



PROPOSED

WORLD-WIDE FUEL CHARTER

JANUARY 2000

Comments due: February 10, 2000

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Alliance of
Automobile Manufacturers



ACEA

European Automobile
Manufacturers Association



Engine Manufacturers
Association



Japan Automobile
Manufacturers Association

January 2000

Dear World-wide Fuel Charter recipient:

Subject: **World-Wide Fuels Harmonisation**

Automotive manufacturers from around the world have determined that the need exists to update our World-wide Fuel Charter to address emerging requirements for more stringent vehicle emission control and reduced fuel consumption. These new requirements are now being planned and implemented in regions of Asia, Europe and North America. Automotive manufacturers have reviewed existing data and concluded that additional substantial reductions in both gasoline and diesel fuel sulfur levels will be essential to enable future vehicle technologies to meet these new requirements.

Advanced technologies such as NO_x traps, particulate matter traps and direct injection engines will be used to meet future vehicle emissions and fuel efficiency goals. 'Lean NO_x' and 'NO_x adsorber' catalyst systems, used on lean burn gasoline or diesel fueled direct injection engines, are intolerant to sulfur. Compliance with emissions requirements over the full useful life of the vehicle will require sulfur free fuels (maximum in the range of 5 to 10 ppm). Additionally, sulfur free fuels are also necessary for conventional diesel engines as governments promulgate further controls for reducing particulate matter.

The attached revised World-wide Fuel Charter includes the addition of a new Category 4 that reflects the need for removing sulfur in gasoline and diesel fuel. We expect to revise other parameters in Category 4 as these needs are further defined. We intend this category to define which fuels are the cleanest burning fuels to minimize emissions from all vehicles on the road and to enable new vehicle technology.

We welcome your comments on these fuel specifications and will continue to work with you to implement these harmonised specifications for the benefit of our industry's customers and the environment.

World-wide Fuel Charter Committee

AAM member companies:

BMW Group, DaimlerChrysler Corporation, Fiat Auto S.p.A., Ford Motor Company, General Motors Corporation, Isuzu Motors America, Inc., Mazda North American Operations, Nissan North America, Inc., Toyota Motor North America, Inc., Volkswagen of America, Inc., Volvo Cars of North America, Inc.

ACEA member companies:

BMW AG, DAF Trucks NV, Fiat Auto SpA, Ford of Europe Inc., General Motors Europe AG, MAN Nutzfahrzeuge AG, DaimlerChrysler AG, Porsche AG, PSA Peugeot-Citroën, Renault SA, Scania AB, Volkswagen AG, AB Volvo.

EMA member companies:

Briggs & Stratton Corporation, Caterpillar Inc., Cummins Engine Company, DaimlerChrysler AG, Deere & Company, Detroit Diesel Corporation, Deutz Corporation, Ford Motor Company, General Electric Company, General Motors Corporation, Hino Motors Ltd., Isuzu Motors America Inc., Kohler Company, Komatsu Ltd., Kubota Tractor Corporation, Mack Trucks Inc., MerCruiser, Mitsubishi Engine North America Inc., Mitsubishi Motors America Inc., Navistar International Transportation Corporation, New Holland North America, Inc., Onan Corporation, Robin America, Inc., Scania CV AB, Tecumseh Products Company, Volkswagen of America, Inc., Volvo Truck Corporation, Waukesha Engine Division, Yamaha Motor Corporation, Yanmar Diesel America Corporation

JAMA member companies:

Daihatsu Motor Co. Ltd., Fuji Heavy Industries Ltd., Hino Motors Ltd., Honda Motor Co. Ltd., Isuzu Motors Limited, Kawasaki Heavy Industries Ltd., Mazda Motor Corporation, Mitsubishi Motors Corporation, Nissan Diesel Motor Co. Ltd., Nissan Motor Co. Ltd., Suzuki Motor Corporation, Toyota Motor Corporation, Yamaha Motor Co. Ltd.

Supporting organisations:

- Canadian Motor Vehicles Manufacturers' Association
- Chinese Association of Automotive Industry
- Korean Automobile Manufacturers Association
- National Association of Automobile Manufacturers of South Africa
- Asociacion Mexicana de la Industria Automotriz, A.C.

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AAM	Alliance of Automobile Manufacturers
AAMA	American Automobile Manufacturers Association (whose members were formerly Chrysler, Ford and GM until its dissolution on December 1, 1998)
ACEA	Association des Constructeurs Européens d'Automobiles (European automotive manufacturers association)
AIAM	Association of International Automobile Manufacturers
AMA	Accelerated Mileage Accumulation
AQIRP	Air Quality Improvement Research Programme (part of the US Auto Oil programme, 1989-1992)
ASTM	American Society for Testing and Materials
CCD	Combustion Chamber Deposits
CFPP	Cold Filter Plugging Point
CI	Cetane Index
CN	Cetane Number
CO	Carbon monoxide
CO₂	Carbon dioxide
CP	Cloud Point
CRC	Co-ordinating Research Council, US
DECSE	Diesel Emission Control – Sulfur Effects
DI	Driveability Index
EMA	Engine Manufacturers Association
EPA	Environmental Protection Agency (US)
EPEFE	European Programme on Emissions, Fuels and Engine Technology (part of the European Auto Oil I programme, 1993-1995)
FBP	Final Boiling Point
HC	Hydrocarbons
HFRR	High Frequency Reciprocating Rig
IVD	Intake Valve Deposits
JAMA	Japan Automobile Manufacturers Association
JARI	Japan Automobile Research Institute
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
NO_x	Oxides of nitrogen
OBD	On-Board Diagnostics
OFP	Ozone Forming Potential
Oxy	Oxygen
PAH	Polyaromatic hydrocarbons
PM	Particulate Matter
ppm	parts per million
RON	Research Octane Number
SULEV	Super-ultra-low Emission Vehicle
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, world-wide recommendations for 'quality fuels', taking into consideration customer requirements and vehicle emission technologies, which will in turn benefit our customers and all other affected parties.

Development of these common recommendations will ensure that automotive manufacturers provide consistent fuel quality advice, world-wide.

Implementation of the recommendations will:

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

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 minimal requirements for emission control; based primarily on fundamental vehicle/engine performance concerns.

Category 2:

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

For example, markets requiring US Tier 0 or Tier 1, EURO 1 and 2, or equivalent emission levels.

Category 3:

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

For example, markets requiring US California LEV, ULEV and EURO 3 and 4, or equivalent emission levels.

Category 4:

Markets with further advanced requirements for emission control, to enable sophisticated NO_x and particulate matter after-treatment technologies.

For example, markets requiring US California LEV-II, US EPA Tier 2, EURO 4 in conjunction with increased fuel efficiency constraints or equivalent emission levels.

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 industry is exploring advanced propulsion technologies world-wide. While Category 3 has been defined as those requirements needed by advanced technologies, as they exist today, Category 4 has been defined as a 'sulfur free' fuel to meet the needs of future vehicle technologies. Other parameters in Category 4 are expected to be revised in future editions, as the needs of future vehicle technologies become better known. In addition, the existing Categories will be reviewed and revised as appropriate to reflect changes in the vehicle markets and the petroleum refining industry.

Markets with no or minimal requirements for emission controls; based primarily on fundamental vehicle/engine performance concerns.

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	--
Sulfur content	% m/m		--	0.10 ⁽²⁾
Lead content	g/l		--	0.013 ⁽³⁾
Manganese content	g/l		--	⁽³⁾
Oxygen content	% m/m		--	2.7 ⁽⁴⁾
Aromatics	% v/v		--	50.0
Benzene content	% v/v		--	5.0
Volatility			See Following Tables, page 10	
Unwashed gums	mg/100 ml		--	70
Washed gums	mg/100 ml		--	5
Density	kg/m ³		715	780
Copper corrosion	merit		Class I	
Appearance			Clear and Bright	
Carburettor cleanliness	merit		8.0 ⁽⁵⁾	--
Fuel injector cleanliness	% flow loss		--	10 ⁽⁵⁾
Intake valve cleanliness I	merit		9.0 ⁽⁵⁾	--

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) Lower sulfur content preferred for catalyst-equipped vehicles. Limit of 0.10 %m/m may be referred to as 1000 ppm.

(3) No intentional addition.

(4) Where oxygenates are used, ethers are preferred. Where up to 10% of volume ethanol (meeting ASTM D 4806 and a pH of 7 - 9) is permitted by pre-existing regulations, the blended fuel must meet all other Category I requirements. Higher (C > 2) alcohols are limited to 0.1 % maximum by volume. Methanol is not permitted.

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

Variances for Leaded Gasoline, where legally permitted.

PROPERTIES	UNITS	LIMIT	
		Min.	Max.
Lead content, leaded gasoline	g/l	0.05 ⁽¹⁾	0.40 ⁽²⁾

Footnotes:

(1) Only necessary to protect older vehicles with soft valve seats.

(2) Lead content should be minimised where feasible.

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	--	
Sulfur content	% m/m	--		0.02 ⁽²⁾
Lead content	g/l			Non-detectable ⁽³⁾
Phosphorus content	g/l			Non-detectable ⁽³⁾
Manganese content	g/l			Non-detectable ⁽³⁾
Silicon	g/kg			Non-detectable ⁽³⁾
Oxygen content	% m/m	--		2.7 ⁽⁴⁾
Olefins content	% v/v	--		20.0
Aromatics content	% v/v	--		40.0
Benzene content	% v/v	--		2.5
Volatility				See Following Tables, page 11
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 I
Appearance				Clear and Bright
Fuel injector cleanliness	% flow loss	--		5
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	%			140
Method 2 (CEC-F-20-A-98)	mg/engine			3500

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): Limit of 0.02 %m/m commonly referred to as 200 ppm.

(3): At or below detection limit of test method used. No intentional addition.

(4): Where oxygenates are used, ethers are preferred. Where up to 10% of volume ethanol (meeting ASTM D 4806 and a pH of 7 - 9) is permitted by pre-existing regulations, the blended fuel must meet all other Category 2 requirements. Higher (C > 2) alcohols are limited to 0.1 % maximum by volume. Methanol is not permitted.

(5): Compliance with either the Unwashed Gum limit or the Combustion Chamber Deposits limit is permitted.

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	--	
Sulfur content	% m/m	--	0.003 ⁽²⁾	
Lead content	g/l			Non-detectable ⁽³⁾
Phosphorus content	g/l			Non-detectable ⁽³⁾
Manganese content	g/l			Non-detectable ⁽³⁾
Silicon	g/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 Following Tables, page 11
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 I
Appearance				Clear and Bright
Fuel injector cleanliness	% flow loss	--	5	
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	%		140	
Method 2 (CEC-F-20-A-98)	mg/engine	--	2500	

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): Limit of 0.003 %m/m commonly referred to as 30 ppm.

(3): At or below detection limit of test method used. No intentional addition.

(4): Where oxygenates are used, ethers are preferred. Where up to 10% by volume ethanol (meeting ASTM D 4806 and a pH of 7 - 9) is permitted by pre-existing regulations, the blended fuel must meet all other Category 3 requirements. Higher (C > 2) alcohols are limited to 0.1 % maximum by volume. Methanol is not permitted.

(5): Compliance with either the Unwashed Gum limit or the Combustion Chamber Deposits limit is permitted.

Markets with further advanced requirements for emission control, to enable sophisticated NO_x 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	--	
Sulfur content	% m/m	--		Sulfur Free ⁽²⁾
Lead content	g/l			Non-detectable ⁽³⁾
Phosphorus content	g/l			Non-detectable ⁽³⁾
Manganese content	g/l			Non-detectable ⁽³⁾
Silicon	g/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 Following Tables, page 11
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 I
Appearance				Clear and Bright
Fuel injector cleanliness	% flow loss	--		5
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	%			140
Method 2 (CEC-F-20-A-98)	mg/engine	--		2500

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): 5-10 ppm maximum based on available data on advanced technology vehicles. As more data becomes available, a more specific maximum will be defined.

(3): At or below detection limit of test method used. No intentional addition.

(4): Where oxygenates are used, ethers are preferred. Where up to 10% by volume ethanol (meeting ASTM D 4806 and a pH of 7 - 9) is permitted by pre-existing regulations, the blended fuel must meet all other Category 4 requirements. Higher (C > 2) alcohols are limited to 0.1 % maximum by volume. Methanol is not permitted.

(5): Compliance with either the Unwashed Gum limit or the Combustion Chamber Deposits limit is permitted.

CATEGORY 1

Class *	A	B	C	D	E
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

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

CATEGORY 2, 3 and 4

Class *	A	B	C	D	E
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

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

Examples of how these classes would align with current market classifications are provided below: (e.g. Class A would be appropriate for Japan Summer Fuel).

	Japan	Summer		Winter	
United States		'A'	'B'	'C'	'D'
Canada			'A'	'B'	'C'

Note:

D.I. (Driveability Index) = $(1.5 \times T10) + (3 \times T50) + T90 + (11 \times \text{oxy.wt}\%)$; Temperatures in degrees Celcius

For Category 3 and 4, oxygenate correction does not apply to ethers. Limited data on LEV/ULEV vehicles suggests 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 becomes available.

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.

PROPERTIES	UNITS	ISO	ASTM	JIS	Other
Research Octane Number	-	5164-90	D 2699-86	K 2280-96	
Motor Octane Number	-	5163-90	D 2700-86	K 2280-96	
Oxidation stability	minutes	7536-94	D 525-95	K 2287-96	
Sulfur content	% m/m	4260-87	D 2622-94	K 2541-96	
Lead content	g/l		D 3237-97	K 2255-95	EN 237-96
Phosphorus content	g/l		D3231-94		
Manganese content	g/l		D 3831-94		
Silicon	g/kg				ICP-AES (Reference in-house methods with detection limit = 1ppm)
Oxygen content	% m/m		D 4815-94		
Olefins content	% v/v	3837-93	D 1319-95a	K 2536-96	See footnote
Aromatics content	% v/v	3837-93	D 1319-95a	K 2536-96	See footnote
Benzene content	% v/v		D 4420-94	K 2536-96	EN 238-96
Vapour Pressure	kPa		D 5191-96	K 2258-87	
Distillation: T10/T50/T90, E70/E100/E180, End Point, residue		3405-88	D 86-97	K 2254-90	
Driveability Index					(1.5 x T10)+(3 x T50)+T90 + (11 x O2[wt%])
Vapour/liquid ratio (V/L)	°C		D5188-96		
Sediment	mg/l		D 5452-97		
Unwashed gums	mg/100 ml	6246-95	D 381-94	K 2261-92	May be replaced with CCD test
Washed gums	mg/100 ml	6246-95	D 381-94	K 2261-92	
Density	kg/m ³	3675-93 ° 12185 #	D 4052-96 #	K 2249-95	(Note: # =digital, ° =hydrometer)
Copper corrosion	merit	2160-85	D 130-94	K 2513-91	
Appearance					Visual inspection
Carburettor cleanliness	merit				CEC F-03-T-81
Fuel injector cleanliness	% flow loss		D 5598-95a		
Intake-valve sticking	pass/fail				CEC F-16-T-96
Intake valve cleanliness I	merit				CEC F-04-A-87
Intake valve cleanliness II	avg. mg/valve				
Method 1, 4 valve avg.					CEC F-05-A-93
Method 2, BMW test			D 5500-97		
Method 3, Ford 2.3L			D 6201-97		
Combustion chamber deposits					
Method 1	%		D 6201-97		
Method 2	mg/engine				CEC F-20- A-98

Footnote:

These methods for olefin and aromatic content are used in legal documents; more precise methods are available and may be used.

Markets with no or minimal requirements for emission controls;
based primarily on fundamental vehicle/engine performance concerns.

PROPERTIES	UNITS	LIMIT	
		Min.	Max.
Cetane Number ⁽¹⁾	-	48 ⁽²⁾	--
Cetane Index ⁽¹⁾	-	45 ⁽³⁾	--
Density @ 15°C	kg/m ³	820 ⁽⁴⁾	860
Viscosity @ 40°C	mm ² /s	2.0 ⁽⁵⁾	4.5
Sulfur content	% m/m	--	0.50 ⁽⁶⁾
T95	°C	--	370
Flash point	°C	55 ⁽⁷⁾	--
Carbon residue	% m/m	--	0.30
CFPP ⁽⁸⁾ 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	g/m ³	--	25
Copper corrosion	merit	--	Class I
Ash content	% m/m	--	0.01
Appearance		Clear and bright	
Lubricity (HFRR 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): Compliance with either cetane index or cetane number is allowed.

(2): The minimum limit can be relaxed to 45 when ambient temperatures are below -30°C.

(3): The minimum limit can be relaxed to 42 when ambient temperatures are below -30°C.

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

(5): 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.

(6): Limit of 0.50 %m/m may be referred to as 5000 ppm.

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

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

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

PROPERTIES	UNITS	LIMIT	
		Min.	Max.
Cetane Number	-	53 ⁽¹⁾	--
Cetane Index	-	50 ⁽²⁾	--
Density @ 15°C	kg/m ³	820 ⁽³⁾	850
Viscosity @ 40°C	mm ² /s	2.0 ⁽⁴⁾	4.0
Sulfur content	% m/m	--	0.030 ⁽⁵⁾
Total aromatics content	% m/m	--	25
Polyaromatics 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	g/m ³	--	25
Biological growth	-	'Zero' content	
Vegetable Derived Esters	% m/m	See Footnote ⁽⁸⁾	
Total acid number	mg KOH/g	--	0.08
Corrosion performance	-	--	Light rusting or less
Copper corrosion	merit	Class I	
Ash content	% m/m	--	0.01
Particulates	mg/l	--	24
Injector cleanliness	% air flow loss	--	85
Lubricity (HFRR 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): The minimum limit can be relaxed to 48 when ambient temperatures are below -30°C.

(2): The minimum limit can be relaxed to 45 when ambient temperatures are below -30°C.

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

For environmental purposes, a minimum of 815 kg/m³ can be adopted.

(4): 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.

(5): Limit of 0.030 %m/m commonly referred to as 300 ppm.

(6): Compliance either with T90 or T95 is required, not both.

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

(8): Up to 5% vegetable derived esters (VDE), conforming to DIN V51606 or equivalent standard, can be used where it is allowed under pre-existing regulations. Where VDE is used, it is recommended that fueling pumps are marked accordingly.

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

PROPERTIES	UNITS	LIMIT	
		Min.	Max.
Cetane Number	-	55 ⁽¹⁾	--
Cetane Index	-	52 ⁽²⁾	--
Density @ 15°C	kg/m ³	820 ⁽³⁾	840
Viscosity @ 40°C	mm ² /s	2.0 ⁽⁴⁾	4.0
Sulfur content	% m/m	--	0.003 ⁽⁵⁾
Total aromatics content	% m/m	--	15
Polyaromatics 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	g/m ³	--	25
Foam volume	ml	--	100
Foam vanishing time	sec.	--	15
Biological growth	-	'Zero' content	
Vegetable Derived Esters	% m/m	Non-detectable	
Total acid number	mg KOH/g	--	0.08
Corrosion performance	-	--	Light rusting or less
Copper corrosion	merit	Class I	
Ash content	% m/m	--	0.01
Particulates	mg/l	--	24
Injector cleanliness	% air flow loss	--	85
Lubricity (HFRR 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): The minimum limit can be relaxed to 50 when ambient temperatures are below -30°C.

(2): The minimum limit can be relaxed to 47 when ambient temperatures are below -30°C.

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

For environmental purposes, a minimum of 815 kg/m³ can be adopted.

(4): 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.

(5): Limit of 0.003 %m/m commonly referred to as 30 ppm.

(6): Compliance either with T90 or T95 is required, not both.

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

Markets with further advanced requirements for emission control, to enable sophisticated NO_x and PM aftertreatment technologies.

PROPERTIES	UNITS	LIMIT	
		Min.	Max.
Cetane Number	-	55 ⁽¹⁾	--
Cetane Index	-	52 ⁽²⁾	--
Density @ 15°C	kg/m ³	820 ⁽³⁾	840
Viscosity @ 40°C	mm ² /s	2.0 ⁽⁴⁾	4.0
Sulfur content	% m/m	--	Sulfur Free ⁽⁵⁾
Total aromatics content	% m/m	--	15
Polyaromatics 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	g/m ³	--	25
Foam volume	ml	--	100
Foam vanishing time	sec.	--	15
Biological growth	-		'Zero' content
Vegetable Derived Esters	% m/m		Non-detectable
Total acid number	mg KOH/g	--	0.08
Corrosion performance	-	--	Light rusting or less
Copper corrosion	merit		Class I
Ash content	% m/m	--	0.01
Particulates	mg/l	--	24
Injector cleanliness	% air flow loss	--	85
Lubricity (HFRR 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): The minimum limit can be relaxed to 50 when ambient temperatures are below -30°C.

(2): The minimum limit can be relaxed to 47 when ambient temperatures are below -30°C.

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

For environmental purposes, a minimum of 815 kg/m³ can be adopted.

(4): 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.

(5): 5-10 ppm maximum based on available data on advanced technology vehicles. As more data becomes available, a more specific maximum will be defined.

(6): Compliance either with T90 or T95 is required, not both.

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

PROPERTIES	UNITS	ISO	ASTM	JIS	Other
Cetane Number	-	5165-92	D 613-95	K 2280-96	
Cetane Index	-	4264-95	D 4737-96	K 2280-96	
Density @ 15°C	kg/m ³	3675-93 °	D 4052-96 #	K 2249-95	ISO 12185 # (Note: # =digital, ° = hydrometer)
Viscosity @ 40°C	mm ² /s	3104-94	D 445-95	K 2283-93	
Sulfur content	% m/m	4260-87	D 2622-94	K 2541-96	
Total aromatics content	% m/m		D 5186-96		EN 12916
Polyaromatics content (di+tri+)	% m/m		D 2425-93		EN 12916
T90, T95, FBP	°C	3405-88	D 86-96	K 2254-90	
Flash point	°C	2719-88	D 93-96	K 2265-96	
Carbon residue	% m/m	10370-93	D 4530-93	K 2270-90	
Cold Filter Plugging Point (CFPP)	°C			K 2288-93	EN 116, IP 309
Low Temperature Flow Test (LTFT)	°C		D 4539-94		
Cloud Point (CP)	°C	3015-92	D 2500	K 2269-87	
Water content	mg/kg	DIS 12937	D 1744-91	K 2275-96	
Oxidation stability	g/m ³	12205-95	D 2274-94		
Foam volume	ml				NFM 07-075
Foam vanishing time	sec.				NFM 07-075
Biological growth	-				NF M 07 070-93
Vegetable Derived Esters	% m/m				NFT 60-703
Total acid number	mg KOH/g		D 974-97		NFT 60 112-86
Corrosion performance	-		D 665-95		
Copper corrosion	merit	2160-85	D 130-94	K 2513-91	
Ash content	% m/m	6245-93	D 482-95	K 2272-85	
Particulates	mg/l		D 2276-97		DIN 51419 / pr EN 12662
Injector cleanliness	% air flow loss				CEC (PF-023) TBA/Cummins L10
Lubricity (HFRR wear scar diameter @ 60°C)	micron	12156-1.3	D 6079-97		CEC F-06-A-96
Lubricity - pump test					Pump test under development

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 and power will suffer and at very low octane levels, knock may still occur. Using gasoline with an octane rating higher than that required will 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.

SULFUR

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

There has been extensive testing done on the impact of sulfur on vehicle emissions. The following studies (Figure 1) indicate the emission reductions that occur with different vehicle technologies as sulfur is reduced from the ‘high’ sulfur gasoline to the ‘low’:

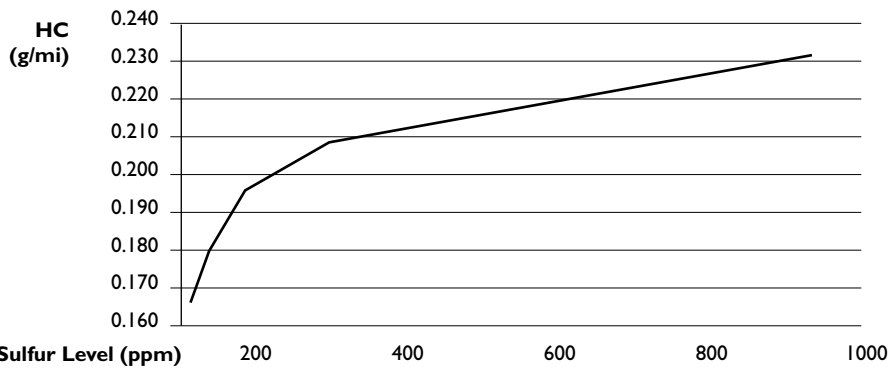
(* Reduction achieved during hot EUDC (extra-urban) portion of test.)

Figure 1:

Study	Vehicle Technology	Sulfur Range (ppm)		Emission Reduction, % (high to low sulfur)		
		high	low	HC	CO	NO _x
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

This Figure (Figure 2) depicting the HC reductions from the US AQIRP study indicates the typical emission reduction for the different studies as the sulfur level changes, including the significant reduction when sulfur is reduced from about 100 ppm to the 'Low' sulfur fuel. This suggests the importance of a very low sulfur limit for advanced technology vehicles.

Figure 2: Sulfur Effects on Tier 0 Technology



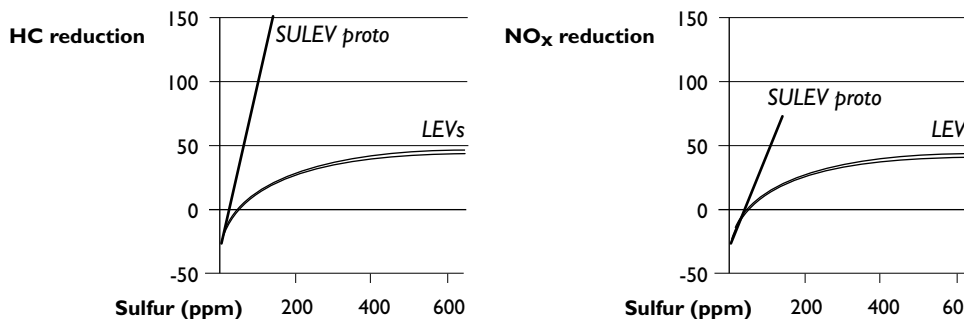
In addition, laboratory research of catalysts has demonstrated delays in light-off time, increases in light-off temperature and reductions in efficiency resulting from higher sulfur fuels across a full range of air/fuel ratios. Studies have also demonstrated that sulfur slows the rich to lean transition, 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 (ie., excluding the start-up portion) must be 98% or better for 100,000 miles to ensure that emission limits are met. These standards represent significant technological hurdles, even in markets with high quality (Category 3) gasoline.

Figure 3 indicates the significant HC and NO_x reductions when lowering sulfur. Future technologies indicate an even higher sensitivity to sulfur.

Figure 3: Effects of Fuel Sulfur on Emissions



Sulfur 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 emission increase by 1.5 times the standard. There is concern that the loss of catalyst efficiency resulting from high sulfur 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 sulfur fuel.

Future Technology

Manufacturers are working toward ambitious goals for improved fuel consumption/reduced CO₂ 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 unburned HC and CO are effectively removed by existing catalysts during lean operation, NO_x is removed only during stoichiometric or rich operation.

Many manufacturers are developing and introducing lean-burn technology. These technologies have the potential to reduce fuel consumption by up to 15 to 20%, but require NO_x control technologies which can function under lean conditions. These technologies are very sensitive to fuel sulfur.

Figures 4 and 5 provide examples of the adverse effect of sulfur on lean NO_x adsorbers (or traps). With increased exposure time, the lower sulfur gasolines allow the catalysts to retain a higher NO_x conversion efficiency. Further tests in vehicles (Figures 6 and 7) confirm the critical need for very low sulfur gasolines. Sulfur free gasolines are required to achieve and maintain high NO_x conversion efficiencies.

Figure 4: Effect of Fuel Sulfur on NO_x Storage Reduction Catalyst

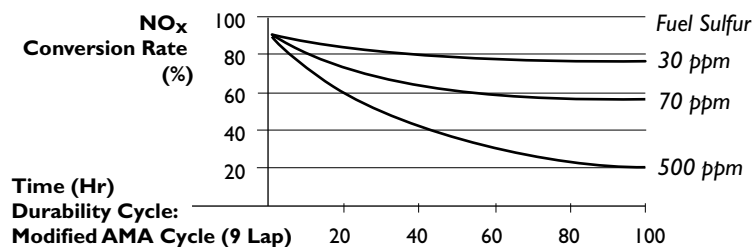


Figure 5: Effect of Fuel Sulfur on Lean NO_x Traps Flow Reactor Study

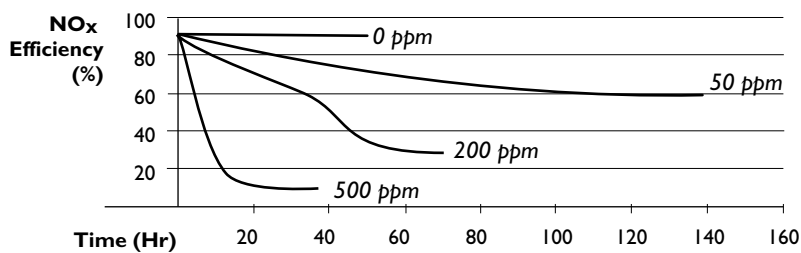


Figure 6: Influence of Sulfur Concentration in Gasoline on Vehicle Aftertreatment System Durability

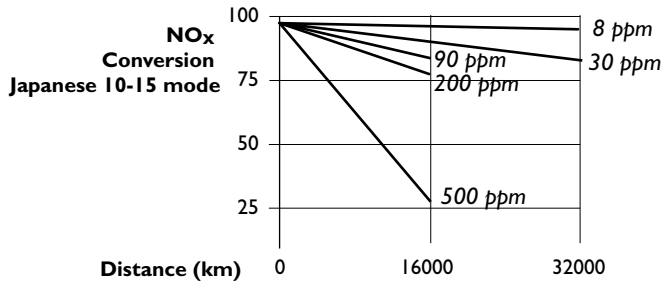
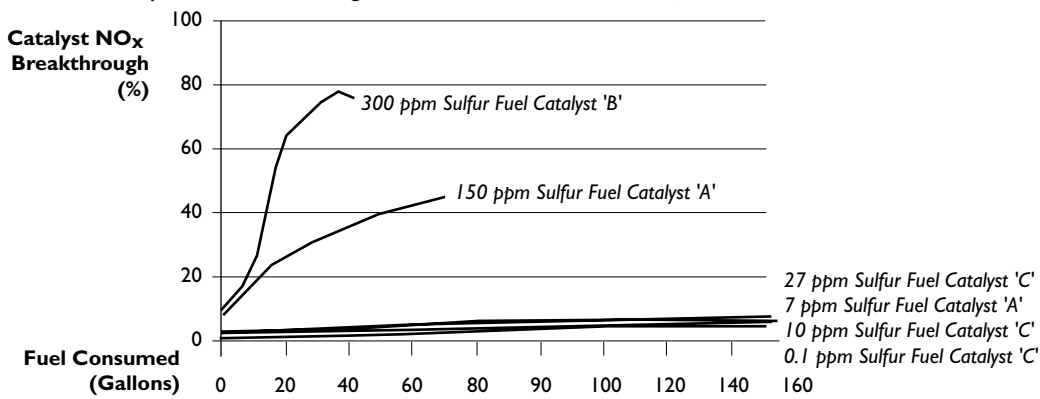
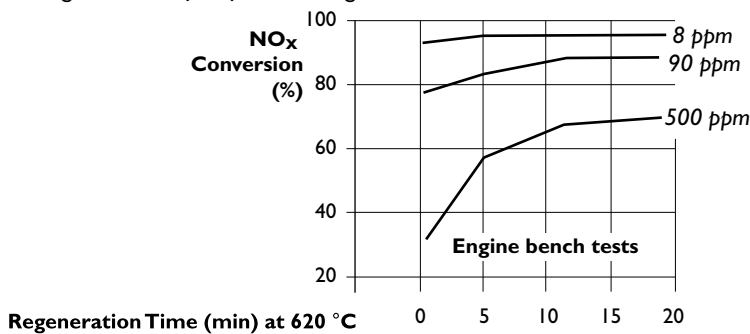


Figure 7: Lean NO_x Adsorber Catalyst Data – Catalyst NO_x Breakthrough vs Fuel Consumed & Fuel Sulfur Content



Over time, sulfur poisons the catalyst and reduces the NO_x conversion efficiency. Some of the lost NO_x conversion efficiency can be recovered by temporarily introducing a 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. Sulfur free gasolines, however, will maintain the necessary NO_x conversion efficiency (Figure 8). Sulfur free gasoline is therefore necessary to maximize the benefits of lean-burn, fuel-efficient technology.

Figure 8: Regeneration of Sulfur Poisoning



LEAD

Lead alkyl additives have been used historically as inexpensive octane enhancers for gasoline. Concerns over health effects associated with the use of this additive have resulted in many markets eliminating leaded gasoline. While the phase-out of leaded gasoline is supported, consideration must be given to the existing vehicle fleet as some older vehicles may require lead (or lead replacement additives) for engine protection. Low-lead gasoline at 0.05 g/l is supported in leaded gasoline markets. This reduces the risk of unleaded contamination and still provides adequate engine protection.

Unleaded gasoline is necessary to support vehicle emission control technologies such as catalytic converters and oxygen sensors. As vehicle catalyst efficiencies are increased, tolerance to lead contamination is very low, such that even slight lead contamination can destroy a modern catalyst. A lead-free market, therefore, is essential in the long term.

ASH-FORMING ADDITIVES

Today's vehicles employ sophisticated emission control equipment such as three-way catalysts and exhaust gas 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 (e.g., oxygen sensor) in an irreversible way that increases emissions. Thus, high-quality gasoline should be used and ash-forming additives should be avoided.

■ Manganese (MMT)

MMT (Methylcyclopentadienyl manganese tricarbonyl) is a manganese-based compound marketed as an octane-enhancing fuel additive for gasoline and combustion improver for diesel.

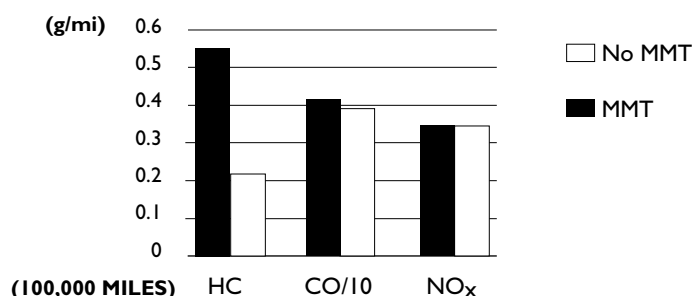
The use of this gasoline additive has been debated in many countries. In spite of its approval for use in non-reformulated gasolines in the US in 1995, it is marketed in very few, if any, gasolines. Several auto companies indicate in their Owner Guides that the use of fuels containing MMT is not recommended and any damage caused by MMT may not be covered by the warranty. A study is currently being conducted by AAMA/AIAM member companies to assess the effects of MMT on emissions control systems; a report of results is expected at a later date.

Effects of MMT:

Studies have shown that only a small percent of the MMT-derived manganese consumed in the fuel is emitted from the tailpipe -- the majority of the balance remaining within internal components of the vehicle (catalyst, engine parts, etc.).

- The combustion products of MMT coat internal engine devices such as spark plugs, causing a misfire condition that can lead to increased emissions and poor engine performance. These conditions lead to increased owner dissatisfaction and warranty expense by a manufacturer.
- The combustion products also accumulate on the catalyst. Once coated or plugged, the light-off performance and steady-state efficiency of the catalyst are degraded, and the ability of the catalyst to convert exhaust emissions is reduced (Figure 9). MMT always increases HC and sometimes increases CO exhaust emissions. NO_x is sometimes affected. Studies have also indicated that particulate emissions also may increase (SAE 920731).

Figure 9: Emission Effects of MMT 1991 Escort/Explorer Fleet



- When MMT combustion products are deposited on the surface of a catalyst, they may provide enough oxygen storage activity that the OBD catalyst monitor will interpret the unit as operating normally. This possible false reading by the OBD system could allow a failed catalyst to go unnoticed and not repaired while the vehicle emits higher emissions.

■ 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 catalysts and other exhaust system parts as iron oxide. Iron oxide acts as a physical barrier between the catalyst/oxygen sensor and the exhaust gases. As a result the emission control system is not able to function as designed and emission increase. Thus, ferrocene should be avoided in unleaded gasoline.

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 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, are often added to gasoline to increase octane, to extend gasoline supplies, or to induce a lean shift in engine stoichiometry to reduce carbon monoxide emissions. The leaner operation reduces carbon monoxide emissions, especially with carbureted vehicles without electronic feedback controlled fuel systems.

These emission benefits are not realised as much in modern electronic feedback controlled vehicles because the leaning effect only occurs during cold operation or during rapid accelerations. In fact, fuel leaning caused by oxygenates can degrade driveability depending on the leanness of the engine's base calibration with all-HC (ie., non-oxygenated) gasoline. This over-leaning can also cause emissions to increase. Because ethanol has a higher heat of vapourisation than ethers, some of the driveability degrad-

ation of gasoline oxygenated with ethanol can be attributed to the additional heat needed to vaporise the gasoline.

The California Air Resources Board (CARB) conducted emission tests on 14 1990-1995 vehicles using 2 gasolines with 10% ethanol and 11% MTBE. When the ethanol fuel was compared to the MTBE fuel, it decreased toxic emissions by 2% and CO by 10%, but it increased NO_x by 14%, total HC by 10% and Ozone Forming Potential by 9%.

Based on past experience with impurities in ethanol that have led to degradation of fuel systems, fuel ethanol must have a specification to control pH and its blending properties (ASTM D 4806). The limits and restriction on the oxygenates permitted in each Category were developed on the basis of emission benefits, vehicle performance and pre-existing regulations. Thus, when oxygenates are used, ethers are preferred.

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

OLEFINS

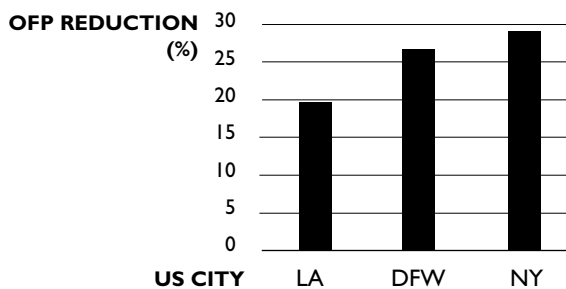
Olefins are unsaturated hydrocarbons and, in many cases, are also good octane components of gasoline. However, olefins in gasoline can lead to deposit formation and increased emissions of reactive (ie., ozone-forming) hydrocarbons and toxic compounds.

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 10).

Figure 10: 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 10. 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 CO₂.

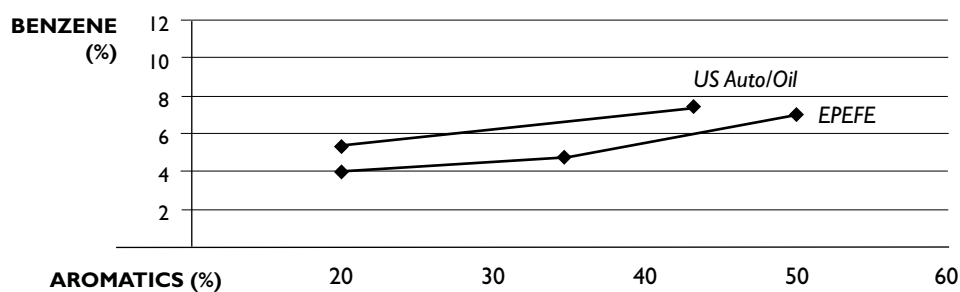
Influence of Aromatics on Engine Deposits

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 NO_x. 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 11)

Figure 11: 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 CO₂ Emissions

Gasoline aromatic content also has a direct effect on tailpipe CO₂ emissions. The European EPEFE programme demonstrated a linear relationship between CO₂ emissions and aromatic content. The reduction of aromatics from 50 to 20% was found to decrease CO₂ 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

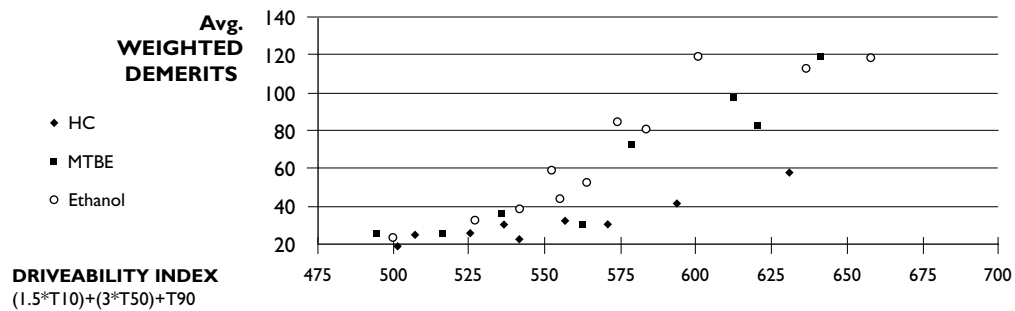
The vapour pressure of gasoline should be controlled seasonally to allow for the differing volatility needs of vehicles at different temperatures. The vapour pressure must be tightly controlled at high temperatures to reduce the possibility of hot fuel handling problems, such as vapour lock or carbon 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 Driveability Index (DI), derived from T10, T50, T90, and oxygen content can also be used to assure good cold start and warm-up performance.

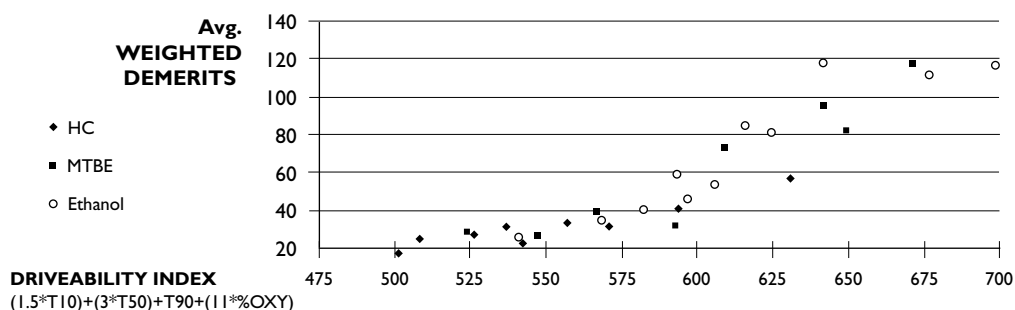
Driveability concerns are measured as demerits. Figure 12 provides the test results from a recent CRC study which tested 29 test fuels: 9 all hydrocarbon, 11 with 10% ethanol and 9 with 15% MTBE. The data indicate that driveability problems increase for all fuel types as DI increases. At DI levels higher than those specified in this Charter (550 - 570) driveability concerns increase dramatically.

Figure 12: Effect of DI on Driveability



An oxygen correction factor is required to correct for higher driveability demerits for oxygenated fuels as compared to all-HC gasoline. Figure 13 indicates how the correction factor smooths the data presented in Figure 12.

Figure 13: Effect of DI on Driveability (Oxygen Corrected)



The driveability index is also directly related to tailpipe HC emissions, as shown in Figure 14. As with driveability demerits, HC emissions increase significantly at DI levels higher than those specified in this Charter (550 - 570).

Figure 14: Effect of DI on Driveability and Exhaust Emissions

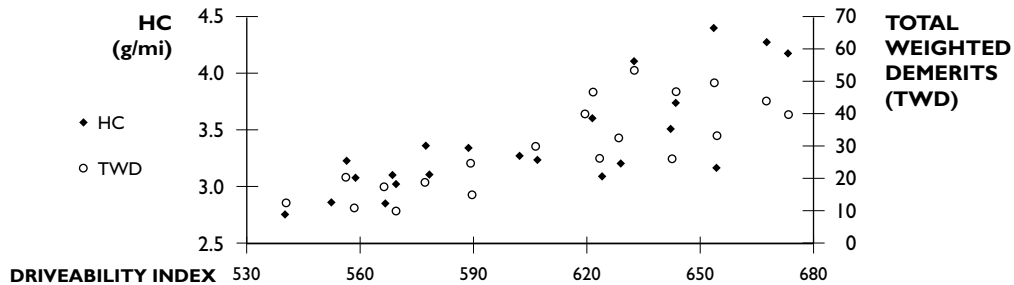
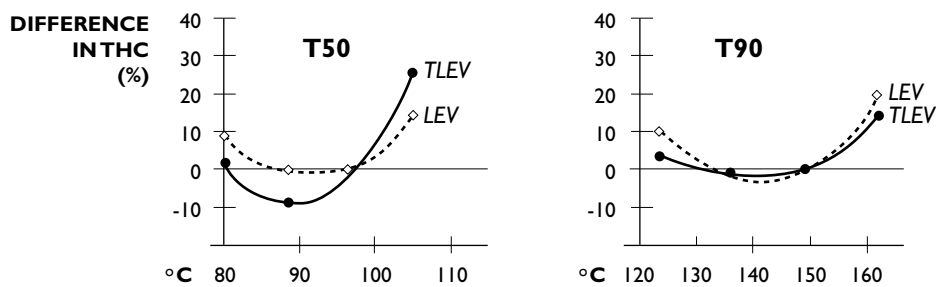


Figure 15 indicates that optimum values for T50 and T90 exist to achieve lower exhaust THC emissions.

Figure 15: Effect of T50/T90 on Exhaust Emissions Comparison of LEV and TLEV



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.

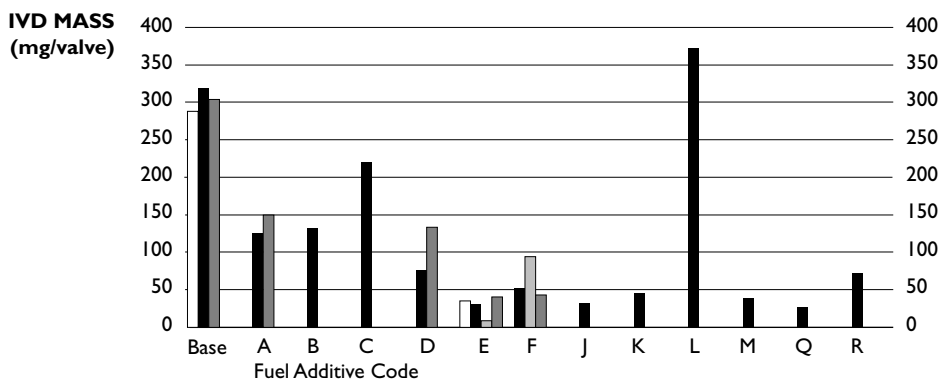
Port Fuel Injectors

Port fuel injector deposit control additives were introduced by US gasoline marketers 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 16 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 16: 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 13 and 14. 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 17: Engine Dynamometer Results

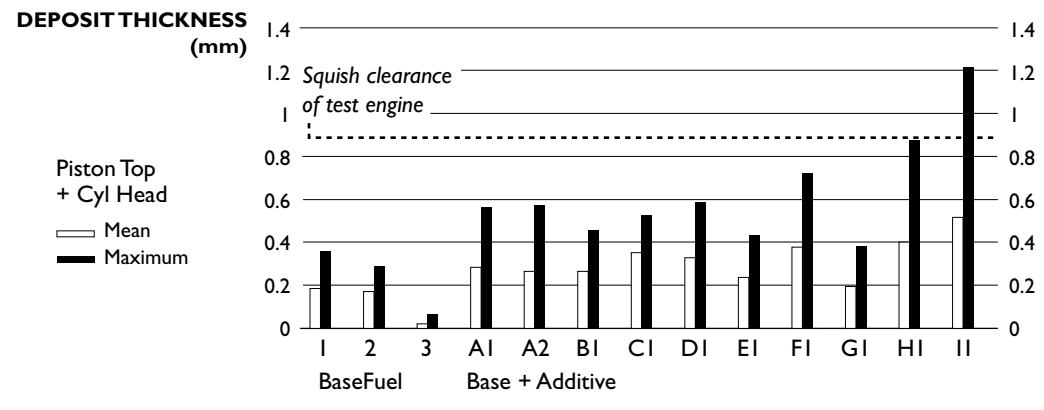
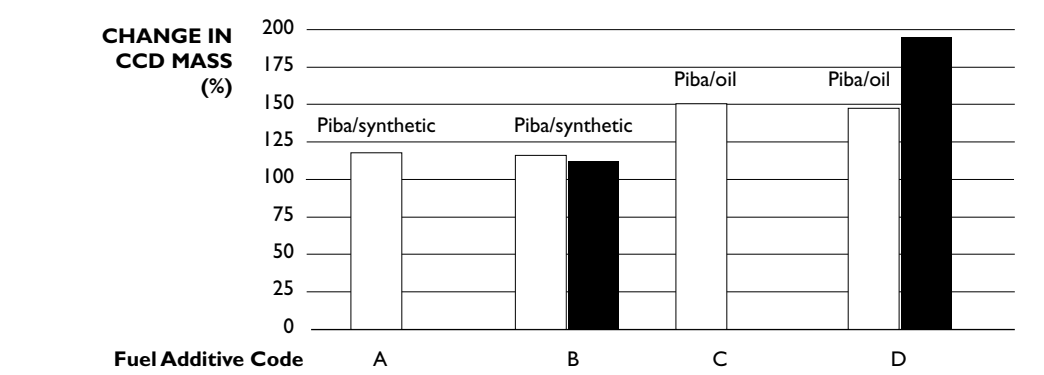


Figure 18: CCD Performance of Gasolines Ford 2.3L Dynamometer Test - Using ASTM D6201

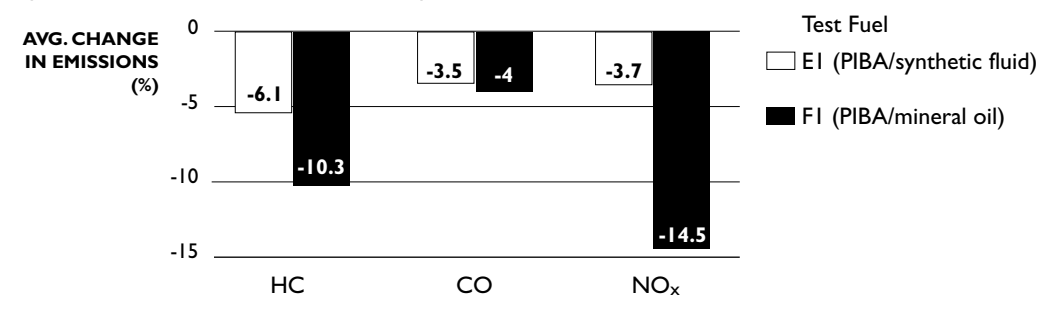


Note: Piba/Synthetic - polyisobutene amine/synthetic oil
 Piba/Oil - polyisobutene amine/mineral oil

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 NO_x by 15% as shown in Figure 19 for fleet vehicles after accumulating 50,000 miles.

Figure 19: Effect on CCD Removal on Engine-Out Emissions

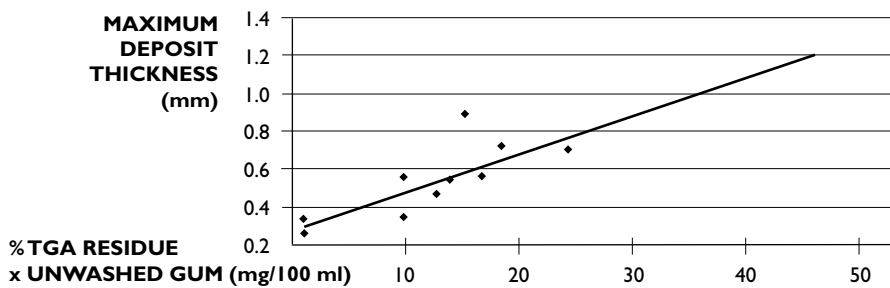


'Carbon Knock' in modern engines did not occur even at high mileages in Japan. When these same engines were sold in the US, customers began objecting to the engine noise after only a few thousand miles in some cases. Some customers required replacement of the cylinder heads because of the damage caused 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 20.

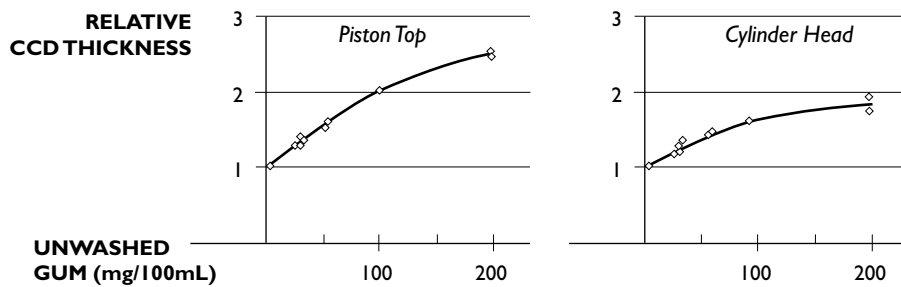
Figure 20: Relationship of CCDs to TGA Test



Relationship Between Unwashed Gum and CCD Thickness

Figure 21 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 21: 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.

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 is the 'natural' cetane of the fuel which is calculated based on measured fuel properties. 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 additivised cetane levels. Therefore, to avoid excessive additive dosage, a minimum difference between cetane index and cetane number must be maintained.

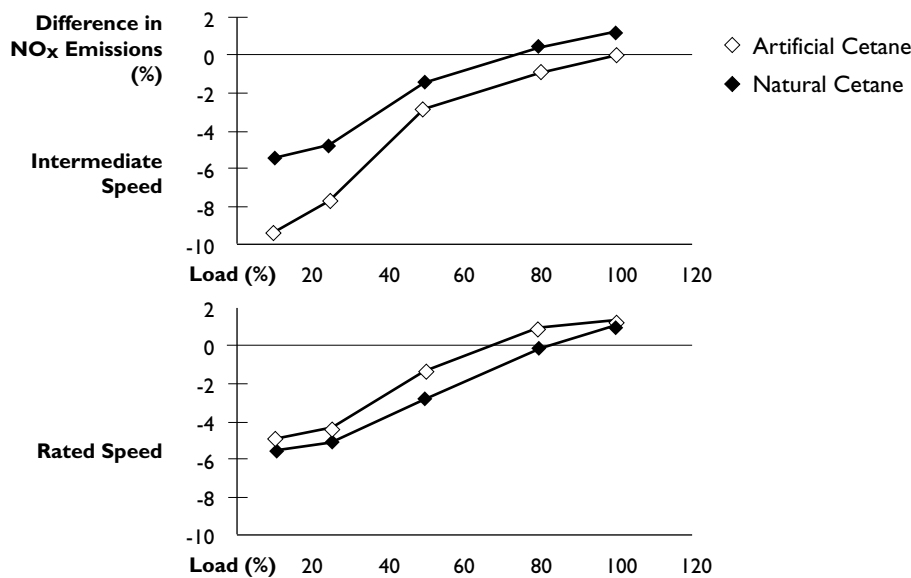
Influence of Cetane on Cold Startability

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 NO_x 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 NO_x (Figure 1), particularly at low loads, where reductions of up to 9% are achieved. (Note that each point in the graph below shows the NO_x reduction achieved for cetane increase at a given load.) The cetane increase also demonstrated a 30-40% reduction in HC emissions.

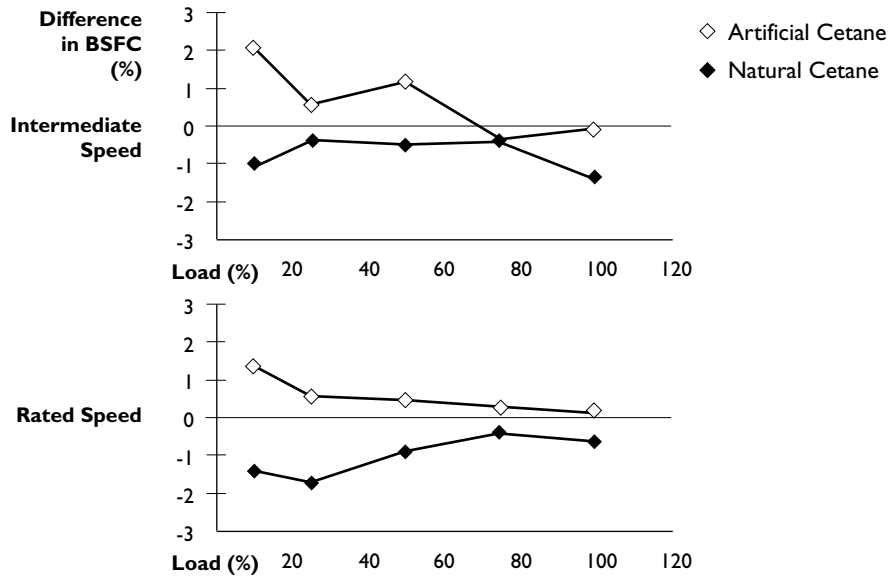
Figure 1: Effect of Cetane on NO_x Emissions 50 to 58 CN



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.

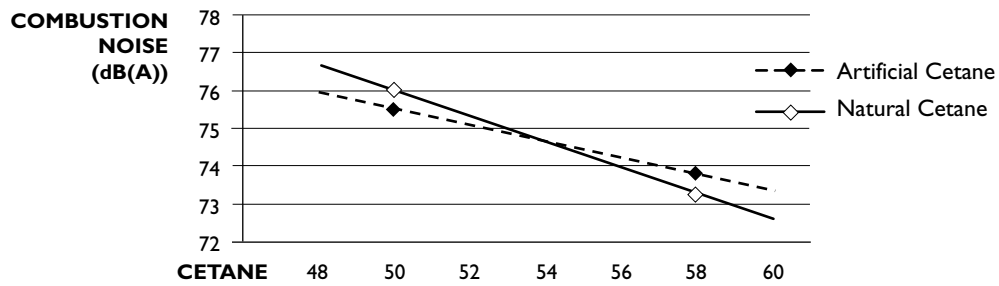
Figure 2: Effect of Cetane on Fuel Consumption 50 to 58 CN



Cetane Influence on Combustion Noise

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

Figure 3: Effect of Cetane on Engine Noise 50 to 58 CN



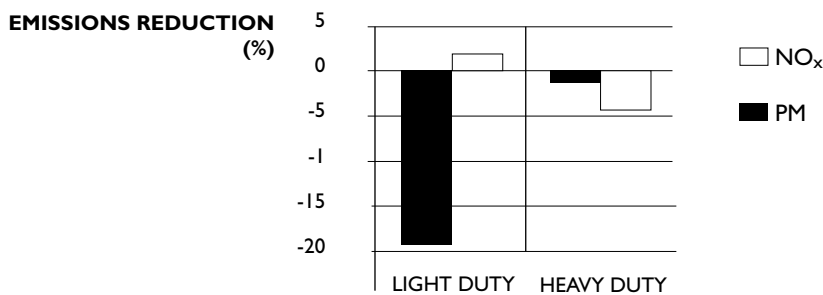
DENSITY and VISCOSITY

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

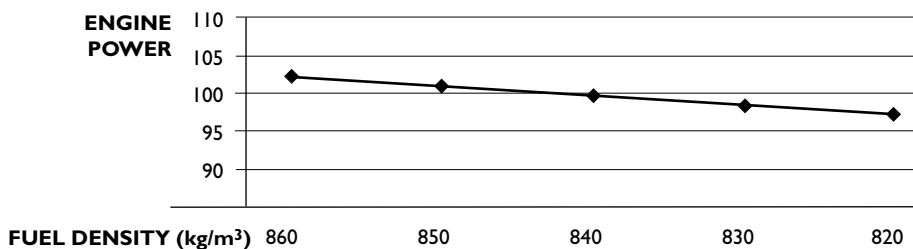
Emissions testing has demonstrated that reduced density will reduce PM emission from all diesel vehicles, and NO_x emissions from heavy duty vehicles (Figure 4).

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 (ie., 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 CO₂ 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.

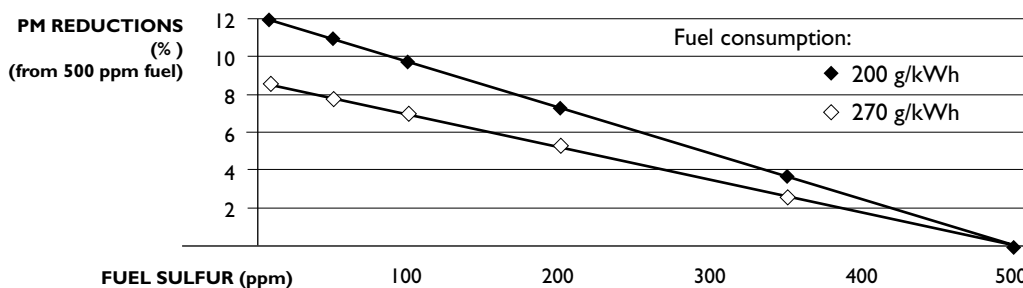
SULFUR

Sulfur naturally occurs in crude oil. If the sulfur is not removed during the refining process it will contaminate vehicle fuel. Diesel fuel sulfur contributes significantly to fine particulate matter (PM) emissions, through the formation of sulfates both in the exhaust stream and, later in the atmosphere. Sulfur can lead to corrosion and wear of engine systems. Furthermore the efficiency of some exhaust after-treatment systems is reduced as fuel sulfur content increases, while others are rendered permanently ineffective through sulfur poisoning.

Effect of Sulfur on PM Emissions

The impact of sulfur 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 will 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 nor the fuel consumption. A correction factor has been developed by European heavy duty manufacturers to better reflect the relationship between PM emissions and fuel sulfur levels. This correction suggests that the real benefit from sulfur reductions will be more significant, as shown here (Figure 6) for heavy duty trucks. Reductions in fuel sulfur will also provide particulate emission reductions in all engines, regardless of emission calibration.

Figure 6: 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 sulfur fuel were about double the emissions when operating on 2 ppm fuel. (JSAE 9831171)

Fuel Sulfur Contribution to Particulate Matter

The sulfur in fuel is oxidized during combustion to form SO₂, which is the primary sulfur compound emitted from the engine. Some of the SO₂ is further oxidized to sulfate (SO₄). The sulfate and associated water coalesce around the carbon core of the particulate. This increases the mass of the PM and thus fuel sulfur has a significant influence on the PM.

Typically the conversion rate from sulfur to sulfate is around 1% and the sulfate 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 SO₂ will be oxidized to SO₄, 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 Sulfur Contribution to PM

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

- The fuel consumption of the engine
- The fuel sulfur content
- The S to SO₄ conversion rate

Both the fuel sulfur 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 sulfur on PM:

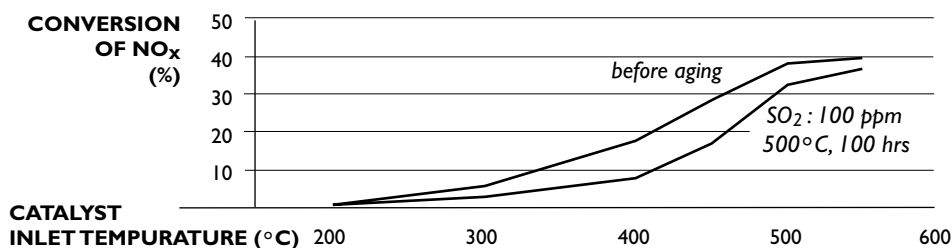
$$SO_4 = BSFC * FSC/100 * CR/100 * 7$$

- where BSFC = brake specific fuel consumption in g/kWh
- FSC = fuel sulfur content in % mass
- CR = S to SO₄
- 7 = S to (SO + water) weight increase factor

Effect of Sulfur on Diesel Aftertreatment

Future regulations will require lower NO_x and particulate emissions in combination with lower fuel consumption and CO₂ emissions. De-NO_x catalyst systems, which can remove NO_x emissions from the diesel's oxygen-rich exhaust, could be the solution to break the trade-off between NO_x, PM and fuel consumption. However, as shown in Figure 7, these systems are very sensitive to fuel sulfur content. The level of sulfur in diesel fuel (and gasoline) is an important factor in the performance of De-NO_x catalyst systems. The catalyst performance is always better with sulfur free fuel.

Figure 7: Influence of Sulfur Dioxide Aging on NO_x Conversion



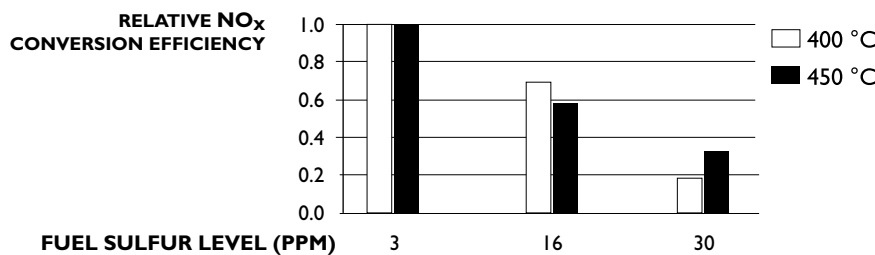
Other technologies under development include NO_x adsorber catalysts, Continuously Regenerating Diesel Particulate Filters (CR-DPF) and Catalyzed Diesel Particulate Filters (CDPF). The recent collaborative program between the US Department of Energy (DOE), Engine Manufacturers Association (EMA) and Manufacturers of Emission Control Devices (MECA) studied the impact of diesel fuel sulfur levels of 3, 16, 30, 150 and 350 ppm on a number of these technologies on both heavy and light duty engines.

NO_x Adsorber

NO_x adsorbers, are poisoned and rendered ineffective by the presence of sulfur. These devices can be up to 90% efficient in NO_x removal if operated on sulfur-free fuel. The concern with fuel sulfur is that SO₂ is formed during combustion and released in the exhaust. In a NO_x adsorber catalyst, this SO₂ undergoes reactions that are similar to those of NO_x. However, SO₂ generates a stronger adsorbate (SO₃) when compared with NO₂. As a result, SO₂ is a poison for the NO_x adsorption sites.

The effect of fuel sulfur content on NO_x adsorber conversion efficiency is shown in Figure 8 below. The figure illustrates the effect of fuel sulfur on relative NO_x conversion efficiencies. Compared to 3 ppm sulfur fuel both 16 and 30 ppm sulfur fuels resulted in a significant decline in performance.

Figure 8: Effect of Fuel Sulfur Level on NO_x Conversion Efficiency (150 hours aging)



Engine tested: 1.9 litre, High Speed Direct Injection, Common Rail, 81 kW

Particulate Filters

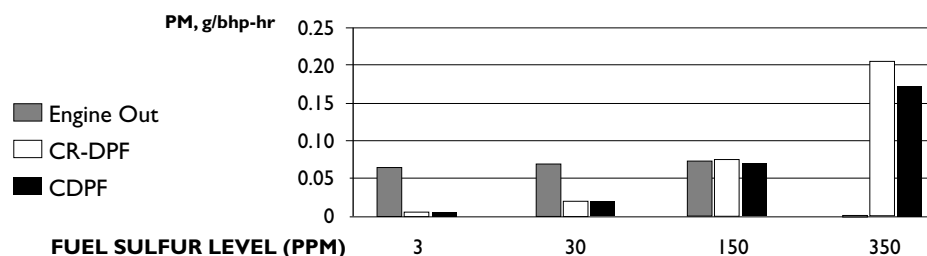
The Continuously Regenerating Diesel Particulate Filter (CR-DPF) and Catalyzed Diesel Particulate Filter (CDPF) represent two approaches to regeneration of DPFs.

The CR-DPF accomplishes this filter regeneration by continuously generating NO₂ from engine-emitted NO over a diesel oxidation catalyst placed upstream of the CR-DPF. NO₂ has been established as a more effective low-temperature oxidizing agent for diesel PM than oxygen. Sulfur in the exhaust is oxidized over the CR-DPF, forming sulfates, which contribute to PM. Sulfur oxides also compete for the critical NO and NO₂ 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. Sulfur in the exhaust is oxidized over the CDPF to form sulfates. Exhaust-gas temperature and fuel-sulfur level are critical factors that affect the performance of both types of DPFs (CR-DPF and CDPF).

Fuel sulfur has a significant effect on PM emissions. Both DPF's were effective in reducing PM emissions (95% over the OICA cycle) when used with 3-ppm sulfur fuel (Figure 9). With 30-ppm sulfur fuel, the PM reduction efficiencies dropped to 72 and 74% for the CR-DPF and CDPF, respectively. At the 150-ppm sulfur test point, PM reductions were near zero.

Figure 9: Effect of Fuel Sulfur Level on PM Emissions – OICA Cycle



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

AROMATICS

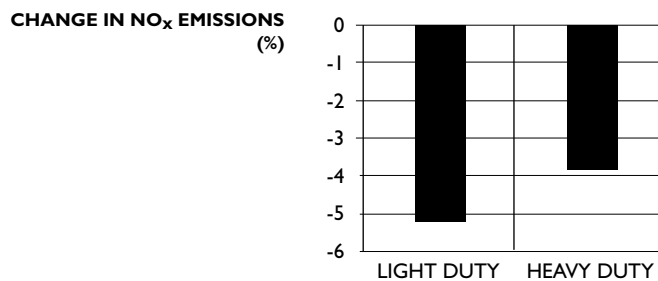
Aromatics are fuel molecules which contain at least one benzene ring. The fuel aromatic content will affect combustion and the formation of particulate and PAH emissions.

The diesel fuel aromatics content influences flame temperature, and therefore, NO_x emissions during the combustion. Polyaromatics in the fuel affect the formation of particulates and the polyaromatic hydrocarbon (PAH) emissions from a diesel engine.

Influence of Total Aromatics Content on NO_x Emissions

A higher aromatic content in the fuel will increase the flame temperature during combustion which results in increased NO_x 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 NO_x emissions as shown in Figure 10.

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

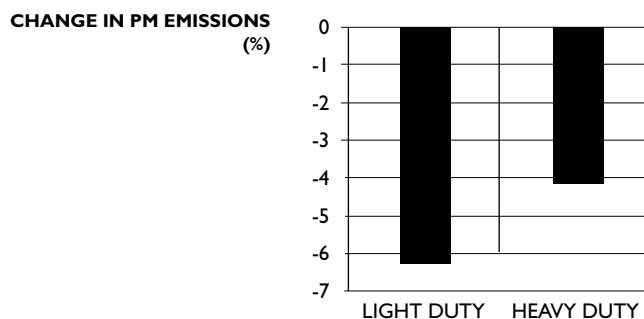


The light duty data is based on the combined ECE/EUDC cycle, the heavy duty on the 88/77/EEC 13-mode cycle.

Influence of Polyaromatic Content on Particulate Emissions

The influence of polyaromatic (di+) content on PM emissions was also investigated in the EPEFE programme. Figure 11 shows the reductions of PM emissions which were measured when the polyaromatic content was reduced from 9 to 1 %.

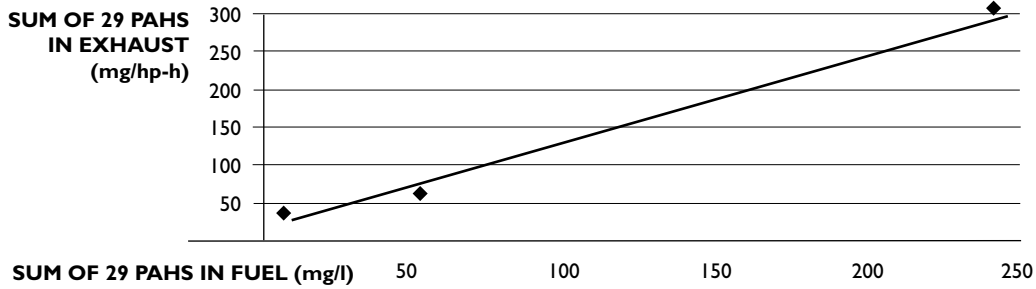
Figure 11: Effect of Total Aromatics on PM Emissions 9 to 1% di+ polyaromatics



Influence of Polyaromatic Content on PAH Emissions

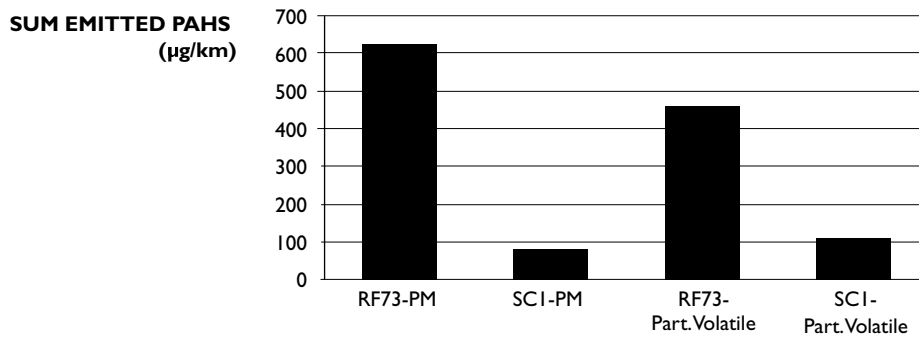
PAH (tri+) content in diesel fuel has been shown to directly correlate to PAH emissions in vehicle exhaust. The PAH emissions of a truck diesel engine on the US transient cycle using fuels with different PAH contents were measured in a Swedish study. The results shown in Figure 12 demonstrate this direct correlation.

Figure 12: 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 I fuel (SCI, PAH =24 mg/l) and European reference fuel (RF73; PAH=2100 mg/l). Figure 13 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 13: Effect of Fuel PAH on Emissions of PAH



DISTILLATION CHARACTERISTICS

The distillation curve of diesel fuel indicates the amount of fuel which 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 NO_x 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 NO_x 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. Therefore, adequate cold flow performance 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 control systems.

VEGETABLE DERIVED ESTERS

Vegetable derived esters (VDE) are increasingly being used as extenders to, or replacements of, diesel fuel. This has been driven largely by national efforts to exploit agricultural produce and/or to reduce the dependency on imported oil products. Some data suggests that environmental benefits can be achieved through the use of these esters. However, manufacturers do have concerns over the introduction of vegetable derived esters in high quality diesel fuel.

Many oils may be used for making methyl esters, eg., rapeseed, sunflower, palm, soya, cooking oils and animal fats, but to date, the rapeseed product comes closest to the behaviour of conventional diesel

fuel. For example, typical characteristics for rapeseed methyl ester (RME) are as follows:

cetane number = 51

density = 0.880

viscosity at 40°C = 3.5 cSt

The technical advantages of methyl ester are primarily that they ensure lubricity of injection equipment (lubricity can be diminished by the refining processes to remove diesel sulfur) and they reduce exhaust gas particulate matter. The disadvantages of methyl esters are as follows:

- They require special care at low temperatures to avoid excessive rise in viscosity and loss of fluidity. Additives may be required to alleviate the problems.
- Being hygroscopic, special care is needed to prevent high water content and the consequent risk of corrosion.
- Deposit formations tend to be higher than for diesel fuel, so detergent additive treatment is strongly advisable.
- Seals and composite materials in the fuel system are attacked by methyl esters unless they are specially chosen for their compatibility.

Based on the technical effects of VDE, it is strongly advised that VDE content be restricted to less than or at 5%. As a pure fuel, or at higher levels in diesel fuel, the vehicles need to be adapted to the fuel, and particular care is needed to avoid problems.

The European standards organisation, CEN, is currently developing proposals for fatty acid methyl esters (FAME; includes VDEs) quality to be used as diesel fuel and as an extender to diesel fuel. The group is also evaluating the diesel fuel specifications to determine if changes are needed to either the parameters or test methods to accommodate the introduction of FAME as a diesel extender at levels up to 5%. Until this work is completed and based on the technical concerns raised by the introduction of VDE in diesel fuel, it should not be introduced into a high quality fuel such as required in Category 3 markets.*

INJECTOR CLEANLINESS

The fuel injector is a component of very high-precision designed to meter fuel to a high degree of accuracy. 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, 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.

* Revised on reprint of March 1999

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 will become an even higher priority in the near future 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.

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.

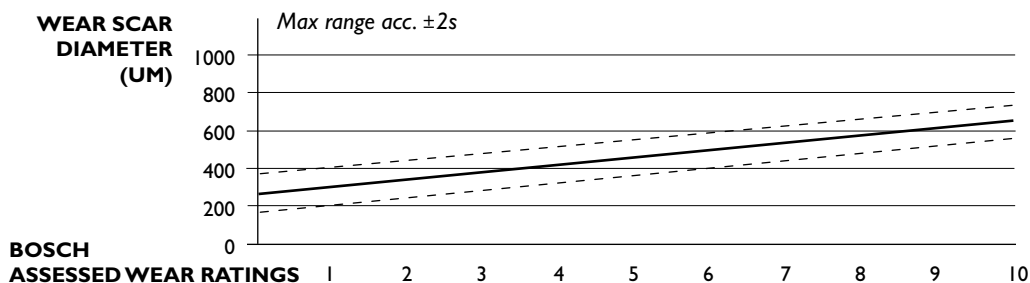
Refining processes to remove diesel fuel sulfur tend to simultaneously reduce the components of the fuel which provide natural lubricity. As diesel fuel sulfur levels decrease, the risk of inadequate lubricity also increases; however, poor lubricity has been observed even in diesel fuels with very high sulfur levels.

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 which provides good correlation to measured pump effects.

Figure 12 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 an HFRR limit of 400 μ m). At a wear rating of 4, the pump will have decreased endurance, and ratings above 7 indicate potential fatal breakdown.

Figure 14: Assessed Pump Wear Rating vs. HFRR Results



A pump rig test method is under development which will complement the HFRR. The new test will provide better correlation between test results and actual in-use observations of the protection provided by lubricity additives.

GASOLINE Sources

Figure 1	US AQIRP, EPEFE, AAMA/AIAM, SAE 982726, JSAE 9838985
Figure 2	US AQIRP
Figure 3	TOYOTA, 1999
Figure 4	TOYOTA/CRC AUTO/OIL SYMPOSIUM, SEPT. 11-13, 1997
Figure 5	SAE 962051
Figure 6	TOYOTA, 1999
Figure 7	GENERAL MOTORS, 1999
Figure 8	TOYOTA, 1999
Figure 9	SAE 920730
Figure 10	US AQIRP
Figure 11	US AQIRP, EPEFE REPORT
Figure 12	CRC REPORT, No 605
Figure 13	CRC REPORT, No 605
Figure 14	GM/SAE 962023
Figure 15	TOYOTA/SAE 972851
Figure 16	FORD, 1996
Figure 17	FORD/SAE 962012
Figure 18	FORD, 1996
Figure 19	FORD/SAE 962012
Figure 20	FORD/SAE 962012
Figure 21	TOYOTA/SAE 941893

DIESEL

Figure 1,2,3	ACEA REPORT: INFLUENCE OF DIESEL FUEL QUALITY ON HEAVY DUTY DIESEL ENGINE EMISSIONS, MARCH 1997
Figure 4,5	EPEFE REPORT
Figure 6	ACEA REPORT: INFLUENCE OF DIESEL FUEL QUALITY ON HEAVY DUTY DIESEL ENGINE EMISSIONS, MARCH 1997
Figure 7	JAMA, PRESENTED AT 30TH ISATA, JUNE 1997
Figure 8	DECSE PROGRAM, PHASE I, NUMBER 2, OCTOBER 1999, US DOE/EMA
Figure 9	DECSE PROGRAM, PHASE I, NUMBER 3, NOVEMBER 1999, US DOE/EMA
Figure 10	ACEA REPORT: INFLUENCE OF DIESEL FUEL QUALITY ON HEAVY DUTY DIESEL ENGINE EMISSIONS, MARCH 1997
Figure 11	DATA FROM THE EPEFE REPORT
Figure 12	KARLSSON (SCANRAFF REFINERY) AND RÖJ (VOLVO): DIESEL FUEL QUALITY FOR REDUCED EMISSIONS, WORLD FUELS CONFERENCE SAN FRANCISCO, 1995
Figure 13	GRÄGG, AP SVENSK BILPROVNING/MOTORTTESTCENTER, REPORT 9/1995
Figure 14	BOSCH, 1997

