuel molecules that contain at least one benzene ring. In general, aromatics are good octane components of gasoline and high-energy density fuel molecules. Fuel aromatic content can increase engine deposits and increase tailpipe emissions, including CO_2.

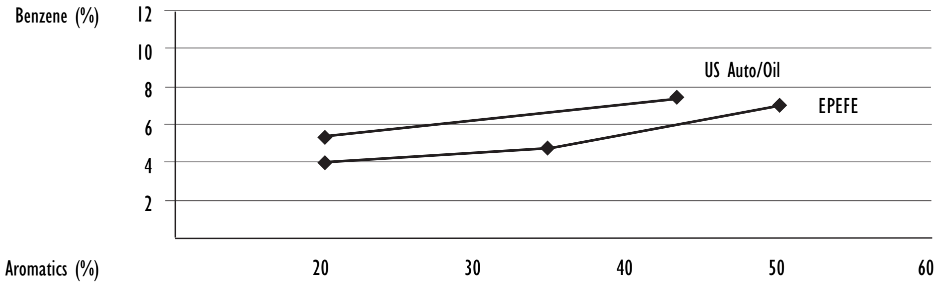
Influence of Aromatics on Engine Deposits

Heavy aromatics, and other high molecular weight compounds, have been linked to engine deposit formation, particularly combustion chamber deposits. As discussed below ('Deposit Control Additives'), these deposits increase tailpipe emissions, including HC and NOx. Since it is not feasible to specify limits for individual hydrocarbon compounds in the fuel, the total aromatic limit in Category 1 and the final boiling point limits in Categories 2 and 3 provide the best means to limit heavy aromatics.

Influence of Aromatics on Tailpipe Emissions

Combustion of aromatics can lead to the formation of carcinogenic benzene in exhaust gas and increased combustion chamber deposits which can increase tailpipe emissions. Lowering aromatic levels in gasoline significantly reduces toxic benzene emissions in exhaust from vehicles as shown in both the US AQIRP and the European EPEFE studies. (Figure 15)

Figure 15: Fuel Aromatics Effect on Benzene Exhaust Emissions



Findings from the US AQIRP programme showed that of all the fuel properties tested, aromatic level had the largest effect on total toxics, largely due to its effect on exhaust benzene emissions as shown in the above figure. Reducing total aromatics from 45% to 20% caused a reduction in total exhaust air toxics of 28% (74% of the total toxic emissions was benzene).

Influence of Aromatics on CO_2 Emissions

Gasoline aromatic content also has a direct effect on tailpipe CO_2 emissions. The European EPEFE programme demonstrated a linear relationship between CO_2 emissions and aromatic content. The reduction of aromatics from 50 to 20% was found to decrease CO_2 emissions by 5%.

BENZENE

Benzene is a naturally occurring constituent of crude oil and is also a product of catalytic reforming that produces high octane gasoline streams. It is also a known human carcinogen.

The control of benzene levels in gasoline is the most direct way to limit evaporative and exhaust emissions of benzene from automobiles. The control of benzene in gasoline has been recognised by regulators in many countries as an effective way to reduce human exposure to benzene. These gasoline recommendations recognise the increasing need for benzene control as emission standards become more stringent.

VOLATILITY

Proper volatility of gasoline is critical to the operation of spark ignition engines with respect to both performance and emissions. Volatility is characterised by two measurements, vapour pressure and distillation.

Vapour Pressure

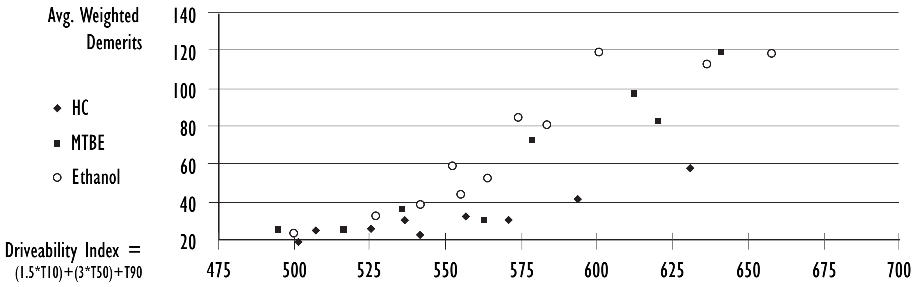
The vapour pressure of gasoline should be controlled seasonally to allow for the differing volatility needs of vehicles at different temperatures. The vapour pressure must be tightly controlled at high temperatures to reduce the possibility of hot fuel handling problems, such as vapour lock or carbon canister overloading. Control of vapour pressure at high temperatures is also important in the reduction of evaporative emissions. At lower temperatures higher vapour pressure is needed to allow ease of starting and good warm-up performance.

Distillation

Distillation of gasoline yields either a set of 'T' points (T50 is the temperature at which 50% of the gasoline distills) or 'E' points (E100 is the percentage of a gasoline distilled at 100 degrees). Excessively high T50 (low E100) can lead to poor starting and warm-up performance at moderate ambient temperatures. Control of the Distillation Index (DI), derived from T10, T50, T90, and oxygen content can also be used to assure good cold start and warm-up performance.

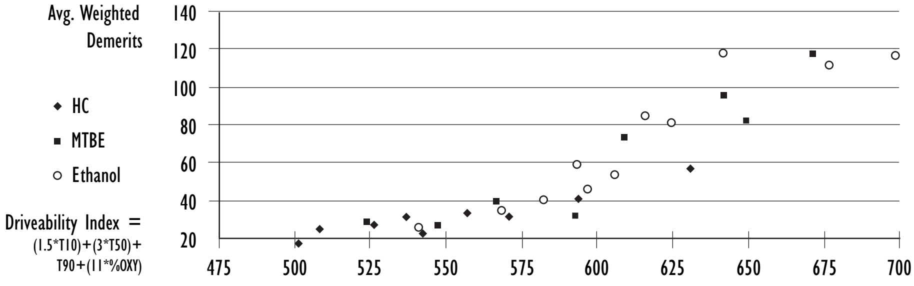
Driveability concerns are measured as demerits. Figure 16 provides the test results from a recent CRC study which tested 29 test fuels: 9 all hydrocarbon, 11 with 10% ethanol and 9 with 15% MtBE. The data indicate that driveability problems increase for all fuel types as Driveability Index increases. At Driveability Index levels higher than those specified in this Charter driveability concerns increase dramatically.

Figure 16: Effect of Driveability Index on Driveability



An oxygen correction factor is required to correct for higher driveability demerits for oxygenated fuels as compared to all-HC gasoline. Figure 17 indicates how the correction factor smoothes the data presented in Figure 16.

Figure 17: Effect of DI on Driveability (Oxygen Corected)



The DI is also directly related to tailpipe HC emissions, as shown in Figure 18. As with driveability demerits, HC emissions increase significantly at DI levels higher than those specified in this Charter.

Figure 18: Effect of DI on Driveability and Exhaust Emissions

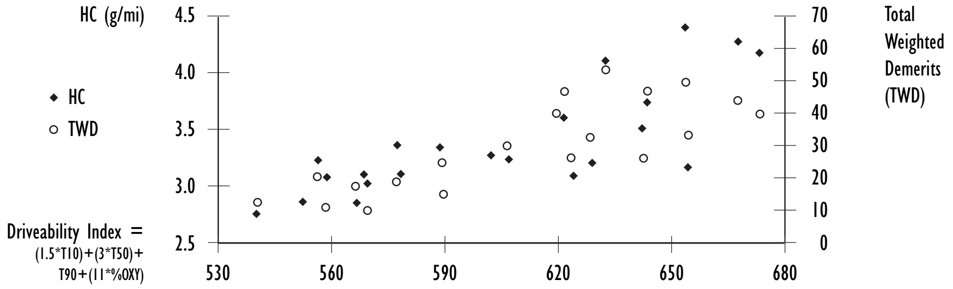
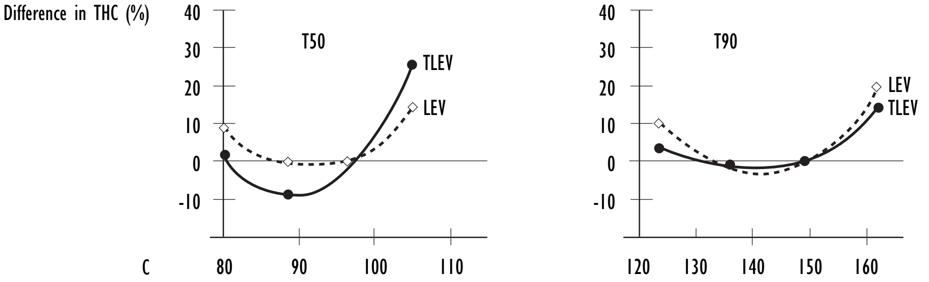


Figure 19 indicates that optimum values for T50 and T90 exist to achieve lower exhaust THC emissions.

Figure 19: Effect of T50/T90 on Exhaust Emissions Comparison of LEV and TLEV



In 1999, the US automakers petitioned the US-EPA to keep DI at 1200. This petition contains a compilation of available data on the impact of DI on emissions. This document is available at www.autoalliance.org.

Vapour Lock

Excessively high gasoline volatility can cause hot fuel handling problems such as vapour lock, canister overloading, and higher emissions. Vapour lock occurs when too much vapour forms in the fuel system and fuel flow decreases to the engine. This can result in loss of power, rough engine operation or engine stalls. Since vapour pressure and distillation properties are not sufficient to assure good vehicle performance, a Vapour/Liquid Ratio specification is necessary.

DEPOSIT CONTROL ADDITIVES

Combustion of even good quality gasoline can lead to deposit formation. Such deposits will increase engine-out emissions and affect vehicle performance. High quality fuel contains deposit control additives to significantly reduce deposit formation.

Carburettors

First generation additives were developed in the early 1950's and are based on amine chemistry still used in some countries at levels of 50 parts per million treat rate. Many of these additives were multifunctional, providing anti-icing protection, corrosion inhibition and carburettor detergency performance.

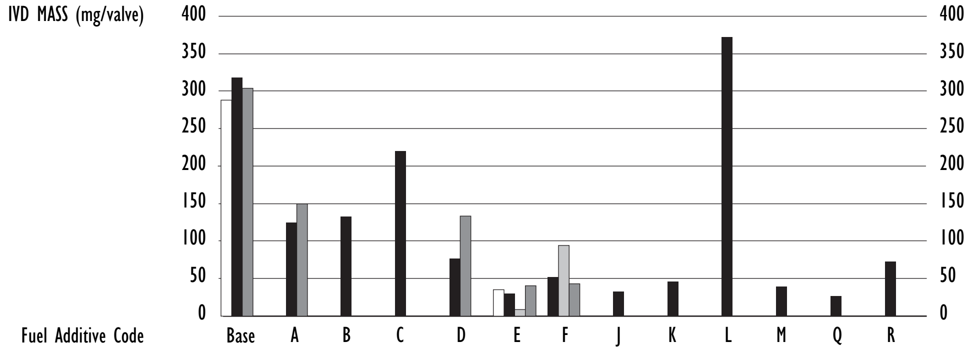
Port Fuel Injectors

US gasoline marketers introduced port fuel injector deposit control additives around 1985 to overcome problems with fuel injector fouling that led to driveability problems. However, treat rates were nearly double those for carburettor detergents resulting in increased intake valve deposits in many cases.

Intake Valves

The impact of intake valve deposits on driveability in both North America and Europe was so severe that vehicle manufacturers required improved gasoline quality in terms of fuel detergents to keep valves clean and provide clean-up ability. Various tests are available to evaluate the gasoline's capability of maintaining acceptable intake valve cleanliness. Figure 20 shows the performance of base fuel without detergent additives and fuels with various detergent additive chemistries in the Ford 2.3L IVD test (ASTM D6201-97). Moderate additive treat rates combined with effective carrier fluids help avoid intake valve sticking. Passing the VW Wasserboxer Intake Valve Sticking Test minimises the likelihood of this problem occurring.

Figure 20: IVD Performance of Gasolines Ford 2.3L Dynamometer Test



Combustion Chambers

As combustion chamber deposits (CCDs) form, they reduce the space available in the chamber for combustion while adding small crevices that increase the surface area of the chamber. This phenomenon has three undesirable effects: 1) higher compression ratios and end gas temperatures that increase the octane requirements higher than the engine was designed for, 2) increased exhaust emissions, and 3) mechanical interference between the piston top and cylinder head called 'Carbon Knock'.

Engine Dynamometer Results

Detergent additives usually increase the level of CCDs relative to base fuel as shown in Figures 21 and 22. Detergent packages with higher ratios of mineral oil carriers tend to increase CCDs, while detergent packages with optimised high-quality synthetic carrier fluids and compounds like polyether amines (PEA) minimise CCD buildup. Additive packages should be optimised to minimise CCDs, which will allow engine designers to further improve combustion chamber designs to provide lower emissions and fuel consumption.

Figure 21: Engine Dynamometer Results

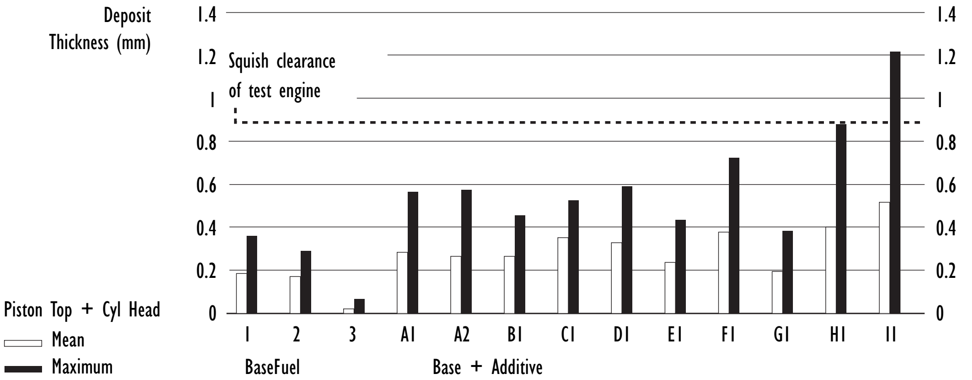
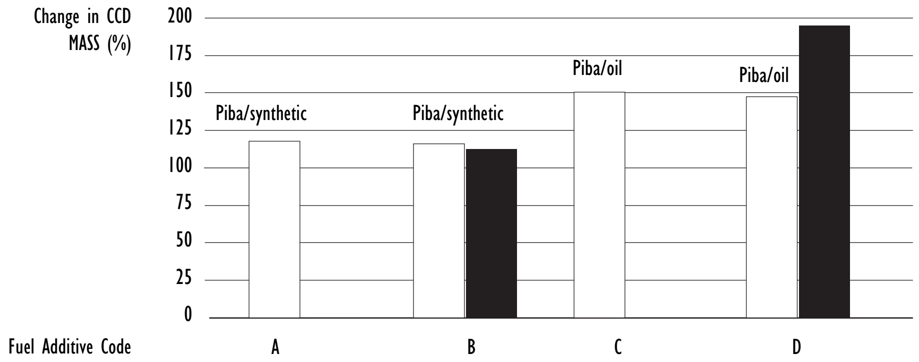


Figure 22: CCD Performance of Gasolines Ford 2.3L Dynamometer Test Using ASTM D6201

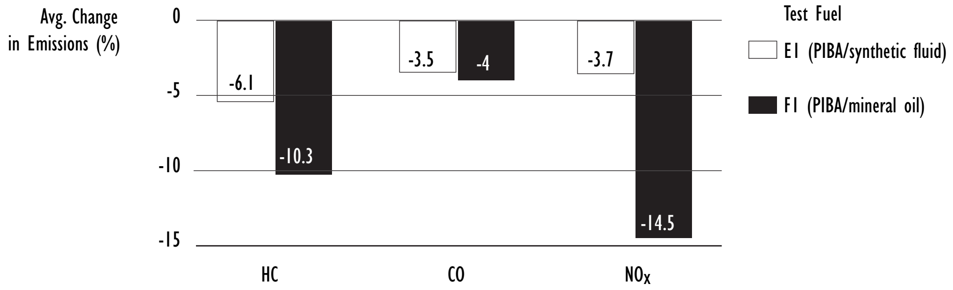


Note: Piba/Synthetic - polyisobutene amine/synthetic oil
Piba/Oil - polyisobutene amine/mineral oil

Effect of CCD Removal on Engine-Out Emissions

The removal of CCDs can reduce engine out HC emissions by up to 10%, CO by 4%, and NOx by 15% as shown in Figure 23 for fleet vehicles after accumulating 50,000 miles.

Figure 23: Effect on CCD Removal on Engine-Out Emissions



'Carbon Knock' in modern engines did not occur even at high mileages in Japan. When these same engines were sold in the US, customers began objecting to the engine noise after only a few thousand miles in some cases. Some customers required replacement of the cylinder heads because of the damage caused by the piston hitting the deposits. Other customers switched brands of gasoline or used after-market deposit control additives to help remove deposits causing carbon knock. The problem in the US was attributed to high-additive treat rates being used for IVD control.

Relationship of CCDs to TGA Test

A test procedure with the Mercedes M111 E engine is being developed to evaluate the CCD-forming tendency of gasolines. A thermogravimetric analysis (TGA) bench test method has been developed that provides a good correlation with CCDs in a dynamometer-based multicylinder engine test as shown in Figure 24.

Figure 24: Correlation of CCD and TGA results of commercial fuels in Ford 2.3L IVD test (ASTM D 6201)

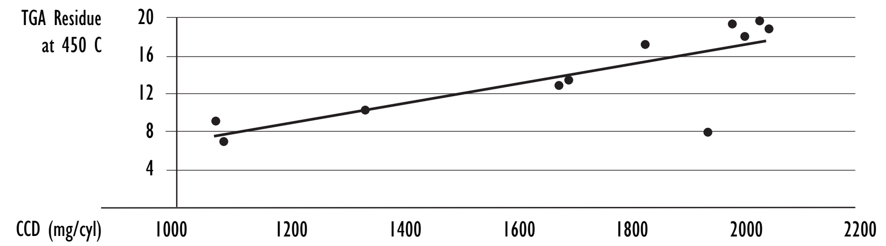
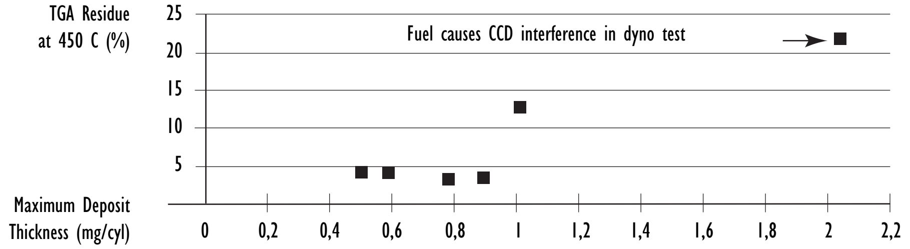


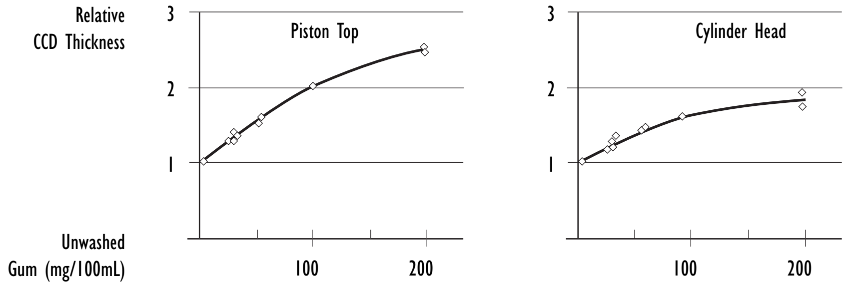
Figure 24 Bis: TGA proposed pass/fail limit - 4.0 L dynamometer test results



Relationship Between Unwashed Gum and CCD Thickness

Figure 25 indicates the correlation between unwashed gums and CCD formation. Thus, the Charter allows compliance to either an unwashed gum limit or a CCD requirement.

Figure 25: Relationship Between Unwashed Gum and CCD Thickness



As emission standards become more stringent, it is critical for fuel quality to support improvements in emission control technology to meet these limits. Detergent additives that prevent the formation of CCDs have the benefit of helping meet environmental standards while improving vehicle performance.

GOOD HOUSEKEEPING PRACTICES

The problems encountered by vehicles from poor quality fuel often are caused by adulteration that occurs in the fuel distribution system, after the fuel has left the refinery gate. Failure to invest in adequate pipeline and storage facilities and failure to maintain the equipment can lead to volatility losses, fuel leakage and contamination by particulates and water that, in turn, can lead to a host of vehicle problems. Poor operating practices at the service station, such as too infrequent replacement of fuel dispenser filters or "dipping" of tanks to check for water, can magnify these problems.

CORROSIVE SULPHUR

Certain fuel sulphur compounds can tarnish silver and silver alloy metals, which are widely used in the electrical contacts of fuel level sender units, devices that measure the amount of fuel in a fuel tank. These compounds may include elemental sulphur, hydrogen sulphide (H_2S), mercaptans and other sulphur-containing molecules. When present in fuel, these compounds can react with the sender unit's silver or silver alloy to form silver sulphide on the electrical contacts. This process interrupts the flow of current to the fuel gauge and causes the gauge to display erratic readings. To date, automakers are unaware of a fully satisfactory test method to identify problem fuels.

TECHNICAL BACKGROUND
FOR HARMONISED
FUEL RECOMMENDATIONS

DIESEL FUEL

CETANE NUMBER AND INDEX

Cetane number is a measure of the compression ignition behaviour of a fuel; it influences cold startability, exhaust emissions and combustion noise. Cetane index, which is based on measured fuel properties, is a calculated value that approximates the 'natural' cetane of a fuel. "Natural" cetane equals the cetane number when the fuel does not contain any cetane improver. The cetane number is measured on a test engine and reflects the effects of cetane improver additives. As shown below, natural cetane levels affect vehicle performance differently than cetane levels achieved through additives. To avoid excessive additive dosage, the minimum difference between cetane index and cetane number must be maintained.

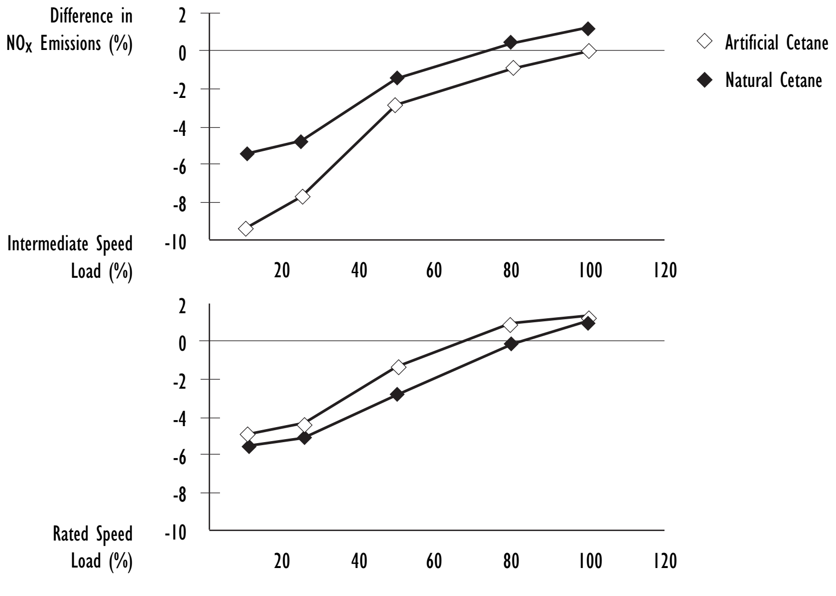
Influence of Cetane on Cold Startability

Increasing cetane number will decrease engine crank time (the time before the engine reaches 'starter off') at a given engine speed. The ACEA EPEFE follow-up programme, which looked at the influence of diesel fuel quality on heavy duty diesel engine emissions, demonstrated a significant (up to 40%) reduction in crank time for an increase in cetane number from 50 to 58.

Influence of Cetane on Exhaust Emissions and Fuel Consumption

The influence of cetane on NOx emissions and fuel consumption is shown as functions of engine load in the following figures (data on EPEFE heavy duty engines). Cetane is clearly shown to have a significant effect on NOx (Figure 1), particularly at low loads, where reductions of up to 9% are achieved. (Note that each point in the graph below shows the NOx reduction achieved for cetane increase at a given load.) The cetane increase also demonstrated a 30-40% reduction in HC emissions.

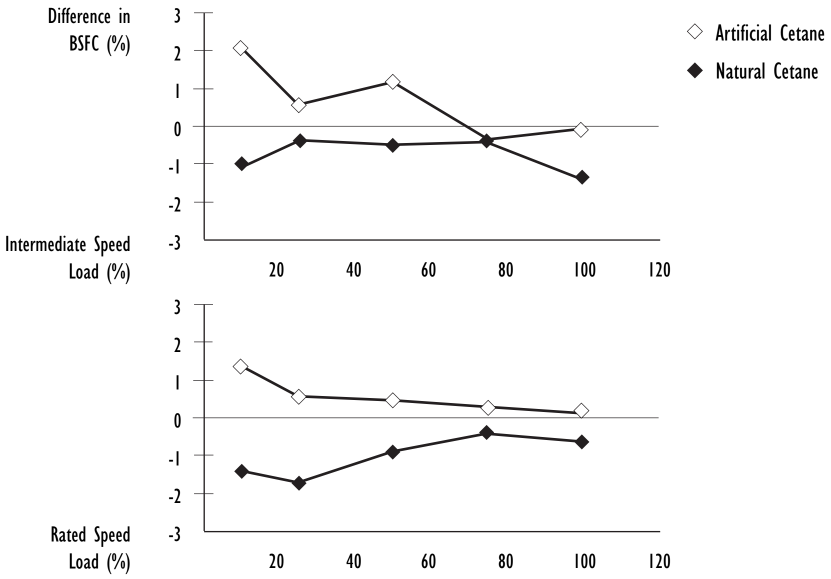
Figure 1: Effect of Cetane on NOx Emissions 50 to 58 CN



For light duty vehicles, EPEFE concluded that significant reductions in HC and CO would be achieved by increasing cetane number. The increase in cetane number from 50 to 58 resulted in a 26% reduction in both HC and CO emissions.

An increase in natural cetane has been shown to reduce fuel consumption. The data shown in Figure 2 demonstrates the importance of natural cetane (cetane index) compared to artificial cetane on heavy duty brake specific fuel consumption (BSFC). The increase in natural cetane (from 50 to 58) improved BSFC at every load level tested.

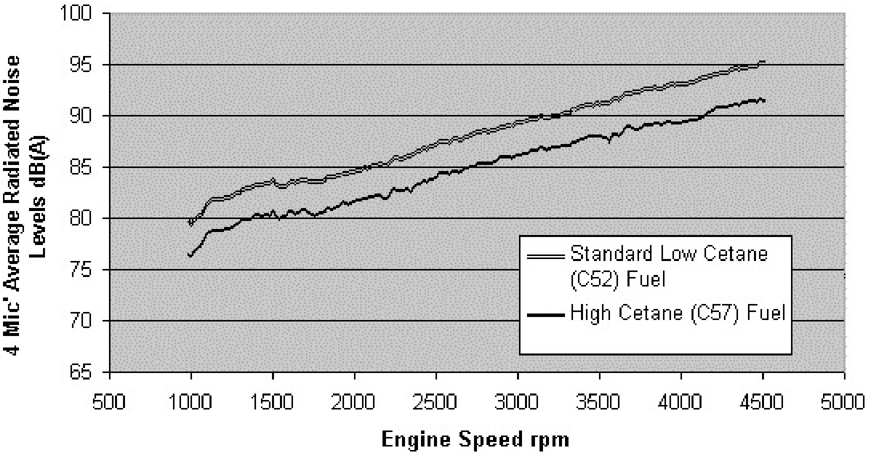
Figure 2: Effect of Cetane on Fuel Consumption 50 to 58 CN



Cetane Influence on Combustion Noise

Increased cetane will also reduce noise, as demonstrated by the results shown here (Figure 3). In this case, natural and artificial cetane have similar effects.

Figure 3: Effect of Cetane on Engine Noise, 52 to 57 CN



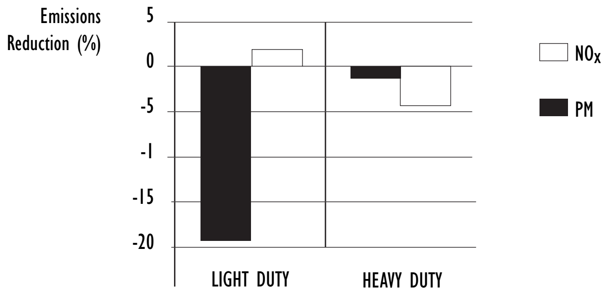
DENSITY and VISCOSITY

The diesel fuel injection is controlled volumetrically or by timing of the solenoid valve. Variations in fuel density (and viscosity) result in variations in engine power and, consequently, in engine emissions and fuel consumption. The European EPEFE programme further found that fuel density also influences injection timing of mechanically controlled injection equipment, which has further effects on emissions and fuel consumption. Therefore, in order to optimise engine performance and tailpipe emissions, both minimum and maximum density limits must be defined in a fairly narrow range.

Effect of Density on Emissions and Fuel Consumption

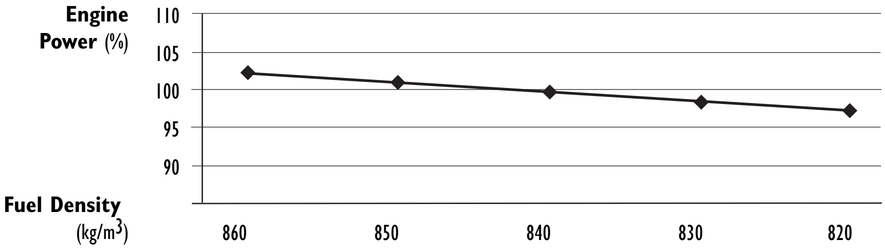
Emissions testing has demonstrated that reduced density will reduce PM emissions from all diesel vehicles, and NOx emissions from heavy duty vehicles (Figure 4).

Figure 4: Effect of Density on Exhaust Emissions 855 to 828 kg/m3



However, due to the volumetric fuel injection of diesel engines, reduced density will also increase fuel consumption and reduce power output. EPEFE testing has shown that reductions in fuel density decreases engine power output (Figure 5) and increases volumetric fuel consumption. Variations in fuel viscosity (i.e., reduced density generally reduces viscosity) may accentuate the density effects on power (not necessarily fuel consumption), particularly in combination with distributor-type injection pumps.

Figure 5: Effect of Density on Engine Power 855 - 828 kg/m3



Despite the increase in fuel consumption, EPEFE found that reduced density actually decreased CO_2 emissions slightly (about 1%). This is explained by the higher hydrogen/carbon ratio in low density fuels when other fuel parameters (most importantly cetane number/index) are kept constant.

Influence of Fuel Density on Emission Control Systems

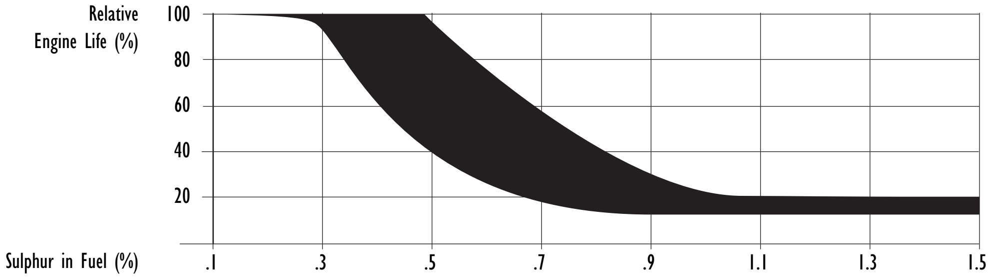
Production diesel engines are set to a standard density, which determines the amount of fuel injected. The (volumetric) injection quantity is a control parameter for other emission control systems like the exhaust gas recirculation (EGR). Variations in fuel density therefore result in non-optimal EGR-rates for a given load and speed point in the engine map and, as a consequence, influence the exhaust emission characteristics.

Influence of Fuel Viscosity on Injection System Performance
Fueling and injection timing are also dependent on fuel viscosity. High viscosity can reduce fuel flow rates, resulting in inadequate fueling. A very high viscosity may actually result in pump distortion. Low viscosity, on the other hand, will increase leakage from the pumping elements, and in worse cases (low viscosity, high temperature) can result in total leakage. As viscosity is impacted by ambient temperature, it is important to minimise the range between minimum and maximum viscosity limits to allow optimisation of engine performance.

SULPHUR

Sulphur naturally occurs in crude oil. If the sulphur is not removed during the refining process it will contaminate vehicle fuel. Sulphur can have a significant effect on engine life. As shown in Figure 6, as sulphur level increases, relative engine life decreases.

Figure 6: Effect of Sulphur on Engine Life

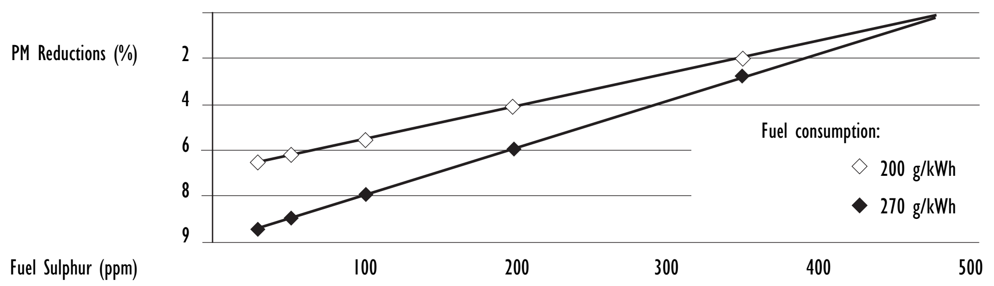


Diesel fuel sulphur also contributes significantly to fine particulate matter (PM) emissions, through the formation of sulphates both in the exhaust stream and, later, in the atmosphere. Sulphur can lead to corrosion and wear of engine systems. Furthermore the efficiency of some exhaust after-treatment systems is reduced as fuel sulphur content increases, while others are rendered permanently ineffective through sulphur poisoning.

As sulphur levels are reduced, fuel stability requires special attention. The industry has developed a "Standard Test Method for High Temperature Stability of Distillate Fuels" (ASTM D 6468) for thermal oxidative stability. Inadequate thermal stability can result in fuel filter plugging. As fuel injection system pressures and temperatures increase, it may be more appropriate to measure the thermal oxidative stability of diesel fuel rather than only long-term storage stability.

Effect of Sulphur on PM Emissions
The impact of sulphur on particulate emissions is widely understood and known to be significant. In the European Auto Oil programme it was predicted that a reduction from 500 ppm to 30 ppm would result in PM emission reductions of 7% from light duty vehicles and 4% from heavy duty trucks. However, the predictive equations do not take into account the absolute PM level or the fuel consumption. A correction factor has been developed by European heavy duty engine manufacturers to better reflect the relationship between PM emissions and fuel sulphur levels. This correction suggests that the real benefit from sulphur reductions will be more significant, as shown here (Figure 7) for heavy duty trucks. Reductions in fuel sulphur will also provide particulate emission reductions in all engines, regardless of emission calibration.

Figure 7: Effect of Diesel Fuel Sulfur Level on PM Emissions Heavy Duty Engines (PM = 0,10 g/kWh)



Testing performed on heavy duty vehicles using the Japanese diesel 13 mode cycle have shown significant PM emission reductions can be achieved with both catalyst and non-catalyst equipped vehicles. The testing showed that PM emissions from a non-catalyst equipped truck running on 400 ppm sulphur fuel were about double the emissions when operating on 2 ppm fuel. (JSAE 9831171)

Fuel Sulphur Contribution to Particulate Matter

The sulphur in fuel is oxidised during combustion to form SO_2, which is the primary sulphur compound emitted from the engine. Some of the SO_2 is further oxidised to sulphate (SO_4). The sulphate and associated water coalesce around the carbon core of the particulate. This increases the mass of the PM and thus fuel sulphur has a significant influence on the PM. Typically the conversion rate from sulphur to sulphate is around 1% and the sulphate contribution to engine out PM has been negligible. However, the use of an after-treatment containing an oxidation catalyst dramatically increases the conversion rate to up to 100% depending on the catalyst efficiency. Therefore, for vehicle systems with an oxidation catalyst, a large proportion of the engine out SO_2 will be oxidized to SO_4, increasing the amount of PM emitted from the vehicle. This has a significant impact on the efficiency of the vehicle after-treatment system.

Calculation of Sulphur Contribution to PM

The mass of sulphates emitted from the engine depends on the following parameters:

- The fuel consumption of the engine
- The fuel sulphur content
- The S to SO_4 conversion rate

Both the fuel sulphur content and fuel consumption are measurable parameters, whereas the conversion rate can only be predicted as it varies from engine to engine. The use of an after-treatment containing an oxidation catalyst dramatically increases the conversion rate to up to 100% depending on the catalyst efficiency.

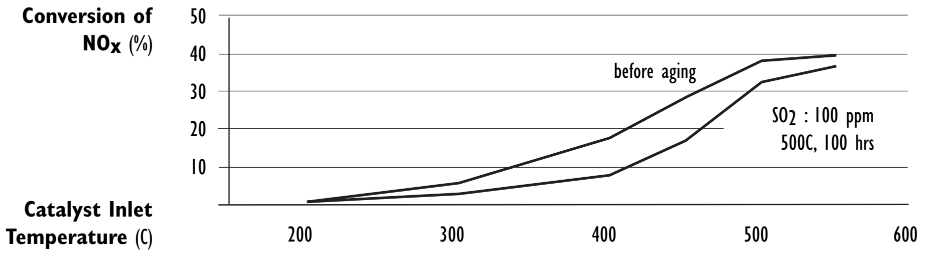
The following formula clearly shows the impact of the fuel sulphur on PM:

$BSSO_4 = BSFC * FSC/100 * PCSC/100 * 7$ where **$BSSO_4$** = Brake specific sulphate in mass/brake power-hour
BSFC = brake specific fuel consumption in g/kWh
FSC = fuel sulphur content in % mass
PCSC = Percent sulphur conversion (to SO_4)
7 = S to (SO_4 + water) weight increase factor

Effect of Sulphur on Diesel Aftertreatment

Future regulations will require lower NOx and particulate emissions in combination with lower fuel consumption and CO_2 emissions. De-NOx catalyst systems, which can remove NOx emissions from the diesel's oxygen-rich exhaust, could be the solution to break the trade-off between NOx, PM and fuel consumption. However, as shown in Figure 8, these systems are very sensitive to fuel sulphur content. The level of sulphur in diesel fuel (and gasoline) is an important factor in the performance of De-NOx catalyst systems. The catalyst performance is always better with sulphur-free fuel.

Figure 8: Influence of Sulphur Dioxide Aging on NOx Conversion



Other technologies under development include NOx catalyst, Continuously Regenerating Diesel Particulate Filters (CR-DPF) and Catalysed Diesel Particulate Filters (CDPF). The Diesel Emission Control-Sulfur Effects (DECSE) project, a collaborative program conducted by the US Department of Energy (DOE), Engine Manufacturers Association (EMA) and Manufacturers of Emission Controls Association (MECA), studied the impact of diesel fuel sulphur levels of 3, 16, 30, 150 and 350 ppm on a number of these technologies on both heavy and light duty engines. Reference: http://www.ott.doe.gov/decse.

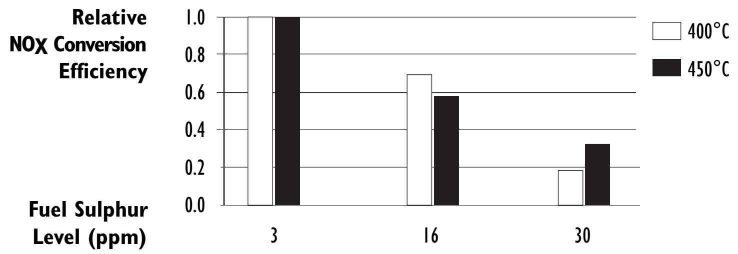
The Advanced Petroleum Based Fuels - Diesel Emission Control (APBF-DEC) Program, another collaborative effort, has identified optimal combinations of low-sulphur diesel fuels, lubricants, diesel engines and emission control systems to meet projected emission standards for the 2001 to 2010 time period. Reference: http://www.ott.doe.gov/apbf.shtml.

NOx Adsorber

NOx adsorbers are poisoned and rendered ineffective by the presence of sulphur. These devices can be up to 90% efficient in NOx removal if operated on sulphur-free fuel. The concern with fuel sulphur is that SO_2 is formed during combustion and released in the exhaust. In a NOx adsorber catalyst, this SO_2 undergoes reactions that are similar to those of NOx. However, SO_2 generates a stronger adsorbate (SO_3) when compared with NO_2. As a result, SO_2 is a poison for the NOx adsorption sites.

The effect of fuel sulphur content on NOx adsorber conversion efficiency is shown in Figure 9 below. The figure illustrates the effect of fuel sulphur on relative NOx conversion efficiencies. Compared to 3 ppm sulphur fuel, both 16 and 30 ppm sulphur fuels resulted in a significant decline in performance.

Figure 9: Effect of Fuel Sulfur Level on NOx Conversion Efficiency (150 hours aging)



Diesel Particulate Filter

The Diesel Particulate Filter (DPF), which appeared in the market on production vehicles in mid-2000, allows vehicles to achieve extremely low values of particulate emissions. The filtration of exhaust gas particulates has been possible for many years, but the disposal of the accumulated particulate has remained as a difficult problem to solve. Apart from removing the filter frequently for cleaning, a reliable and cost-effective system of on-board filter regeneration by combustion of the particulate was not available. The latest generation of common rail engines opened possibilities through electronic injection strategies for increasing exhaust gas temperatures, so combusting the trapped particulate. Through a combination of catalytic additive mixed on-board with the fuel, post-combustion fuel injection into the cylinder and a pre-filter HC combustion, reliable regeneration of the filter has become possible, so allowing DPFs to be used in service.

The latest generation of common rail direct injection diesel engines emits 60% less particulate matter than its immediate prechamber predecessors, and when combined with a DPF system, reduces the number of particulates in the exhaust gases to the level of ambient air, and completely eliminates black smoke. What is more, this 10^3 -10^4 reduction magnitude in particulate emissions is constant over the whole range of particulate size. Thus, using DPF systems further enhances the potential of the diesel engine as a low-polluting power unit.

The sulphur contained in diesel fuel is likely to be transformed into gaseous sulphur compounds in the oxidation catalyst contained in the DPF system, and may be transformed through secondary sulphate particulates in the atmosphere. Therefore, the use of sulphur-free fuels in vehicles with DPF systems is highly recommended to avoid this phenomenon.

Continuously Regenerating Diesel Particulate Filters

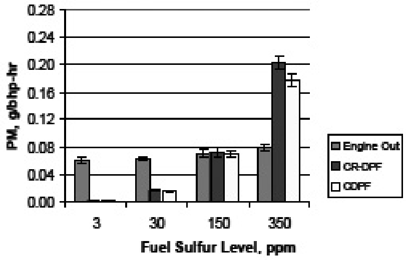
The Continuously Regenerating Diesel Particulate Filter (CR-DPF) and Catalysed Diesel Particulate Filter (CDPF) represent two approaches to regeneration of DPFs.

The CR-DPF accomplishes this filter regeneration by continuously generating NO_2 from engine-emitted NO over a diesel oxidation catalyst placed upstream of the DPF. Proper vehicle calibration is necessary to ensure that sufficient NO_2 is generated for this purpose. NO_2 has been established as a more effective low-temperature oxidizing agent for diesel PM than oxygen. Sulphur in the exhaust is oxidised over the CR-DPF, forming sulphates, which contribute to PM. Sulphur oxides also compete for the critical NO and NO_2 reaction, making the regeneration of the trap less effective.

The CDPF accomplishes the DPF regeneration by using a catalyst coating on the DPF element to promote oxidation of the collected PM using available oxygen in the diesel exhaust. Sulphur in the exhaust is oxidised over the CDPF to form sulphates. Exhaust-gas temperature and fuel-sulphur level are critical factors that affect the performance of both types of DPFs (CR-DPF and CDPF).

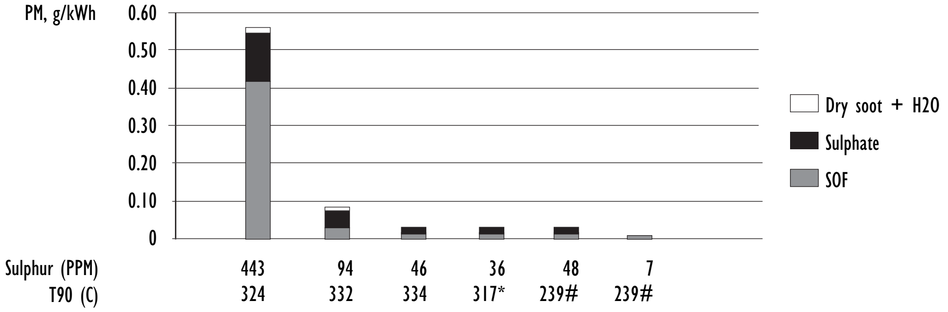
Fuel sulphur has a significant effect on PM emissions. Both types of DPF's effectively reduce PM emissions when the sulphur is very low, but when the sulphur increases, so do sulphate levels which affect the amount of PM emitted. In one study, PM was reduced by 95% over the OICA cycle when the tested DPFs were used with 3-ppm sulphur fuel (Figure 10a). With 30-ppm sulphur fuel, the PM reduction efficiencies dropped to 72 and 74% for the CR-DPF and CDPF, respectively. At the 150-ppm sulphur test point, the sulphur content of the measured mass completely masked the reduction in carbonaceous particles, so that the measured total PM reductions were near zero. A similar outcome was seen in Japanese DPF testing (Figure 10b).

Figure 10a: Effect of Fuel Sulphur Level on PM Emissions – OICA Cycle



Engine tested: Caterpillar 3126, 7.2 litre, Inline 6 cylinder, 205 kW @2200 rpm

Figure 10b: Fuel effect on Diesel Particulate – CR (Continuous Regeneration) - DPF Japan diesel 13 mode



*Blend of diesel fuel and kerosene. #Kerosene.

ASH

Fuel and lubricant derived ash can contribute to coking on injector nozzles (see Figure 15) and will have a significant effect on the life of diesel particulate filters. Ash-forming metals can be present in fuel additives, lubricant additives or as a byproduct of the refining process.

Metallic ash constituents are incombustible, so when they are present in the fuel, they remain in the exhaust and become trapped within the DPF. Thus, the presence of ash-forming materials in the fuel will lead to a premature build-up of backpressure and vehicle operability problems. Non-fuel solutions have been found unsatisfactory. Larger filters would reduce backpressure build-up but otherwise would be unnecessary and may be infeasible (for example, in smaller vehicles). Increased in-use maintenance or, in extreme cases, replacing the DPF may not be allowed in some markets. Therefore, keeping ash-forming compounds out of the fuel to the extent possible provides the best solution.

Ash-forming compounds may be present in fuel in four forms:

- Abrasive solids, such as suspended solids and organometallic compounds that contribute to injector, fuel pump, piston and ring wear and to the formation of engine deposits.
- Soluble metallic soaps, which have little effect on wear but may contribute to engine deposits.
- Soluble metals, which may be present in vegetable-derived fuels as a result of absorption by the plant source and inadequate removal during processing. Biodiesel fuel, for example, may contain metals that were left in the residue resulting from common catalytic production methods.
- Metals that originate in water entrained in the fuel.

Industry standards limiting ash to less than 0.01%, which were intended to protect close tolerance fuel injection equipment and reduce piston ring zone deposits, have addressed the first form of ash-forming compounds. Fuel surveys have confirmed that the content in most fuels has been near the detection limit of the currently available test procedure (0.001%). The remaining forms of metallic ash, however, may enter fuel during the distribution process and must be controlled before dispensing the fuel to the engine or vehicle.

Diesel fuel containing ash at the current detection limit (0.001%) may require the DPF to be serviced during the vehicle's useful life, but many jurisdictions do not allow this for Category 4 engines or vehicles. Therefore, ash-forming metals must be controlled to very low levels so that emission control systems may operate properly over the lifetime of the vehicle. To allow the appropriate level for these ash compounds, a new test procedure capable of measuring lower levels of ash in diesel fuel must be developed.

AROMATICS

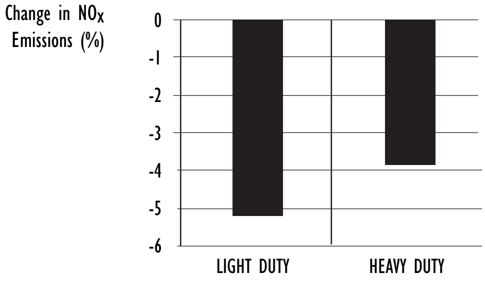
Aromatics are molecules that contain at least one benzene ring. The fuel aromatic content will affect combustion and the formation of particulate and PAH emissions.

The diesel fuel aromatics content influences flame temperature, and therefore, NOx emissions during the combustion. Polycyclic aromatic hydrocarbons (PAH) in the fuel affect the formation of particulates and PAH emissions from a diesel engine.

Influence of Total Aromatics Content on NOx Emissions

A higher aromatic content in the fuel will increase the flame temperature during combustion, which results in increased NOx emissions. Testing in Europe (ACEA follow-up programme to EPEFE) demonstrated that a reduction of the total aromatic content from 30 to 10% yields significantly lower NOx emissions as shown in Figure 11.

Figure 11: Effect of Total Aromatics on NOx Emissions 30 to 10% aromatics

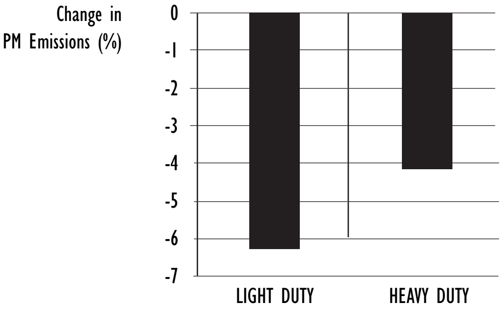


The light duty data is based on the combined ECE/EUDC cycle, the heavy duty on the 88/77/EEC 13-mode cycle.

Influence of Polyaromatic Content on Particulate Emissions

The influence of polyaromatic (di+, tri+) content on PM emissions was also investigated in the EPEFE programme. Figure 12 shows the reductions of PM emissions that were measured when the polyaromatic content was reduced from 9 to 1 %.

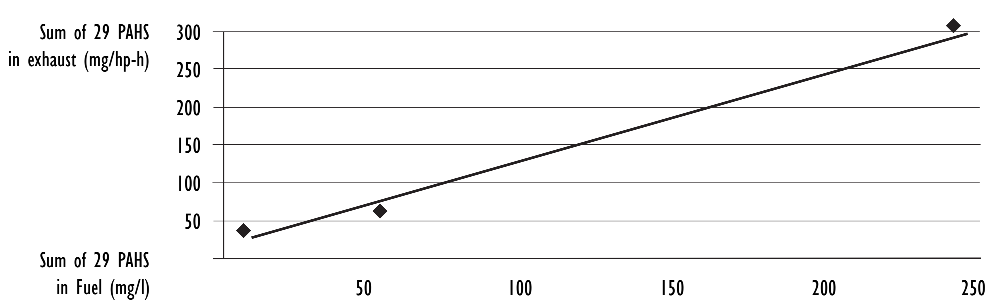
Figure 12: Effect of Polyaromatics on PM Emissions (from 9 to 1% di+ polyaromatics)



Influence of PAH Content on PAH Emissions

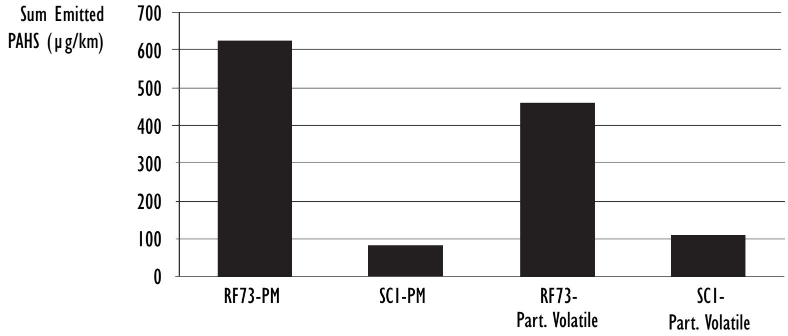
PAH (tri+) content in diesel fuel has been shown to directly correlate to PAH emissions in vehicle exhaust. The PAH emissions of a truck diesel engine on the US transient cycle using fuels with different PAH contents were measured in a Swedish study. The results shown in Figure 13 demonstrate this direct correlation.

Figure 13: Effect of Fuel PAH on Emissions of PAH



The Swedish EPA also tested a Euro 2 diesel engine on the 88/77/EEC and the transient 'Braunschweig'-cycle on Sweden Class 1 fuel (SC1, PAH =24 mg/l) and European reference fuel (RF73; PAH=2100 mg/l). Figure 14 shows the sum of emitted PAH's collected on the filter (PM) and the emissions of partly volatile PAH's (average of four cycles).

Figure 14: Effect of Fuel PAH on Emissions of PAH



DISTILLATION CHARACTERISTICS

The distillation curve of diesel fuel indicates the amount of fuel that will boil off at a given temperature. The curve can be divided into three parts:
- The light end, which affects startability;
- The region around the 50% evaporated point, which is linked to other fuel parameters such as viscosity and density; and,
- The heavy end, characterised by the T90, T95 and final boiling points.

The heavy end has been the most thoroughly studied with respect to its effect on tailpipe emissions.

Influence of Heavy End on PM Emissions

In most new studies only the influence of the upper boiling range has been investigated with respect to exhaust gas emissions, whereas the lower boiling range varied widely. Conclusions concerning the whole boiling range and distillation influence are therefore not possible. However, it is clear that too much fuel in the heavy end will result in coking and increased tailpipe emissions of soot/smoke/particulate matter.

Influence of T95 on Tailpipe Emissions

The effect of T95 on vehicle emissions was examined in the European EPEFE programme. The testing indicated that exhaust gas emissions from heavy duty diesel engines were not significantly influenced by T95-variations between 375°C and 320°C. However, a tendency for lower NOx and higher HC with lower T95 was observed.

In the case of light duty diesel engines the same reduction in T95 resulted in a 7% reduction in PM and 4.6% increase in NOx emissions.

COLD FLOW

Diesel fuel can have a high content (up to 20%) of paraffinic hydrocarbons which have a limited solubility in the fuel and, if cooled sufficiently, will come out of solution as wax. Adequate cold flow performance, therefore, is one of the most fundamental quality criteria for diesel fuels.

The cold flow characteristics are primarily dictated by:
- Fuel distillation range, mainly the back-end volatility;
- Hydrocarbon composition: content of paraffins, naphthenes, aromatics;
- Use of cold flow additives.

Measures of Cold Flow Performance

Specifications for diesel cold flow properties must be specified according to the seasonal and climatic needs in the region where the fuel is to be used. Wax in vehicle fuel systems is a potential source of operating problems; the low-temperature properties of diesel fuels are therefore defined by wax-related tests:
- **Cloud Point, CP (ISO 3015, ASTM D2500)**: The temperature at which the heaviest paraffins start to precipitate and form wax crystals; the fuel becomes ‘cloudy’.
- **Cold Filter Plugging Point, CFPP (EN116)**: The lowest temperature at which the fuel can pass through the filter in a standardised filtration test. The CFPP test was developed from vehicle operability data and demonstrates an acceptable correlation for fuels and vehicles in the market. For North American fuels however, CFPP is not a good predictor of cold flow operability. CFPP can be influenced by cold flow additives.
- **Low Temperature Flow Test, LTFT (ASTM D4539)**: The LTFT was developed to predict how diesel fuels in the United States and Canada will perform at low temperatures, in the diesel vehicles present in these markets. LTFT is a slow cooling test and therefore more severe than CFPP. LTFT temperature can be influenced by cold flow additives.

Cold Flow Limits

The diesel fuel cold flow performance can be specified by Cloud Point, by CFPP (with maximum delta between CFPP and Cloud Point), or by LTFT (in USA and Canada).

- If Cloud Point (only) or LTFT is used, the maximum allowed temperature should be set no higher than the lowest expected ambient temperature.
- If CFPP is used to predict cold flow, the maximum allowed CFPP temperature should be set equal to, or lower than, the lowest expected ambient temperature. In this case, the Cloud Point should be no more than 10°C above the CFPP specified.

Example:

- Lowest expected ambient temperature (statistical): - 32°C
- Maximum allowed CFPP temperature: -32°C
- Maximum allowed Cloud Point: -22°C

FOAM

Diesel fuel has a tendency to generate foam during tank filling, which slows the process and risks an overflow. Anti-foamants are sometimes added to diesel fuel, often as a component of a multifunctional additive package, to help speed up or to allow more complete filling of vehicle tanks. Their use also minimises the likelihood of fuel splashing on the ground, which, in turn, reduces the risk of spills polluting the ground, the atmosphere and the consumer.

Foam Control

Silicon surfactant additives are effective in suppressing the foaming tendency of diesel fuels, the choice of silicon and co-solvent depending on the characteristics of the fuel to be treated. Selection of a diesel anti-foamant is generally decided by the speed at which the foam collapses after vigorous manual agitation to simulate the effect of air entrainment during tank filling. It is important that the eventual additive chosen should not pose any problems for the long-term durability of the emission post-treatment con-trol systems.

FATTY ACID METHYL ESTERS

Fatty Acid Methyl Esters (FAME), frequently termed biodiesel, increasingly are being used to extend or replace diesel fuel. Such use has been driven largely by efforts in many nations to exploit agricultural produce and/or to reduce dependency on petroleum-based products.

Several different oils may be used to make biodiesel, for example, rapeseed, sunflower, palm, soy, cooking oils, animal fats and others. These oils must be reacted with an alcohol to form ester compounds before they can be used as biodiesel fuel. Unprocessed vegetable oils, animal fats and non-esterified fatty acids are not acceptable as transportation fuels due to their very low cetane, inappropriate cold flow properties, high injector fouling tendency and high kinematics viscosity level. Historically, methanol has been the alcohol most used to esterify the fatty acids, and the resultant product is called fatty acid methyl ester (FAME). Research is underway to enable use of ethanol as the reactant alcohol, in which case the product is called fatty acid ethyl ester (FAEE).

The European standards organization, CEN, has published an automotive FAME standard (EN 14214) that establishes specifications for biodiesel use as either: (i) a final fuel in engines designed or adapted for biodiesel use; or (ii) a blendstock for conventional diesel fuel. Similarly, ASTM International has established specifications for neat biodiesel (ASTM D 6751) but only for use as a blending component, not as a final fuel.

Generally, biodiesel is believed to enhance the lubricity of conventional diesel fuel and reduce exhaust gas particulate matter. Also, the production and use of biodiesel fuel is reported to lower carbon dioxide emissions on a source to wheel basis, compared to conventional diesel fuel.

At the same time, engine and auto manufacturers have concerns about introducing biodiesel into the marketplace, especially at higher levels. Specifically:

- Biodiesel may be less stable than conventional diesel fuel, so precautions are needed to avoid problems linked to the presence of oxidation products in the fuel. Some fuel injection equipment data suggest such problems may be exacerbated when biodiesel is blended with ultra-low sulphur diesel fuels.
- Biodiesel requires special care at low temperatures to avoid an excessive rise in viscosity and loss of fluidity. Additives may be required to alleviate these problems.
- Being hygroscopic, biodiesel fuels require special handling to prevent high water content and the consequent risk of corrosion and microbial growth.
- Deposit formation in the fuel injection system may be higher with biodiesel blends than with conventional diesel fuel, so detergent additive treatments are advised.
- Biodiesel may negatively impact natural and nitrile rubber seals in fuel systems. Also, metals such as brass, bronze, copper, lead and zinc may oxidize from contact with biodiesel, thereby creating sediments. Transitioning from conventional diesel fuel to biodiesel blends may significantly increase tank sediments due to biodiesel's higher polarity, and these sediments may plug fuel filters. Thus, fuel system parts must be specially chosen for their compatibility with biodiesel.
- Neat (100%) biodiesel fuel and high concentration biodiesel blends have demonstrated an increase in NOx exhaust emission levels.
- Biodiesel fuel that comes into contact with the vehicle's shell may be able to dissolve the paint coatings used to protect external surfaces.

In view of the high level of interest in this fuel, including among auto and engine manufacturers, biodiesel specifications and test methods will continue to be investigated.

SYNTHETIC DIESEL FUEL

In recent years, various types of alternative and renewable diesel fuels have emerged that also can help extend or replace diesel fuel. The Fischer-Tropsch process, which was invented in the 1920s but today represents a variety of similar processes, converts feedstocks of biomass, methane (natural gas) or coal into high cetane, low aromatic fuels, commonly referred to as BTL ("biomass-to-liquid"), GTL ("gas-to-liquid") or CTL ("coal-to-liquid"), as the case may be. These potentially viable clean-burning fuels are usable in any diesel engine either in pure form or blended with conventional diesel fuel. The fuels generally have poor lubricity, which requires the addition of appropriate additives to enable the fuel to meet or exceed requirements. BTL should not be confused with biodiesel (FAME), which is fundamentally a different fuel.

E-DIESEL

Adding ethanol to diesel fuel (E-diesel) has been considered as a way to extend the volume of diesel fuel, reduce dependency on imported oil products or exploit agricultural produce and waste. E-diesel fuel typically has an extremely low flashpoint of about 13°C (55°F), which is well below the minimum limit set by various organisations: ASTM D975 standard of 52°C (126°F), EN590 standard of 55°C min (131°F), JIS K2204 standard of 45°C (113°F). Such flash point levels are likely to generate risks to engines, vehicles and fuel distribution facilities, and raise serious safety concerns (such as explosions), for fuel handling, storage and use. Vehicle and engine manufacturers are concerned that e-diesel may damage vehicle parts, especially fuel injectors, and cause other types of vehicle failure due to low lubricity. The fuel's compatibility with the vehicle in other ways, its impact on vehicle emissions and its health effects remain unknown. Since ethanol has lower energy content than diesel fuel, its presence in the fuel will reduce fuel economy. Therefore, until the many safety, performance and health concerns are resolved and sufficient peer-reviewed research is conducted in these important areas, manufacturers do not support adding ethanol to any category of diesel fuel.

INJECTOR CLEANLINESS

The fuel injector, which is designed to meter fuel to a high degree of accuracy, is a component of very high precision. The correct behaviour of the engine depends on the injector doing its job properly; otherwise there will be repercussions in terms of noise, smoke and emissions.

Effect of Injector Fouling

The tip of the injector is subject to a very harsh environment as it is in direct contact with the combustion process, both in pre-chamber and in direct injection engines. The solid matter products of combustion are deposited on the tip and can alter significantly the operation of the injector. For pre-chamber engines, the combustion products partially block the progressive delivery of the fuel at part load, and the combustion can become violent and disorganised. Likewise in direct injection engines, a partial or complete blockage of one of the fine spray holes will perturb the atomisation of the fuel jet, and the engine no longer functions as designed.

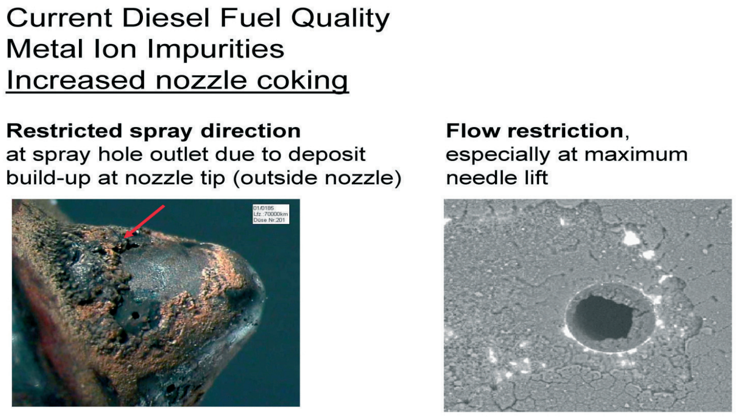
Where pre-chamber engines are concerned, some coking is inevitable due to the type of injector used, and the choice of injector takes this into account. However, the coking level depends on the quality of the fuel, and excessive coking cannot be tolerated. The injectors of direct injection engines are initially more resistant to coking, but poor fuel quality can eventually block a spray hole.

Influence of Detergent Additives

The solution to this difficulty is to be found in the use of detergent additives in the fuel. High doses of these additives can partially clean an already heavily coked injector, while smaller doses can maintain injectors at an acceptably clean state, which ensures correct operation. Many fuel distributors include these additives in commercial diesel fuels as quality features to obtain a 'keep clean' effect.

Cleanliness of the injectors has become an even higher priority at present as high-pressure injection systems are increasingly used on both heavy-duty and light-duty direct injection engines. The conformity of modern engines with their specified performance in terms of power, fuel consumption and emissions over time will depend largely on the cleanliness of their injectors. It has been observed in service and by many laboratories, both in manufacturing facilities and independently, that small quantities of metals such as zinc, copper, lead, sodium and potassium in diesel fuel can lead to significant injector fouling with subsequent engine power loss and increased exhaust gas PM. Figure 15 shows pictures of a nozzle with coking caused by metallic impurities.

Figure 15: Examples of Increased Nozzle Coking Due to Metal Ion Impurities (Reproduced with permission.)



Current Diesel Fuel Quality
Metal Ion Impurities
Increased nozzle coking

Restricted spray direction
at spray hole outlet due to deposit
build-up at nozzle tip (outside nozzle)

Flow restriction,
especially at maximum
needle lift

Metals can contaminate the fuel during the distribution process, even though the fuel is clear when leaving the refinery. Ideally, a standardized engine test on a direct injection diesel engine would permit the setting of an acceptable limit value for injector fouling due either to metals being present in the fuel or to the fuel composition. At present, such a standardized test procedure has not been established, but candidate procedures are being considered. Until an engine performance test is established, therefore, it is prudent to require diesel fuel delivered at the filling station to respect the specific limits for each metal in the fuel, to reduce the risk of severe injector fouling in modern direct injection diesel engines. The technique for measuring the metals should be by inductively coupled plasma, such as with the ASTM D 5185 method (direct measurement improves the detection limit).

LUBRICITY

The lubricating components of the diesel fuel are believed to be the heavier hydrocarbons and polar fuel compounds. Diesel fuel pumps, without an external lubrication system, rely on the lubricating properties of diesel fuel to ensure proper operation.

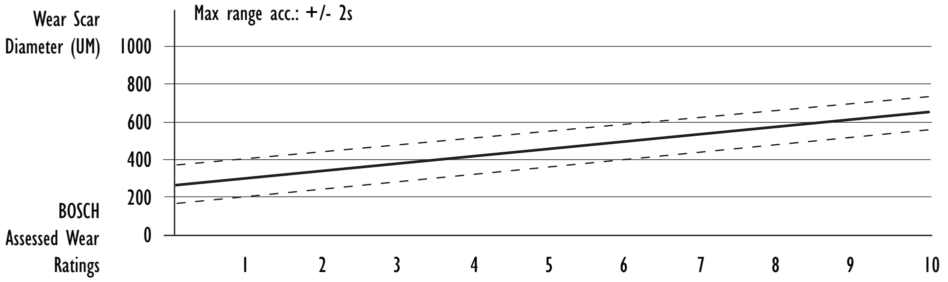
Refining processes to remove sulphur tend to simultaneously reduce diesel fuel components that provide natural lubricity. As diesel fuel sulphur levels decrease, the risk of inadequate lubricity also increases; however, poor lubricity has been observed even in diesel fuels with very high sulphur levels. Inexpensive additives can be used instead of changing the refining process to achieve the desired lubricity level.

Influence of Lubricity on Pump Wear

Inadequate lubricity can result in increased tailpipe emissions, excessive pump wear and, in some cases, catastrophic failure. Concerns over problems experienced with fuels with poor lubricity led to a significant international collaboration between oil companies, OEMs, additive companies and pump manufacturers to develop a test method and performance limit for fuel lubricity. The resultant method, the High Frequency Reciprocating Rig (HFRR) procedure, is a bench test that provides good correlation to measured pump effects.

Figure 16 shows the correlation between actual pump wear (measured by Bosch) and HFRR measured wear scar diameter. Bosch's rating scale describes ‘normal wear‘ as less than 3.5 (which corresponds to a nominal HFRR Wear Scar Diameter of 400 mm). With a Bosch wear rating of 4, the pump will have decreased endurance, and ratings above 7 indicate potential fatal breakdown.

Figure 16: Assessed Pump Wear Rating vs. HFFR Results



PARTICULATE CONTAMINATION

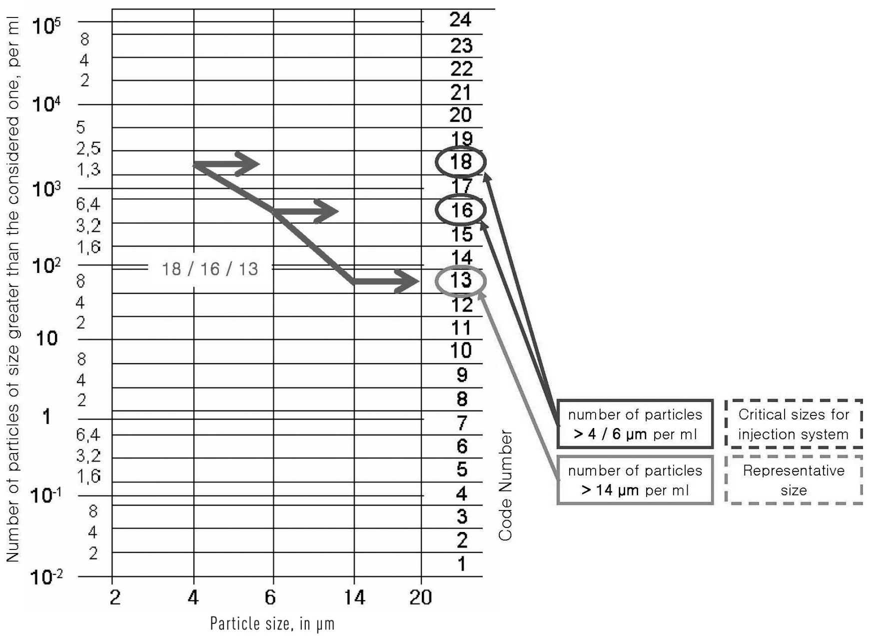
Fuel injection equipment manufacturers continue to develop fuel injection systems to reduce emissions and fuel consumption and to improve performance. Injection pressures have been increasing; currently, they have reached 1600 bars. Such levels of injection pressure demand reduced orifice sizes and component clearances, typically from 2 to 5 µm in injectors. Small, hard particles, which may be carried into these engine parts, are potential sources of engine failure.

Excessive diesel fuel contamination can cause premature clogging of diesel fuel filters, depending on the level of both hard and organic particles, and premature wear of modern fuel injection system parts. These impacts, depending on the size and the nature of the particles, will lead to:

- Reduced part lifetimes;
- Part malfunction;
- Engine failure; and
- Increased exhaust emissions.

Measuring fuel particle contamination necessarily considers both the size and number of particles per size class contained in the fuel, i.e. the particle size distribution. The ISO 4406 protocol provides a means of expressing the level of contamination by coding the size distribution. Three code numbers, corresponding to the numbers of particles of size greater than 4, 6 and 14 µm per milliliter, respectively, are reported. Figure 17 shows how to use the ISO 4406 coding method.

Figure 17: ISO 4406 Particulate Size Distribution Coding Chart

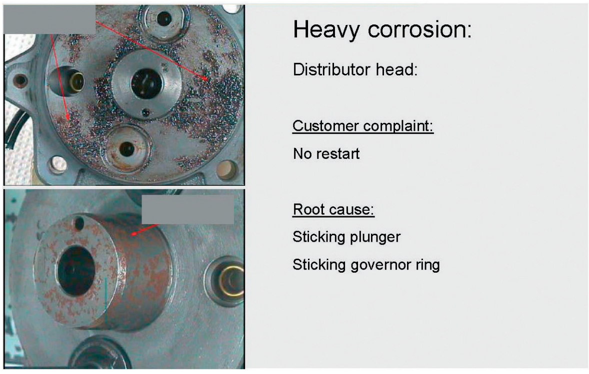


Engine and vehicle manufacturers recommend applying the Worldwide Fuel Charter's particulate contamination specification at the fuel station nozzle to prevent particles originating from fuel transport, storage and logistics from reaching the engine.

GOOD HOUSEKEEPING PRACTICES

The problems encountered by vehicles from poor quality fuel often are caused by adulteration that occurs in the fuel distribution system, after the fuel has left the refinery gate. Failure to invest in adequate pipeline and storage facilities and failure to maintain the equipment can lead to volatility losses, fuel leakage and contamination by particulates and water that, in turn, can lead to a host of vehicle problems. Excess levels of water, for example, will lead to corrosion, as shown in Figure 18. Poor operating practices at the service station, such as too infrequent replacement of fuel dispenser filters or "dipping" of tanks to check for water, can magnify these problems.

Figure 18: Example of Corrosion in Field Pump Caused by Free Water in Diesel Fuel



Heavy corrosion:

Distributor head:

Customer complaint:

No restart

Root cause:

Sticking plunger

Sticking governor ring

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GASOLINE

Table 1	ASTM D 5185
Table 2	US AQIRP, EPEFE, AAMA/AIAM, SAE 982726, JSAE 9838985
Figure 1	US AQIRP
Figure 2	TOYOTA
Figure 3	ALLIANCE/AIAM LOW SULFUR EMISSIONS STUDY, 2001
Figure 4	JAPAN CLEAR AIR PROGRAM
Figure 5	SAE 962051
Figure 6	TOYOTA, 1999
Figure 7	GENERAL MOTORS, 1999
Figure 8	TOYOTA, 1999
Figure 9	SAE 2002-01-2894
Figure 10	FORD, 2000
Figure 11	HONDA, BMW AND FORD
Figure 12	ALLIANCE, AIAM AND CVMA, 2002
Figure 13	CRC REPORT, NO. E65
Figure 14	US AQIRP
Figure 15	US AQIRP, EPEFE REPORT
Figure 16	CRC REPORT, NO. 605
Figure 17	CRC REPORT, NO. 605
Figure 18	GM/SAE 962023
Figure 19	TOYOTA/SAE 972851
Figure 20	FORD, 1996
Figure 21	FORD/SAE 962012
Figure 22	FORD, 1996
Figure 23	FORD/SAE 962012
Figure 24	FORD, 2001
Figure 25	TOYOTA/SAE 941893

DIESEL

Figure 1, 2	ACEA REPORT: INFLUENCE OF DIESEL FUEL QUALITY ON HEAVY DUTY DIESEL ENGINE EMISSIONS, MARCH 1997
Figure 3	FORD, 2004
Figure 4, 5	EPEFE REPORT
Figure 6	DETROIT DIESEL, EFFECT OF SULFUR ON ENGINE LIFE
Figure 7	ACEA REPORT: INFLUENCE OF DIESEL FUEL QUALITY ON HEAVY DUTY DIESEL ENGINE EMISSIONS, MARCH 1997
Figure 8	JAMA, PRESENTED AT 30TH ISATA, JUNE 1997
Figure 9	DECSE PROGRAM, PHASE 1, NUMBER 2, OCTOBER 1999, US DOE/EMA
Figure 10a	DECSE PROGRAM, PHASE 1, NUMBER 3, NOVEMBER 1999, US DOE/EMA
Figure 10b	JAPAN CLEAN AIR PROGRAM
Figure 11	ACEA REPORT: INFLUENCE OF DIESEL FUEL QUALITY ON HEAVY DUTY DIESEL ENGINE EMISSIONS, MARCH 1997
Figure 12	DATA FROM THE EPEFE REPORT
Figure 13	KARLSSON (SCANRAFF REFINERY) AND RÖJ (VOLVO): DIESEL FUEL QUALITY FOR REDUCED EMISSIONS, WORLD FUELS CONFERENCE SAN FRANCISCO, 1995
Figure 14	GRÄGG, AP SVENSK BILPROVNING/MOTORTESTCENTER, REPORT 9/1995 BOSCH, 1997
Figure 15	BOSCH, 2004
Figure 16	BOSCH, 1997
Figure 17	ISO 4406, 1999
Figure 18	BOSCH, 2002

This brochure was printed on paper manufactured without chlorine or optical brightening agents

Thirty one organizations and individuals submitted comments on the August 2005 proposed Worldwide Fuel Charter (WWFC). All comments were carefully reviewed for appropriate action. For brevity, the following discussion has been organized by concept rather than repetitively responding to similar comments. Several helpful editorial suggestions and corrections were adopted but are not described in this document. For reasons of confidentiality, the individual commenters are not identified. It should be noted that the WWFC represents recommendations for a global market, and as such, its specifications will differ in some regards from the standards of any particular country or location.

General Comments on the Worldwide Fuel Charter

COMMENT: Review would be much easier if the new draft highlighted the changes from the previous edition.

RESPONSE: The Committee appreciates the concern and will consider providing better guidance on proposed changes in the future.

COMMENT: Several commenters recommended providing more detailed background on the key properties.

RESPONSE: The technical background is intended to provide a summary of how fuel properties relate to vehicle performance characteristics. With each edition, the Committee reviews the background for opportunities to improve or update the discussions. To the extent readers seek more detailed information and analysis, they are encouraged to review the references cited in the document.

COMMENT: Discussion is lacking of the health and environmental benefits of such topics as eliminating lead additives, reducing sulphur levels, and increasing the use of biofuels.

RESPONSE: The purpose of the Charter is to define fuel specifications as required by engine and vehicle technologies.

COMMENT: Fuel specifications should be based on a variety of factors, including cost, emission benefits and Well-to-Wheel (WTW) CO_2 and energy efficiency analyses.

RESPONSE: The purpose of the Charter is to define the fuel specifications that will lead to the best performance and lowest emissions, given different engine and vehicle technologies and emission standards.

COMMENT: Category 4 fuels are not practical fuels and are not justified.

RESPONSE: The Committee disagrees. Some markets have been providing fuels matching or exceeding several Category 4 limits for many years. Some Category 4 limits are required to enable new technologies, and others facilitate market acceptance of new technologies. For example, ultra-low sulfur levels enable the use of lean NOx catalysts, and ultra-low diesel fuel ash content enables the use of advanced diesel particulate filters. Higher cetane levels are needed to make light duty diesel vehicles acceptable to consumers as well as reduce emissions.

COMMENT: Fuel quality recommendations deviate from current national or European regulations.

RESPONSE: The Charter represents recommendations for a global market, and as such, its specifications will differ from standards specific to any particular country or location. More stringent local regulations would supersede Charter requirements.

COMMENT: The WWFC places arbitrary fixed limits on major fuel components such as aromatics and olefins, which can significantly increase production cost, energy consumption and CO_2 emissions while reducing fuel supply. Given the very low emissions that can be achieved by advanced engines and after-treatment technologies with today's ultra-low sulfur fuels, no significant emissions benefits would be obtained from these types of WWFC specifications.

RESPONSE: The purpose of the Charter is to define the fuel specifications that will lead to the best performance and lowest emissions, given different engine and vehicle technologies and emission standards.

COMMENT: The United States, Europe and Japan have adopted different methodologies of emissions evaluation; consequently a vehicle meeting the emissions limits adopted in the United States might not necessarily meet the European legislative limits when tested by their respective methodologies. Therefore, attention should be given to unifying emission evaluation methodologies before unifying fuels specifications, to allow a true comparison of vehicle performance among countries.

RESPONSE: The Committee agrees that common emission regulations would be beneficial, which is why several members are working toward such worldwide vehicle harmonization. That effort, however, need not precede efforts to improve and harmonize worldwide fuel quality.

COMMENT: Various comments were submitted regarding test methods.

RESPONSE: Some test methods were added and others were corrected as suggested. The year was retained on some methods to maintain the same specification limits and content.

COMMENT: "Non-detectable" limits for the maximum metal content are too vague to be enforced, controlled, or guaranteed. There is no such value listed as detectable in any of the ASTM test method standards. In addition, to our knowledge, it has not been demonstrated that trace metals contamination at such extremely low levels is not attributable to vehicle components rather than to fuels.

RESPONSE: The Committee agrees in the case of metals analysis and has changed the Charter to refer to the Limits of Quantitation, instead. Regarding the source of metal contamination, the Charter defines requirements for fuels as delivered to the customer or vehicle. Any metals or contaminants introduced by engine or vehicle components are accounted for in the design of the engine and vehicle.

COMMENT: The silver corrosion limit as shown in D4814-04b and test method in its Annex A1 were not adopted. It is stated that the auto makers are unaware of a fully satisfactory test method to identify problem fuels.

RESPONSE: The Committee is not yet satisfied that acceptable test methods are available to address this concern.

COMMENT: The inclusion of a second method for measuring fuel injector cleanliness using ASTM D6421 (and the corresponding limits proposed) is not technically justified. Are methods 1 and 2 equivalent?

RESPONSE: The Committee believes that both methods are justified and have different appropriate limits.

COMMENT: Several commenters recommended that the Charter include requirements for alternative fuels, including E-85 and biodiesel, and provide additional text recognizing the growing trend of alternative fuel use.

RESPONSE: The Charter is intended to define conventional fuel standards. The Committee will consider addressing fuels for alternative fueled vehicles in the future.

COMMENT: The WWFC fails to consider unique conditions such as in Brazil. Brazil uses gasoline that contains 25% ethanol; its vehicle fleet increasingly contains flex-fuel vehicles that can be powered either by a gasoline/ethanol blend or by pure hydrated ethyl alcohol (ethanol).

RESPONSE: Brazilian ethanol fuel blends are categorized as alternative fuels because they require unique vehicle calibrations different from vehicles using conventional gasoline. The Committee will consider addressing fuels for alternative fueled vehicles in the future.

Comments Related Specifically to Gasoline Specifications

COMMENT: Aromatic content for regular gasoline (91 RON) in Category 4 should have the same limit as the 95 and 98 octane grades.

RESPONSE: Based on a reevaluation of the Charter requirements, aromatic levels for all octane grades have been unified. The Committee continues to support lower aromatic fuels for lower exhaust emissions. In addition to matching vehicle technologies with the standards, aromatic levels for each of the Categories have been rationalized recognizing regulations and market conditions.

COMMENT: Benzene content should be limited to around 1% max by volume, as has been done in the EU.

RESPONSE: Benzene content is limited to a maximum of 1% by volume for Categories 3 and 4.

COMMENT: Categories 3 and 4 state the maximum limit for unwashed gum is 30 mg/100 ml. Recently introduced 100 octane gasoline fuels have higher levels of unwashed gum because of their high performance additivation. Is it intended to discriminate these fuels from WWFC Categories 3 and 4?

RESPONSE: High unwashed gums have been shown to correlate to high levels of combustion chamber deposits (CCD). Recognizing some detergent additives result in high unwashed gums without affecting CCDs, footnote 6 for Categories 3 and 4 allows compliance with the unwashed gum limit <u>or</u> any of the combustion chamber deposit tests specified.

COMMENT: The technical discussion on sulphur should include additional points: Reduced fuel sulphur levels make vehicles cleaner, reducing emissions of CO, HC, and NOx from gasoline vehicles and PM emissions from diesel vehicles – with and without emissions control technology. Fuel sulphur reduces conversion efficiency in three-way catalysts and contributes to catalyst aging. Sulphur inhibition in catalysts is not completely reversible.

RESPONSE: The Committee agrees and highlights these facts in the Technical Background sections of the Charter.

COMMENT: The improvement in HC reduction from 100 ppm to low sulphur fuel is highlighted. Keeping Category 1 markets in mind, HC reductions are continuous from around 1000 ppm sulphur.

RESPONSE: The Committee agrees that lower sulfur fuels have a positive effect on all vehicle technologies. In addition to matching vehicle technologies with the standards, sulfur levels for each of the Categories have been rationalized recognizing regulations and market conditions.

COMMENT: Lead removal in gasoline is first and foremost a human health issue, and then a technology-enabling issue. Unleaded gasoline is a prerequisite to the useful introduction of catalysts in vehicles, not the other way around.

RESPONSE: The Committee agrees that the removal of lead from fuels worldwide is an important endeavor. The primary purpose of the Charter is to define fuel specifications as required by vehicle technologies.

COMMENT: The recommendation against use of MMT® should be removed because it is not technically defensible and credible. MMT® has been reviewed repeatedly by regulatory and independent technical authorities who have consistently found no harm with its use.

RESPONSE: The Committee disagrees. Previous studies as well as the 2002 study conducted by the Alliance and the AIAM prove the detrimental effects of MMT® on vehicles. Charter members continue to believe any potential benefits from the use of MMT® are outweighed by its known disadvantages.

COMMENT: Possible impact of MMT® on human health, environment, in addition to vehicles and vehicle emissions, is not even mentioned. When debating whether or not to allow the use of MMT®, it should be noted that countries consider all factors, not just vehicle requirements. Consider revising statement to "Many countries have been debating whether to allow the use of this gasoline additive while the *real-world evidence of adverse impacts on human health, the environment, vehicles and vehicle emissions*, continues to grow".

RESPONSE: All fuels should be metal free for optimum vehicle performance. Comments on health and environmental impacts are outside the scope of the Charter.

COMMENT: What is meant by the sentence "higher alcohols (C > 2) are limited to 0.1% maximum by volume" when EN228 and Fuel Quality Directive provides "IPA and IBA = 10% and TBA = 7%".

RESPONSE: The Charter represents recommendations for a global market, and as such, its specifications will differ in some regards from standards specific for any particular country or location. In this case, C3 and higher alcohols are limited to 0.1% maximum.

COMMENT: Given the demonstrated problems of groundwater contamination with ethers such as MTBE, it is recommended that the statements indicating that ethers are preferred over alcohols as gasoline oxygenates should be removed.

RESPONSE: The primary purpose of the Charter is to define fuel specifications as required by vehicle technologies. These statements are related to vehicle performance response differences between ethers and alcohols. Other environmental aspects of fuel blending components are left to local regulations. Comments on health and environmental impacts are outside the scope of the Charter.

COMMENT: The oxygenate paragraph contains little information about requirements and consequences of ethanol blending. Further, there is no information about the flexible fuel option (E-85). Recommend adding a paragraph to summarize these issues, for example, adaptations required to assure drivability, material compatibility, miscibility limits of ethanol blends depending on temperature and water content, etc.

RESPONSE: The Committee agrees that careful handling and blending practices are required when utilizing ethanol as a blending component. In general, the Charter provides recommended properties for the finished fuel as supplied to the end user, leaves blending practices up to the fuel marketer/producer and assumes adherence to the best operating practices. The Committee will consider addressing fuels for alternative fueled vehicles in the future.

COMMENT: When weighing the cost/benefits of ethanol-blended fuels compared to MTBE, a more balanced analysis would take into account more of ethanol's benefits.

RESPONSE: The primary purpose of the Charter is to define fuel specifications as required by vehicle technologies. Other issues are outside the scope of the Charter.

COMMENT: WWFC features the DI (driveability index). Should that be interpreted as manufacturers are committed to propose/obtain such a new specification for petrol?

RESPONSE: Yes, the Committee believes DI is a necessary petrol specification. The Distillation Index relates to driveability and emissions performance, and the Charter reflects these requirements for acceptable vehicle performance.

COMMENT: The Distillation Index equation and driveability discussion are out-of-date and need to be updated to reflect the recent cold-start and warm-up findings for ethanol blends published in CRC Report No. 638 and in SAE Paper 2005-01-3864.

RESPONSE: The Committee believes the DI equation defined by the Charter best represents the population of vehicles in the market at this time.

Comments Related Specifically to Diesel Specifications

COMMENT: The Charter does not need to specify limits for both cetane number and cetane index. Also, the cetane index requirement is unnecessarily high and would be extremely difficult, if not impossible, to achieve.

RESPONSE: The Committee believes that both cetane number and cetane index limits are necessary for adequate engine and vehicle performance. Cetane improvers that yield greater than 3 cetane numbers should be avoided to assure proper ignition performance.

COMMENT: The non-detectable limit for metal content is not practical. Some OEMs use metal-based additives to help regenerate particulate filters. Also, there is always the risk of contamination by very small amounts (< 1 ppm w/w) of metals from the distribution chain or from the vehicle itself.

RESPONSE: The Charter does not address specialty fuels, such as those using metallic additives to regenerate particulate filters. Further, the Charter defines requirements for fuels as delivered to the customer or vehicle. Any metals or contaminants introduced by engine or vehicle components are accounted for in the design of the engine and vehicle.

COMMENT: Work on particulate contamination and size distribution is underway in CEN TC 19 WG31 and WG24. The Committee should wait for the outcome before finalizing this edition.

RESPONSE: The Charter represents the best available knowledge of this parameter at this time. Newer industry standards will be included when complete and deemed adequate.

COMMENT: The induction time method (EN 14112) is basically designed to evaluate the oxidation stability of FAME. The application of this method to diesel fuels, and its significance should be reviewed. Also, the reduction in oxidation stability by diesel desulphurization and FAME blending is evident and has to be controlled by effective means.

RESPONSE: The Committee has substituted a placeholder for this test, pending the development of an acceptable replacement. Additional unresolved concerns with ultra low sulfur fuels (<10 ppm S) also need to be investigated.

COMMENT: With the addition of a second oxidation stability test method for diesel fuel, it is not clear if both have to be run or only one has to be passed.

RESPONSE: The Committee believes both methods provide value. When revisions to the second test are complete and deemed acceptable, and the Committee adopts limits for this method, the Committee will expect both oxidation stability tests to be run and passed. The Committee also expects the industry to further develop data on these methods to inform future specifications.

COMMENT: The transitional limit of 3,000 ppm sulphur seems like an arbitrary level. Why is 3,000 preferable to 4,000 or even 5,000 ppm?

RESPONSE: Lower levels of sulphur lead to longer engine oil and exhaust system life. In addition to matching vehicle technologies with the standards, sulfur levels for each of the Categories have been rationalized recognizing regulations and market conditions. 3000 ppm sulphur from the previous edition is referenced for transitional purposes.

COMMENT: The figure demonstrating the effect of sulphur on engine life can be more fully interpreted in the text. Also, more in-depth analysis should be added regarding the effects of reducing fuel sulphur levels on the reduction of particulate matter (PM) emissions and diesel after-treatment technologies.

RESPONSE: While additional explanation and analysis could be incorporated for many of the parameters, the document includes the best available references to perform this task and help keep the text concise.

COMMENT: The Category 4 footnote on ash content states the "limit and test methods are under review to assure DPF endurance". Specifications should not be set until this work is satisfactorily completed.

RESPONSE: The Charter represents the best available knowledge of this parameter at this time. With DPF technology entering some markets now, the Committee believed it was necessary to provide better limits for this new technology. Newer industry standards will be included when complete and deemed adequate.

COMMENT: It is not correct to establish an ash content limit of 0.001% using ASTM D482 because according to ISO 4259 … "- for a single limit (A_1 or A_2), the specified limit shall be not less than twice the reproducibility R, i.e. $A_1 \geq 2R$ or $A_2 \geq 2R$". Considering that R is 0.005%, it is not possible to specify a limit of less than 0.01%.

RESPONSE: Detection limits are based on lower limit of the applicability range. A new chart defining current detectability limits has been added. We expect further work on ash content test procedures due to the importance of this parameter on component service life.

COMMENT: Ash formation also contributes to injector nozzle coking.

RESPONSE: The Technical Background has been updated with this information.

COMMENT: The recommendation against use of ash-forming additives in all categories of diesel fuel should be removed because it lacks a sound scientific basis. Ash-forming additives have been shown through vehicle testing and years of consumer experience to improve combustion and thereby reduce visible smoke and particulate matter emissions from diesel-fueled vehicles.

RESPONSE: Similar after-treatment technologies are being used on diesel engines as with gasoline fueled engines, and therefore, all fuels should be metal free for optimum engine and vehicle performance.

COMMENT: The Charter should allow biodiesel in Category 4 diesel fuel. Not allowing it in Category 4 fuels will limit the fuel supply.

RESPONSE: There are still some unresolved technical concerns with the use of FAME as a diesel fuel blending component in vehicles with sophisticated after-treatment technologies, and therefore, it is not included in Category 4 fuels at this time. The Committee reviews this position continually as new information becomes available.

COMMENT: “Biodiesel” should be substituted for the acronyms FAME and FAEE, and no limit should be established.

RESPONSE: FAME and FAEE are consistent with industry nomenclature and are the terms the Committee believes are most clear. The Committee also believes that the level of FAME in diesel fuel should not exceed the specification limits for the associated categories for acceptable vehicle performance.

COMMENT: 20% biodiesel should be allowed in all diesel fuel categories.

RESPONSE: There are several unresolved technical concerns with the use of FAME in amounts greater than 5% and with the most advanced emission control technologies. The Charter, therefore, limits FAME content to this upper limit in Categories 1, 2 and 3.

COMMENT: The Charter should include a comment that second generation biodiesel fuels are being developed that may be acceptable if the resulting blend meets the WWFC diesel specifications.

RESPONSE: The Committee agrees that fuels conforming to all requirements defined by the Charter are acceptable, regardless of whether they are synthesized from renewable sources or derived from petroleum.

COMMENT: Biodiesel used for producing biodiesel blends should be allowed to meet either the U.S. (ASTM) or the European standards since the European specification contains certain provisions specific to European feedstocks.

RESPONSE: The current ASTM or the European biodiesel specifications alone are not sufficient to assure a quality product. In general, the Charter provides recommended properties for the finished fuel as supplied to the end user.

COMMENT: Footnotes regarding FAME quality for blending insufficiently describe vehicle requirements. To guarantee stable fuels, it is necessary to refer to EN 14214 or other standards with equivalent or higher quality requirements, only. FAME complying with standards that have no or insufficient oxidation stability requirements do not ensure safe vehicle operation, even if FAME is used as a blending component only.

RESPONSE: The Charter requires both EN 14214 and ASTM D6751, or equivalent standards, to be considered as meeting minimum vehicle needs. The Committee reviews this position continually, as new information becomes available.

COMMENT: Propose adding an explanatory phrase about biodiesel: "Transitioning from conventional diesel fuel to biodiesel blends may lead to an especially large increase in sediments *due to removal of existent deposits by higher fuel polarity* that may plug fuel filters."

RESPONSE: Technical Background has been updated with this information.

COMMENT: Recommend not specifying a limit for the ethanol/methanol content in diesel, considering that some diesel engine and vehicle manufacturers accept or even recommend adding up to 2% by volume ethanol as an anti-icing additive.

RESPONSE: The Committee does not agree with the addition of ethanol or methanol to diesel fuel because of concerns about safety and performance, among other issues. While some individual manufacturers may allow its use, the Charter's recommendations represent the joint position of Committee members applicable to all manufacturers.

COMMENT: The last paragraph relating to lubricity states that a "pump test rig method is under development to complement HFRR". This test method was no longer being pursued.

RESPONSE: Since this work has been suspended, these references have been removed.