Technical Information

FAME Conformity Tests by METI, Japan

Energy Efficiency and Conservation Authority
Bio Fuels Conference 2006

April 21, 2006

Fuels and Lubricants Committee
Japan Automobile Manufacturers Association

Contents

Note) FAME: Fatty acid methyl ester

1. Background

- The Fuel Policy Subcommittee's second interim report (July 5, 2004) pointed out that quality regulation for FAME-blended diesel oil is necessary.

  Those characteristics required of FAME-blended diesel oil such that, when used with ordinary diesel vehicles, they are not harmful from both a safety and environmental perspective, shall be studied. The appropriate specifications shall be reflected in the fuel regulations.

- Local governments and other entities produce FAME from locally available vegetable or waste cooking oil. This FAME is used in garbage collection vehicles or public buses, some of which are modified as necessary.

METI decided to begin with the specifications of FAME-blended diesel oil to up to 5vol% for ordinary diesel vehicles only. MAFF, MLIT, and MOE are also studying FAME.

Note) METI : Ministry of Economy, Trade and Industry
MAFF : Ministry of Agriculture, Forestry and Fisheries
MLIT : Ministry of Land Infrastructure and Transport
MOE : Ministry of the Environment

2. Outline of the FAME Conformity Tests

Phase 1

Test FAME

1. Making a database of FAME properties
2. Oxidation Stability Tests
3. Fuel System Simulation Tests
4. Dipping Tests for Various Materials

} Candidate FAME(1)

Phase 2

5. Long Storage Tests
6. Fuel Line Parts Tests
   (Fuel Filter, Fuel Tank, Fuel Pipe, Fuel Hose)
7. FIE (Fuel Injection Equipment) Durability Tests
8. Engine & Vehicle Durability Tests

} Candidate FAME(2)

2.1 The properties of the Candidate FAME

Property		unit	Candidate FAME(1)	Candidate FAME(2)	EN14214 Limits
Density		g/cm^3	0.8793	0.8768	0.860 - 0.900
Flash Point			167.0	182.0	120 min
CFPP			+9	+8	-
Cetane Number			57.2	57.5	51 min
10% Carbon Residue		mass%	0.09	0.15	0.3 max
Water Content		ppm	561	140	500 max
Oxidation Stability (EN14112)		hrs.	5.95	6.33	6 min
Iodine Number			79.3	74.1	120 max
Metal	Na	ppm	<1	<1	Na+K 5 max
	K	ppm	<1	<1	
	Ca	ppm	<1	<1	Ca+Mg 5 max
	Mg	ppm	<1	<1	
	P	ppm	<1	<1	10 max
Sulfur Content		ppm	<3	<3	10 max
Kinematic Viscosity		/s	4.293	4.355	3.5 - 5.0
Total Acid Number		mgKOH/g	0.52	0.11	0.5 max
Total Contamination		mg/100ml	22.6	1.5	24 max
Sulfated Ash Content		mass%	<0.01	<0.001	0.02 max
Copper Corrosion			1a	1a	1 max
Ester Content		mass%	95.2	99.8	95.5 min
Methanol Content		mass%	0.079	0.03	0.2 max
Linolenic acid methyl ester		mass%	11.2	3.2	12 max
Mono-glyceride		mass%	0.881	0.12	0.8 max
Di-glyceride		mass%	0.079	0.046	0.2 max
Tri-glyceride		mass%	0.064	0.072	0.2 max
Free glycerol		mass%	0.009	0.005	0.02 max
Total glycerol		mass%	0.246	0.048	0.25 max

Note) Candidate FAME(2) was prepared for durability tests in proportions:- PME:RME:SME=60:38:2

Contents

2.2 Long Storage Tests

Test Fuel

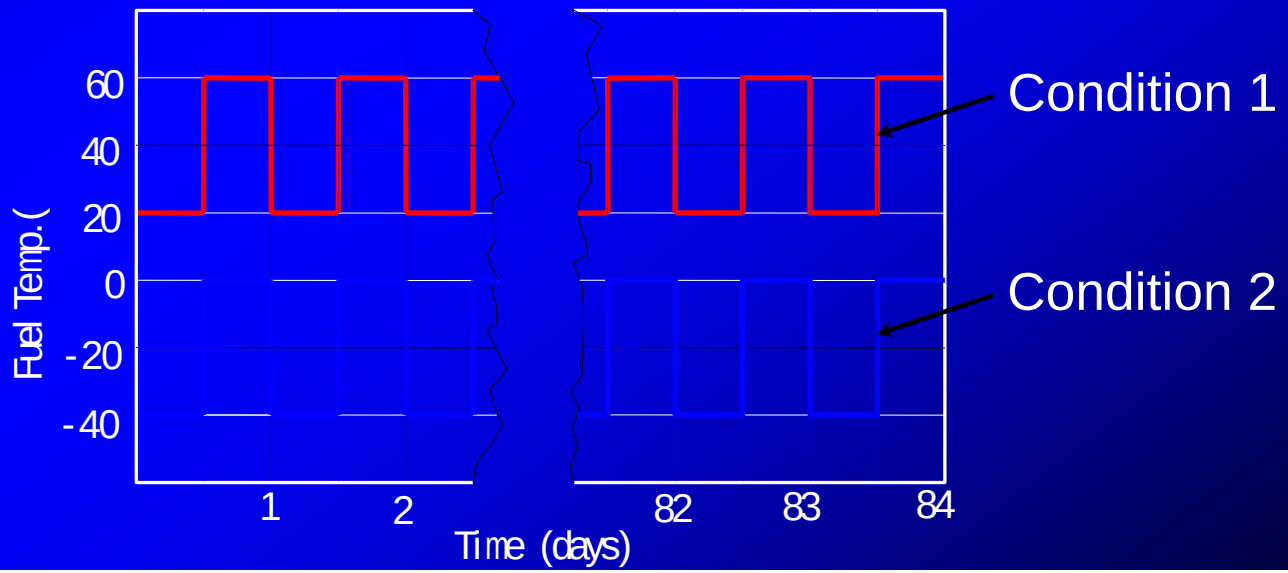
Diesel Fuel (10ppmS) blended with Candidate FAME(2) at 5vol%.

Test Condition

Temperature : Condition 1 20 60 °C Summer pattern
Condition 2 -40 0 °C Winter pattern
Temperature is controlled as in the graphs below

Duration : 84 days

Evaluate : Changes to:
Density, Viscosity, Distillation, Flash Point, PP, CP, CFPP, Sulphur content, Water content, Peroxide value, pH, TAN, Particulate content, Color, Oxidation stability



Contents

2.3 Fuel Line Parts Tests

Fuel Filter

Test Fuel

Diesel Fuel (10ppmS) blended with Candidate FAME(2) by 5vol%.

Test Condition

Test method : JIS D1617 (Test method for Automobile Fuel Filters)
= Dipping test (1000hrs @ 80 ^{o}C)

Evaluate : Changes to:
- Efficiency, pressure loss and estimation of life
- Seal performance
- Pressure proof performance
- Effect on filter case material (resinous and metal)

2.3 Fuel Line Parts Tests (cont.)

Fuel Tank

Fuel Tank Fuel Circulation Test

- Material : EGC3/3 TC92
- Temperature : 60 °C
- Duration : 2000 hrs
- Fuel volume : 50% of Tank capacity (fuel unchanged during test
- Fuel Flow Rate : 2 l/min

Cup Test (Dipping test

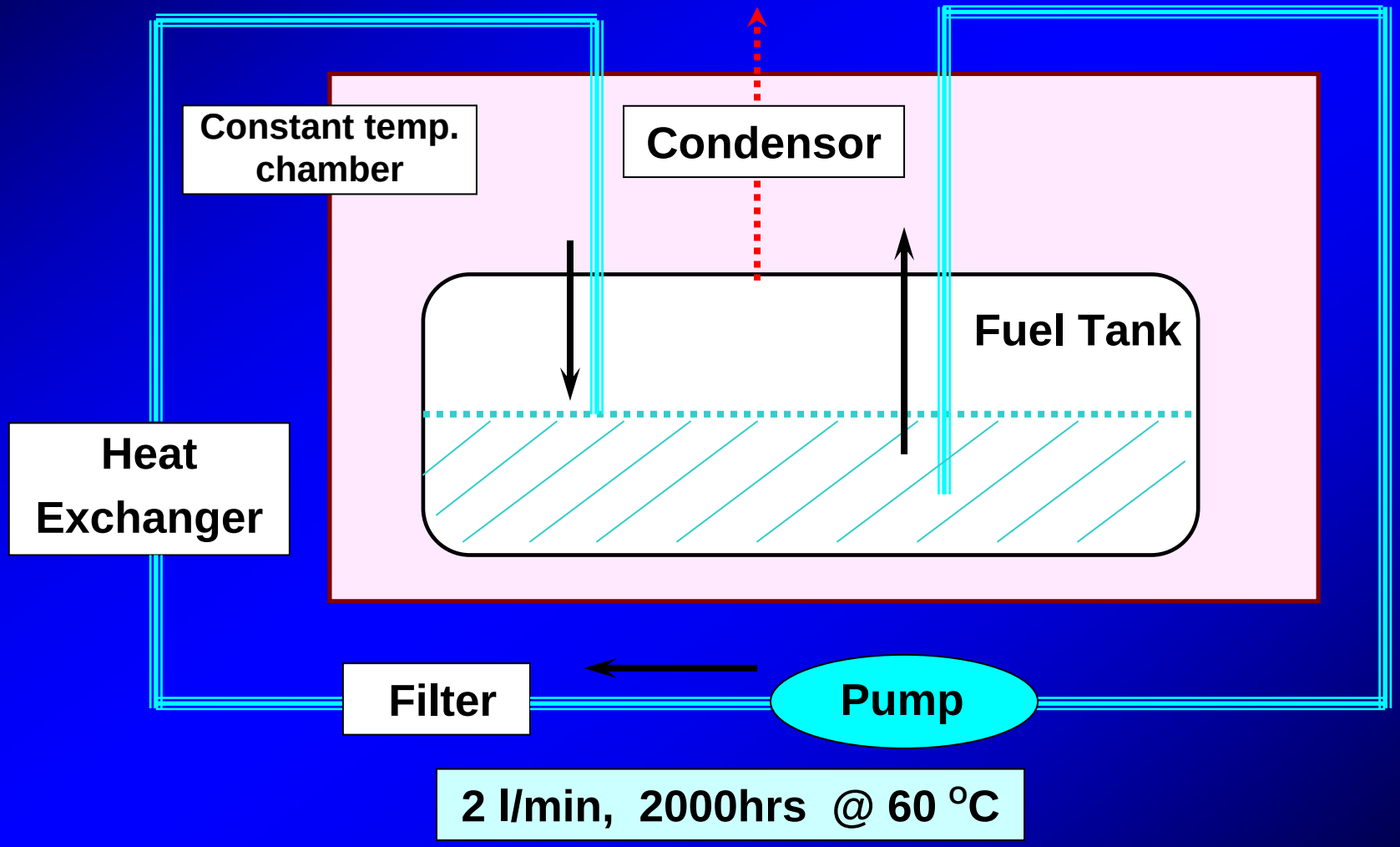
- material : EGC3/3 TC92 ALA5052 SnZn30/30 AlSi30/30
- Cup size : ID 75mm depth 40mm
- Temperature : 60 °C
- Duration : 1000 hrs
- Fuel volume : 100 cc
- Number of test : n=3

Evaluate:

- Depth of corrosion, corrosion ratio, quantity of corroded material, analysis of surface and post-test fuel analysis

Fuel Tank test (cont.)

Fuel Circulation Test



Note) same test condition as gasoline evaluation

2.3 Fuel Line Parts Tests (cont.)

Fuel pipe

Low Pressure Pipe

- Material : Steel pipe with 3um copper plating
  Three kinds of thermal treatment (gas brazing)
- Temperature : 80 ^{o}C
- Duration : 2000 hrs
- Evaluate : Weight change, surface condition, corrosion depth and metal concentration in the fuel

High Pressure Pipe (Analysis of pipes after FIE durability tests)

- Material : Single phase steel pipe
- Evaluate : Corrosion, deposits, cavitation erosion

2.3 Fuel Line Parts Tests (cont.)

Fuel hose

Rubbers

- Material : NBR, H-NBR, NBR PVC, FKM
- Temperature : 80 °C for NBR, NBR PVC
  120 °C for H-NBR, FKM
- Duration : 250 hrs, 500 hrs, 1000 hrs (Fuel changed every 250 hrs)
- Evaluate : Volume change, hardness change, bending stress, pull-off load, sealing performance, permeation, etc.

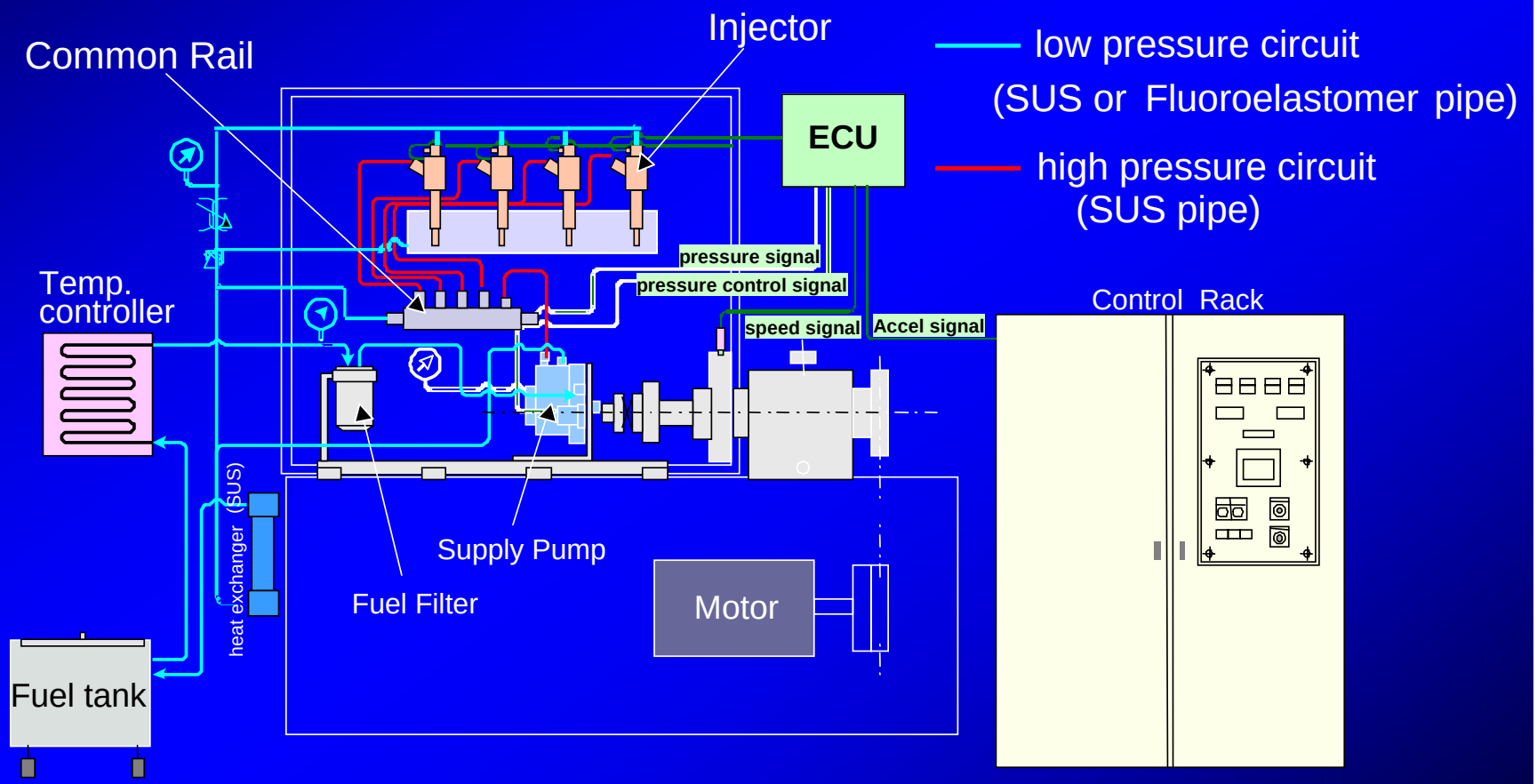
Plastics

- Material : PA11, ETFE, PVC, PA66 PBT PPS POM
- Temperature : 80 °C for PVC
  120 °C for PA11, PA66 PBT PPS POM
- Duration : 250 hrs, 500 hrs, 1000 hrs (Fuel changed every 250 hrs)
- Evaluate : Volume change, hardness change, bending stress, pull-off load, sealing performance, permeation, etc.

Contents

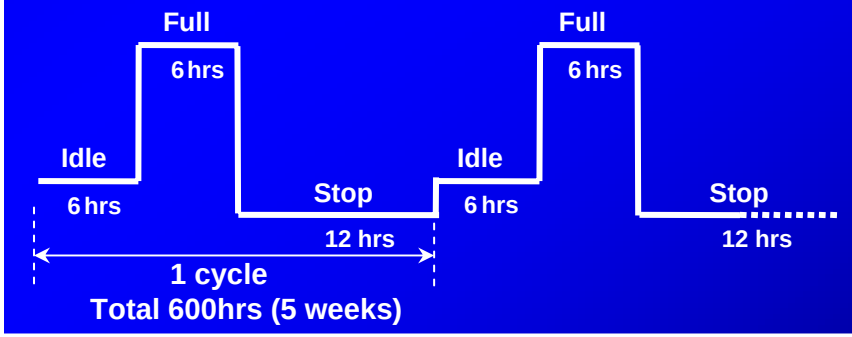
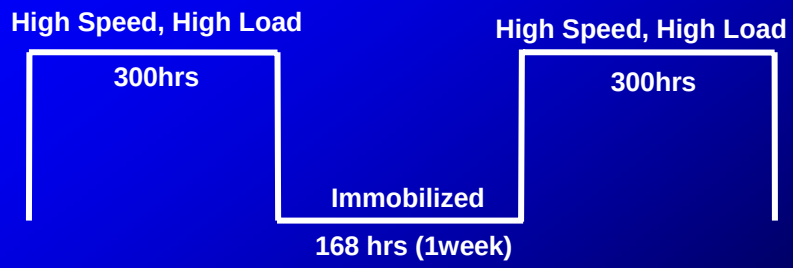
2.4 FIE Durability Tests

- Outline of testing equipment



2.4 FIE Durability Tests (cont.)

- Test Condition : see table
- Evaluate : Wear of moving parts, cavitation erosion, corrosion sludge formation, particulate density

Pattern No.	Atmospheric Temp.	Fuel Temp.	Fuel Change Interval	Driving cycle
1	Room	Full 80 Idle 40	48 hrs	
2	Room	70	48 hrs @Bosch 72 hrs @DENSO	

Contents

2.5 Engine Durability Tests

Light Duty Engine

- Engine (A) description DI-IC
  Displacement 4,899 cc FIE CR system
  Max Output 132 kW@2700 rpm, Max Torque 529 Nm@1600 rpm
- Engine (B) description IDI
  Replacement 2,494 cc FIE Distribution type pump
  Max Output 55 kW@4300 rpm, Max Torque 167 Nm@2200 rpm
- Driving condition:
  [Max Output 150 hrs] + [Max Torque 150 hrs] = 300 hrs
- Evaluate:
  Engine : Wear, corrosion and deposits on pistons, liners, and rings
  Parts : Injectors, injection pump fuel pipes, fuel filter
  Lubricant : Viscosity, particulates, metals, TAN, TBN, carbon residue
- Other conditions:
  Change Interval
  Fuel filter : unchanged
  Lubricant : every 150 hrs DI 75 hrs IDI

2.5 Engine Durability Tests (cont.)

Heavy Duty Engine

- Engine description

  DI 7,790 cc w / IC Turbo FIE:CR system

  Max Output 191 kW@2700 rpm, Max Torque :745 Nm@1400 rpm

- Test Condition:

  (A) Full-Full driving 1000 hrs (B) Cyclic driving (see Fig below) :1000 hrs

- Evaluate:

  Engine : Wear, corrosion and deposits on pistons, liners and rings

  Parts : Injectors, injection pump fuel pipe, fuel filter

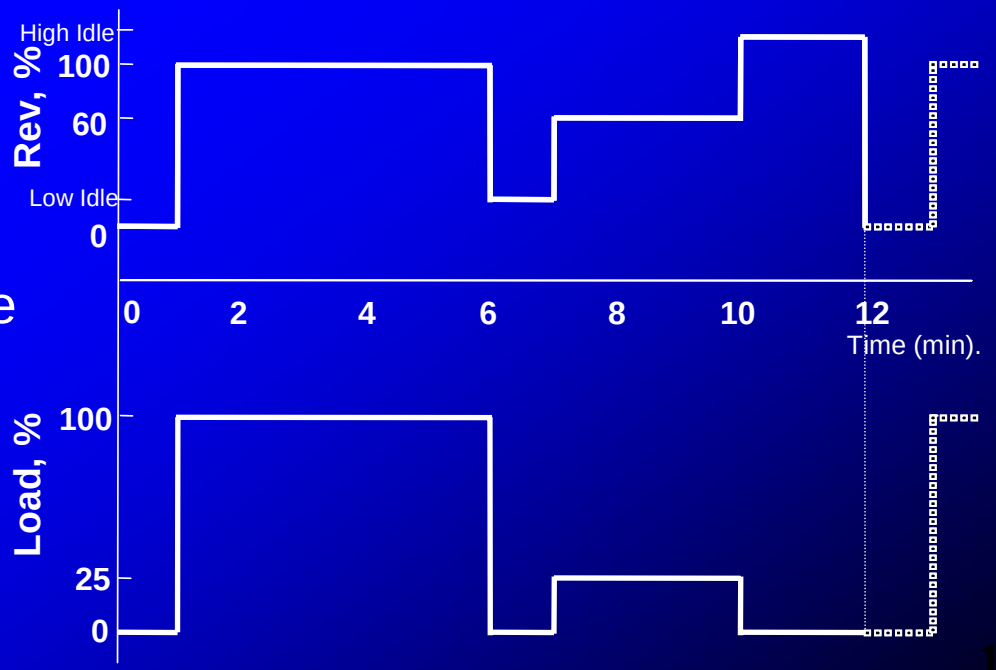
  Lubricants : Viscosity, metals, particulates, TAN, TBN, carbon residue

- Other conditions:

  Change interval

  Fuel filter : 250 hrs

  Lubricant : 250 hrs



2.5 Vehicle Durability Tests

Light Duty Vehicle

- Vehicle description

  Engine : IDI 2,982 cc w / IC Turbo FIE Distribution type pump

  Max Output : 103 kW@3600 rpm Max Torque : 343 Nm@2000 rpm

- Driving condition:

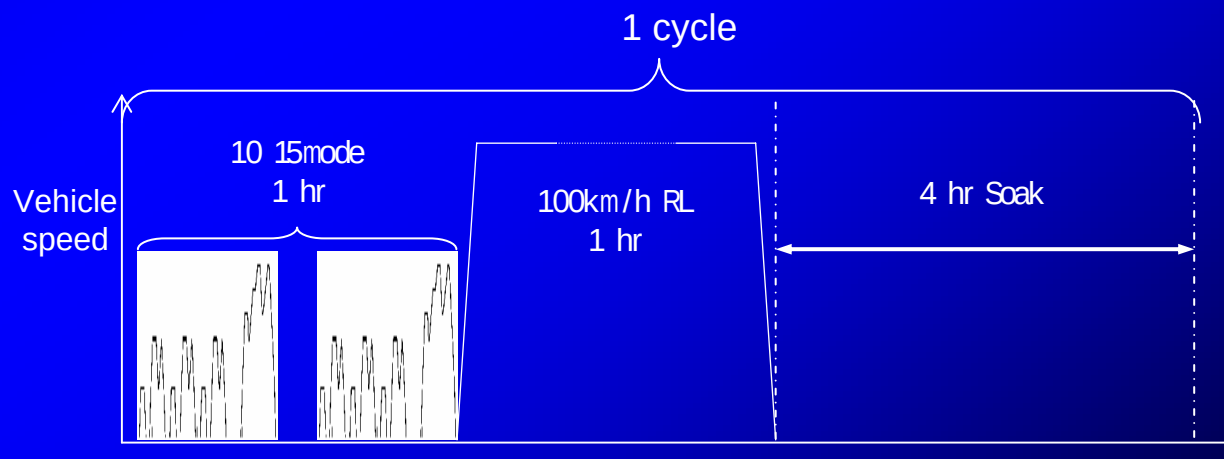
  Urban and Highway mode (see Fig below) 40,000km accumulated

- Evaluate:

  Engine : Wear, corrosion and deposits on pistons, liners and rings

  Parts : Injectors, injection pump, fuel pipe, fuel hose, fuel tank, fuel filter etc.

  Lubricant : Viscosity, particulates, metals, TAN, TBN, carbon residue



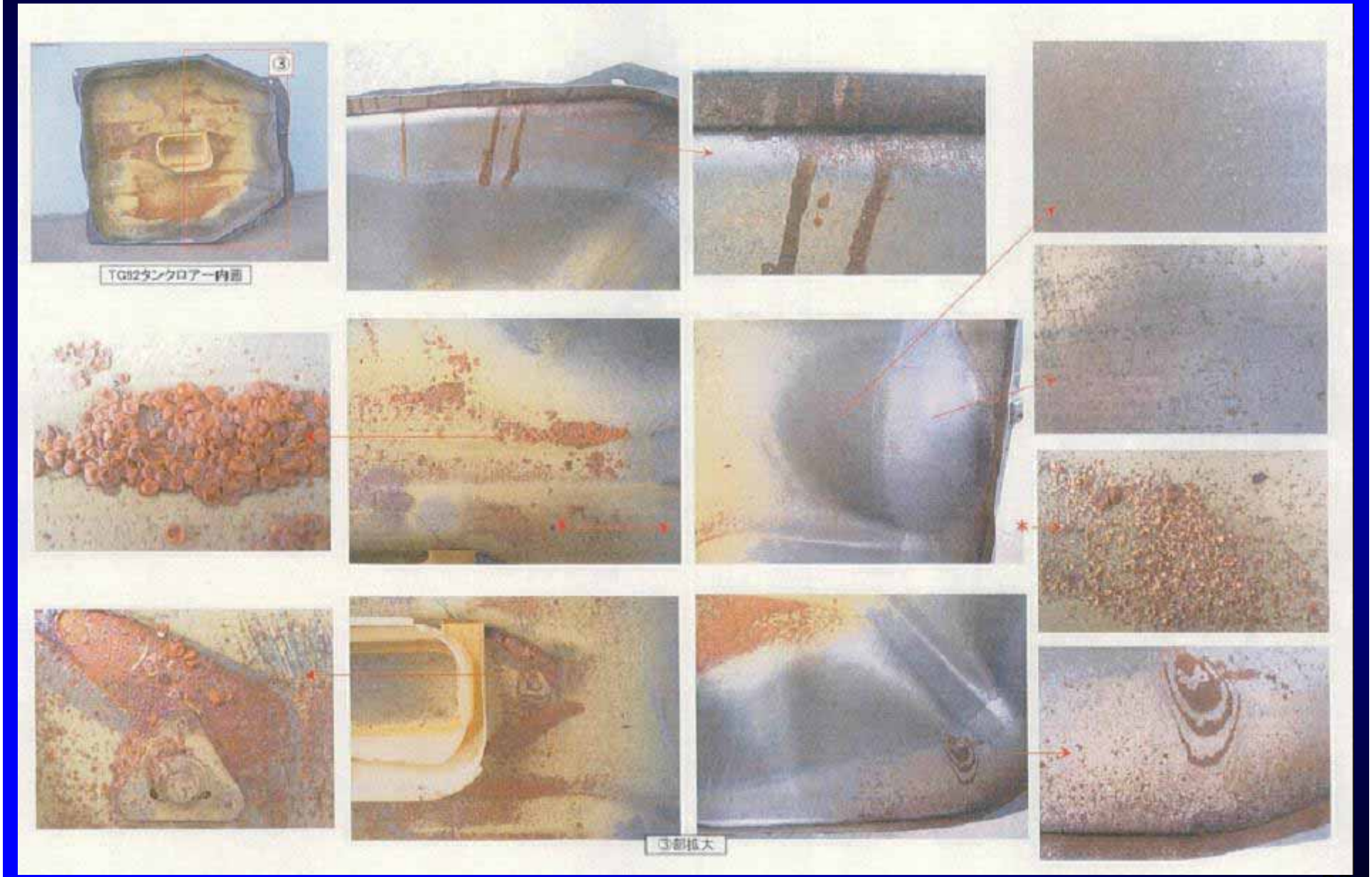
Contents

3. Issues from Phase 2 Testing

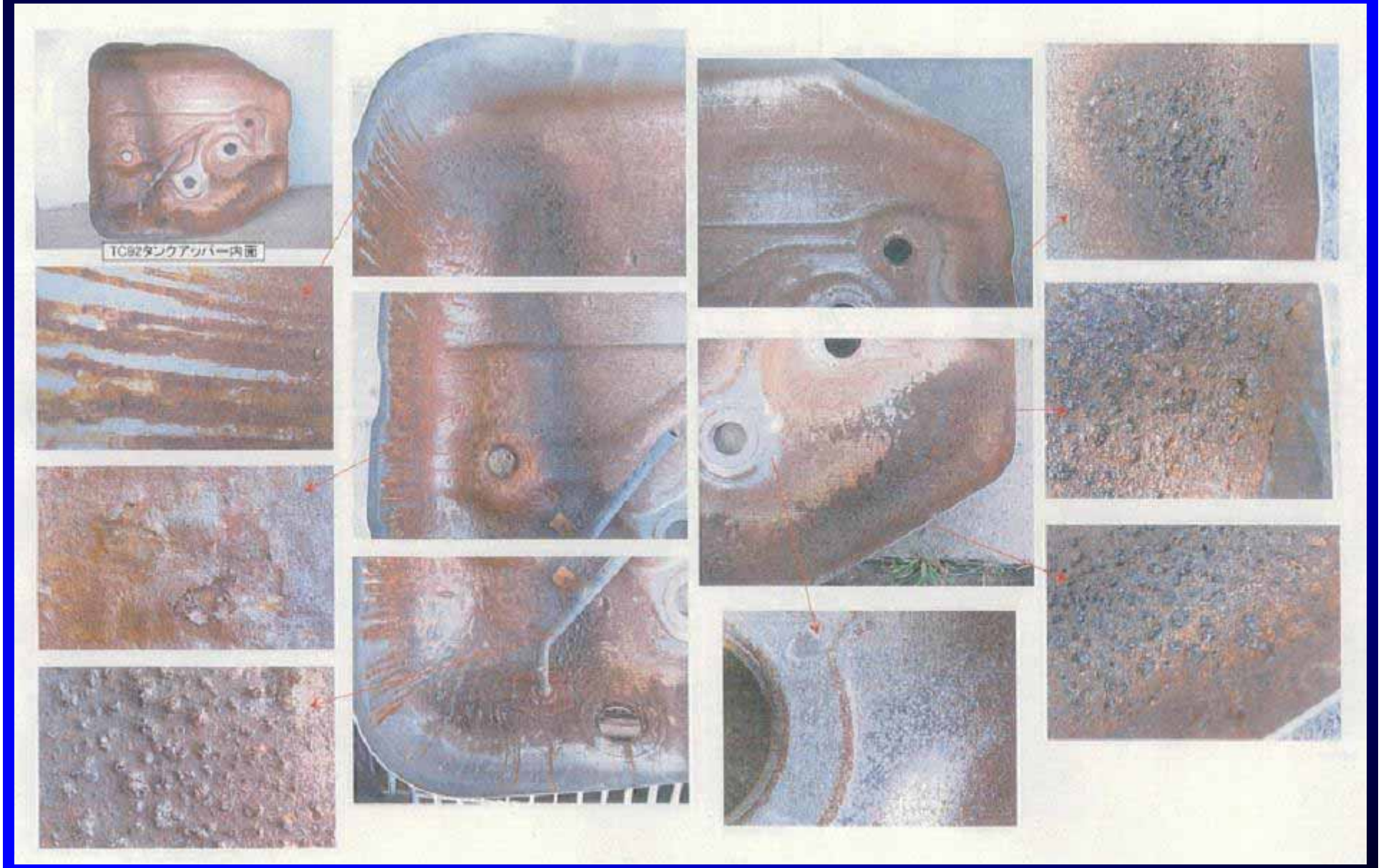
Test Summary

Test	Observations	Possible cause
Fuel tank tests and metal dipping tests	**Heavy corrosion**	**Poor oxidation stability Organic acids present Severe test conditions**
FIE durability tests	Abrasive wear in Injectors **(Both Bosch and DENSO)**	The cause of the wear is unclear. Hard solid particulates **(SiO2 ?)** or FAME itself ? under examination
Engine durability Tests (HDE)	Flow reduction Abrasive wear in injectors	

Corrosion after Fuel Tank Test (1)



Corrosion after Fuel Tank Test (2)



Contents

4. Summary and Future Plans

Some issues were observed in the Phase 2 tests.
This suggests that EN14214 may not be adequate to ensure vehicle performance.

Probably, **Oxidation stability**, **TAN** (and **individual organic acids**) and **Linolenic acid methyl ester** should be reviewed.

Screening tests are being conducted to decide new limits for the 4 items listed above. Also fuel tank tests are being conducted for the second half of the Phase 2 tests (- Mar.'06).

After investigating the wear mechanism, countermeasures to solid particulates will be explored. If necessary, pump tests to confirm their effect will also be conducted.

Contents

5. Re-scheduling of METI's FAME Investigation

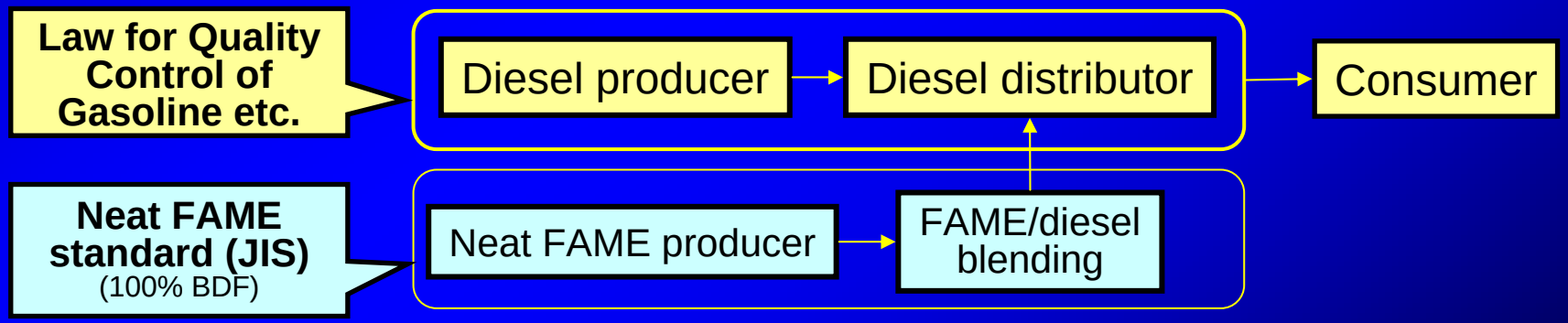
	2003	2004	2005
Phase 1	• Making a database of FAME properties • Oxidation stability tests • Fuel system simulation tests • Dipping tests for various materials Decide on FAME blended diesel fuel for Phase 2 (specification and concentration)	mid-Oct.	
Phase 2	• Long storage tests • Durability tests for fuel line parts • FIE durability rig tests • Durability tests on engine dynamometer • Durability tests on chassis dynamometer	Phase 2 start	~ May. '05
Additional Tests	• FIE durability rig tests • Durability tests for fuel line parts - Fuel Tank - Fuel Filter • Oxidation stability studies • Effect of different acid types on corrosion		May.'06 Conclusion of vehicle safety investigation

* METI is also conducting the emission test to evaluate the effect of FAME blending diesel.

Contents

6. FAME Quality Control Method

- The mandatory Diesel Fuel Standard established under the "Law for Quality Control of Gasoline etc." will be expanded to include FAME and will continue to be applied to diesel fuel producers and distributors.
- Simultaneously, a specialized standard will be introduced for 'neat FAME' having properties appropriate for blending with diesel fuel at a given content (e.g. 5v%).
  This will be a non-mandatory standard such as JIS.



Note) JIS: Japanese Industrial Standards

6. FAME Quality Control Method (cont.)

Using diesel fuel regulation and a new JIS standard for B100, METI will ensure diesel fuel quality after blending with FAME to up to 5vol%.

DRAFT

Parameter	Method	Specification
Oxidation stability (acid formation)	regulation	TBD
Oxidation stability (sludge formation)	regulation	TBD
TAN (and organic acids)	regulation	TBD
Ester content	regulation	5 % max.
Tri-glyceride	regulation	Same as EN
Methanol content	regulation	Same as gasoline
Linolenic acid methyl ester	JIS	Same as EN
Multi unsaturated acid methyl ester	JIS	Same as EN
Glycerol	JIS	Same as EN
Mono, di-glyceride	JIS	Same as EN
Metal	JIS	Same as EN
Phosphorous	JIS	Same as EN
Water content	JIS	Same as EN
Total contamination	JIS	Same as EN

Contents

7. *Basic Position of JAMA on FAME*

The characteristics of FAME are quite different from the raw materials from which it is made. Hence, to ensure the performance of vehicles, it is crucial to decide the proper specification for FAME, and the diesel fuel blended from it, based on technical evidence.

Currently, the Japanese government (METI) is conducting conformity tests on FAME. The results so far from the on-going study suggest that current FAME specifications (EN14214 and ASTM D6751) may not be sufficient.

After receiving the conclusions of the METI tests (early 2006), JAMA will decide its position on FAME and propose specifications and a blending ratio for diesel.