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# Japan Clean Air Program - Step I Study of Diesel Vehicle and Fuel Influence on Emissions

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# ***Overall Program of JCAP Diesel WG***

- Main task of Diesel WG
  - To investigate the future direction of diesel emission control technologies and diesel fuel properties
- Step I study /1997-1999
  - Emission tests: combinations of current vehicles/engines and current fuels
  - Sub-program for more understanding
- Step II study /1999-2001
  - Emission tests: combinations of future vehicles/engines and future fuels
  - Focused on ‘2007’ emission regulation

# ***Diesel Step 1 study***

- **Existing-Step research**
  - To evaluate the exhaust emission level of current engine/vehicle with current fuel quality
- **Model-Step research**
  - Detail analyses on emission control technologies
    - After-treatments
    - Effect of fuel properties
- Experiments for phenomena analyses
- Effect of Engine Oil on PM emission

  -Not included in this report

# ***Test Methods***

- Emission test mode
  - Vehicle:10-15mode (11mode) /Engine:D13mode
- Emission measurements
  - PM,NOx,HC,CO /unregulated emissions
- Statistical methodologies
  - EPEFE
- Selected fuel parameter
  - distillation(T90) /aromatics(total,poly-) /sulfur /cetene number /density

# Existing-Step Research

# *Existing-Step Research*

- Tests of combination of current engines/vehicles and current fuels

| **16 engines/vehicles** | **5 fuels** |
|---|---|
| •The 'Short term' (1990-1994) emission regulation<br>-4 vehicles and 4 engines<br>•The 'Long term' (1997-1999) emission regulation<br>-4 vehicles and 4 engines<br><br>•Compact passenger car to large truck engines | -Average T90:330C, Aroma:25%<br>-T90:310C, Aroma:20%<br>-T90:310C, Aroma:30%<br>-T90:350C, Aroma:20%<br>-T90:350C, Aroma:30%<br><br>•Blending refinery components<br>•T90 and Total aromatics<br>•Other fuel properties change dependently |

# ***Correlation Coefficients among the Fuel Properties***

| | T90 | Total aromatics |
|---|---|---|
| T90 | 1.00 | -0.06 |
| Total aromatics | -0.06 | 1.00 |
| Poly-aromatics | 0.39 | 0.86 |
| Cetane number | 0.52 | -0.69 |
| Density | 0.64 | 0.56 |

# PM Emissions Change (Vehicle)

Base: D-1

| | PM Emission change compared with that of D-1 (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | K | L | M | N | EPEFE 1) |
| D-2 | 3 | -36 | -32 | -57 | -12 | -36 | -36 | -34 | -26 |
| D-3 | 12 | -15 | -13 | -32 | -15 | --- | -11 | -3 | -9 |
| D-4 | -4 | 11 | 2 | -4 | 1 | 1 | 7 | 3 | 4 |
| D-5 | 12 | 56 | 17 | -9 | 4 | --- | 8 | 4 | 7 |

1) calculated values by EPEFE regression equation

- D-2 had the lowest PM emission, followed by D-3
- Comparing JCAP with EPEFE, the levels of fuel influence may be in the same range for PM.

# NOx Emissions Change (Vehicle)

Base: D-1

| | NOx Emission change compared with that of D-1 (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | K | L | M | N | EPEFE 1) |
| D-2 | -3 | -4 | 8 | 16 | 1 | -8 | 13 | -16 | 2 |
| D-3 | -2 | 0 | 7 | 9 | 6 | -10 | 10 | -15 | 4 |
| D-4 | 0 | -3 | -1 | -3 | -1 | 1 | -2 | -1 | -1 |
| D-5 | -1 | -4 | -0 | 6 | 2 | -2 | 2 | 1 | -1 |

1) calculated values by EPEFE regression equation

- Fuel influence:NOx was relatively small compared with PM and varied from vehicle to vehicle

# *PM Emissions Change (Engine)*

Base: D-1

| | PM Emission change compared with that of D-1 (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | E | F | G | H | O | P | Q | R | EPEFE 1) |
| D-2 | -19 | -0 | 0 | -10 | -21 | -28 | -20 | -25 | -3 |
| D-3 | -18 | 2 | 13 | -16 | -17 | -23 | -12 | -7 | 2 |
| D-4 | 5 | 3 | 3 | 6 | 4 | 9 | -22 | 3 | 1 |
| D-5 | 7 | 7 | 15 | 6 | 1 | 10 | 38 | 14 | 3 |

1) calculated values by EPEFE regression equation

- D-2 had the lowest PM emission, followed by D-3
- JCAP results show a larger change than EPEFE

# NOx Emissions Change (Engine)

Base: D-1

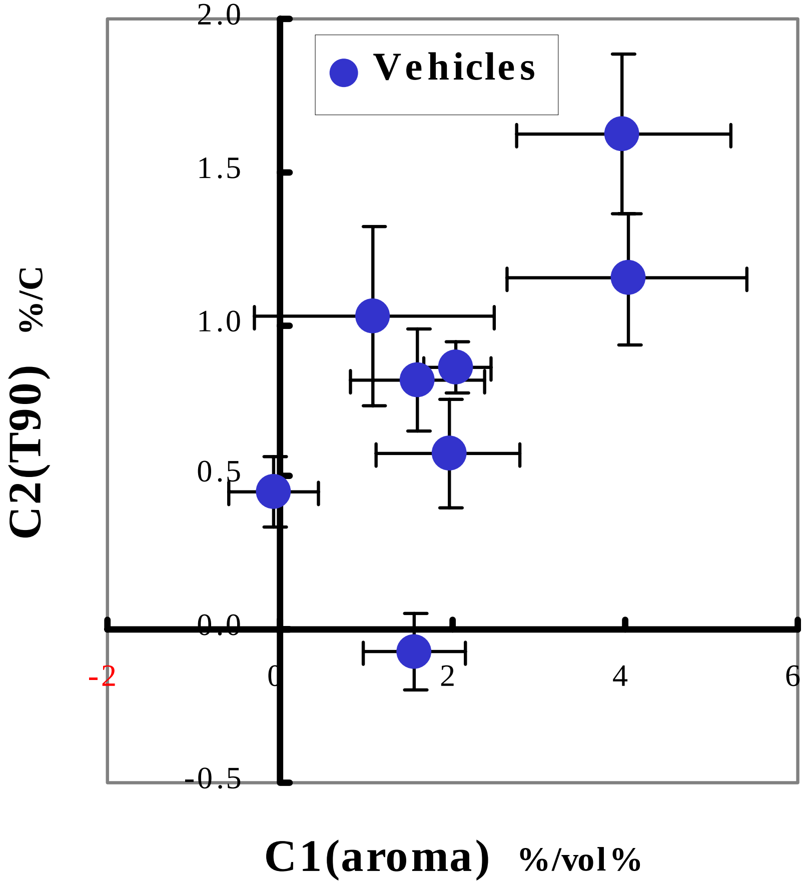
| | NOx Emission change compared with that of D-1 (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | E | F | G | H | O | P | Q | R | EPEFE 1) |
| D-2 | 1 | -2 | 1 | -1 | 1 | 4 | -2 | 4 | -4 |
| D-3 | 10 | 4 | 3 | 11 | 7 | 13 | 3 | 8 | -1 |
| D-4 | -4 | -2 | 1 | -5 | -1 | -4 | -1 | 1 | 0 |
| D-5 | 4 | 2 | 3 | 3 | 2 | 6 | 5 | 4 | 2 |

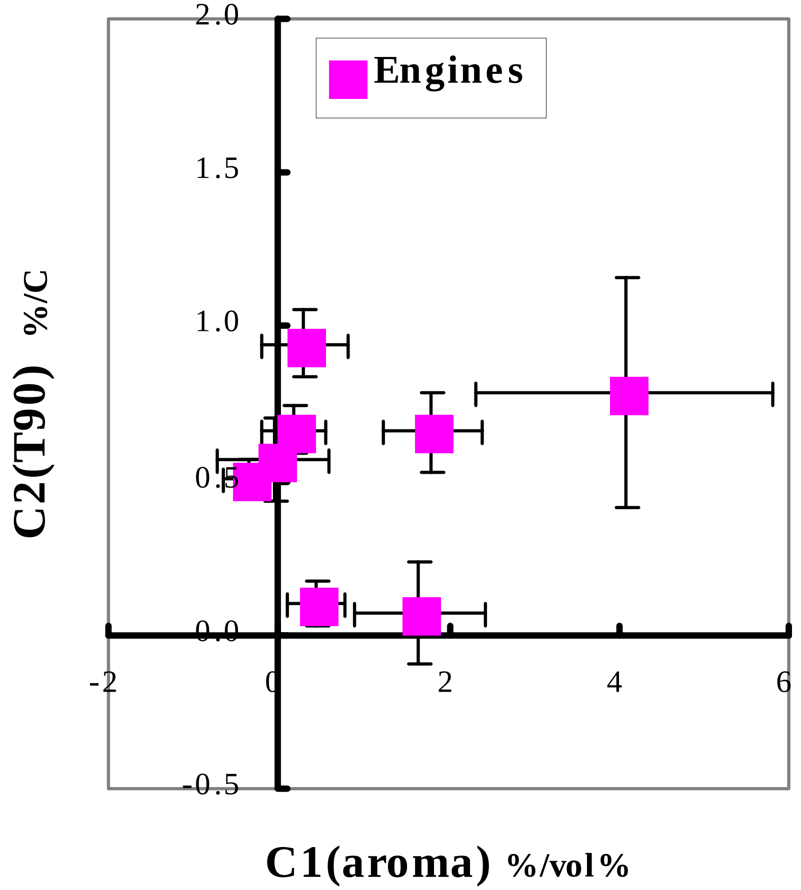
1) calculated values by EPEFE regression equation

- Fuel influence:NOx was relatively small compared with PM

# *Multiple Regression Analyses (Vehicle vs. Engine)*

**PM Emission(%) =C1*Total aroma(vol%) + C2*T90(C)**



# Model-Step Research

# *Model-Step Research*

- Sub-program for detail analyses of after-treatment effect and fuel properties effect on exhaust emission

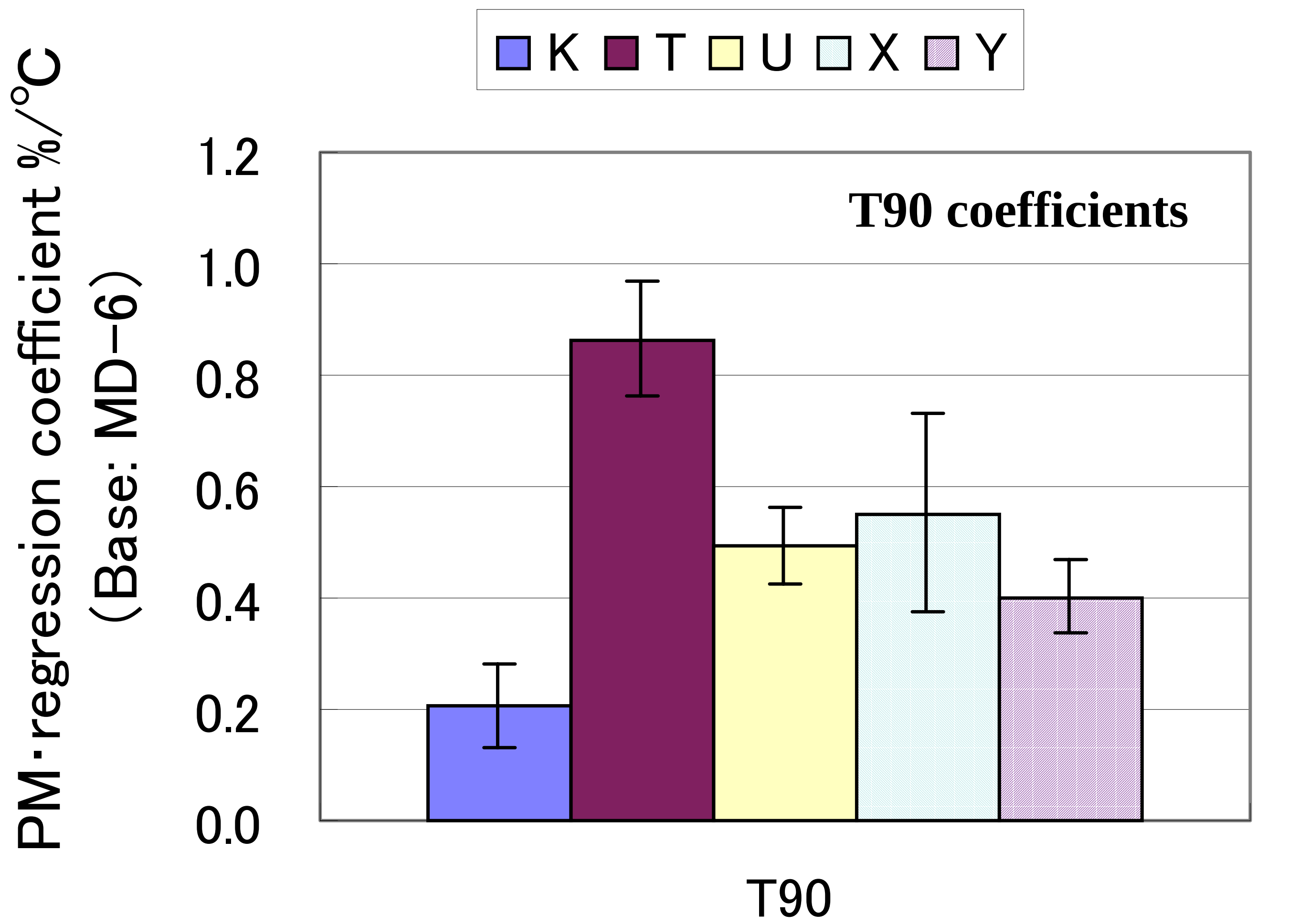
| **5 engines/vehicles and 4 after-treatments** | **8 fuels**<br>(Blending solvents and chemicals) |
|---|---|
| **-Vehicle of highest fuel sensitivity**<br>**-Vehicle of lowest fuel sensitivity**<br>**-Engine of highest fuel sensitivity**<br>**-Engine of lowest fuel sensitivity**<br>**-Vehicle with DI engine**<br>**-High performance catalyst (vehicle test)**<br>**-2 oxidation catalysts (engine test)**<br>**-DPF (engine test)** | **-Average**<br>**-Aromatics free**<br>**-Mono-aromatics**<br>**-Di-aromatics**<br>**-Tri-aromatics**<br>**-Low T90**<br>**-Low sulfur**<br>**-Sulfur free/ aromatics free** |

# ***Correlation Coefficients among the Fuel Properties***

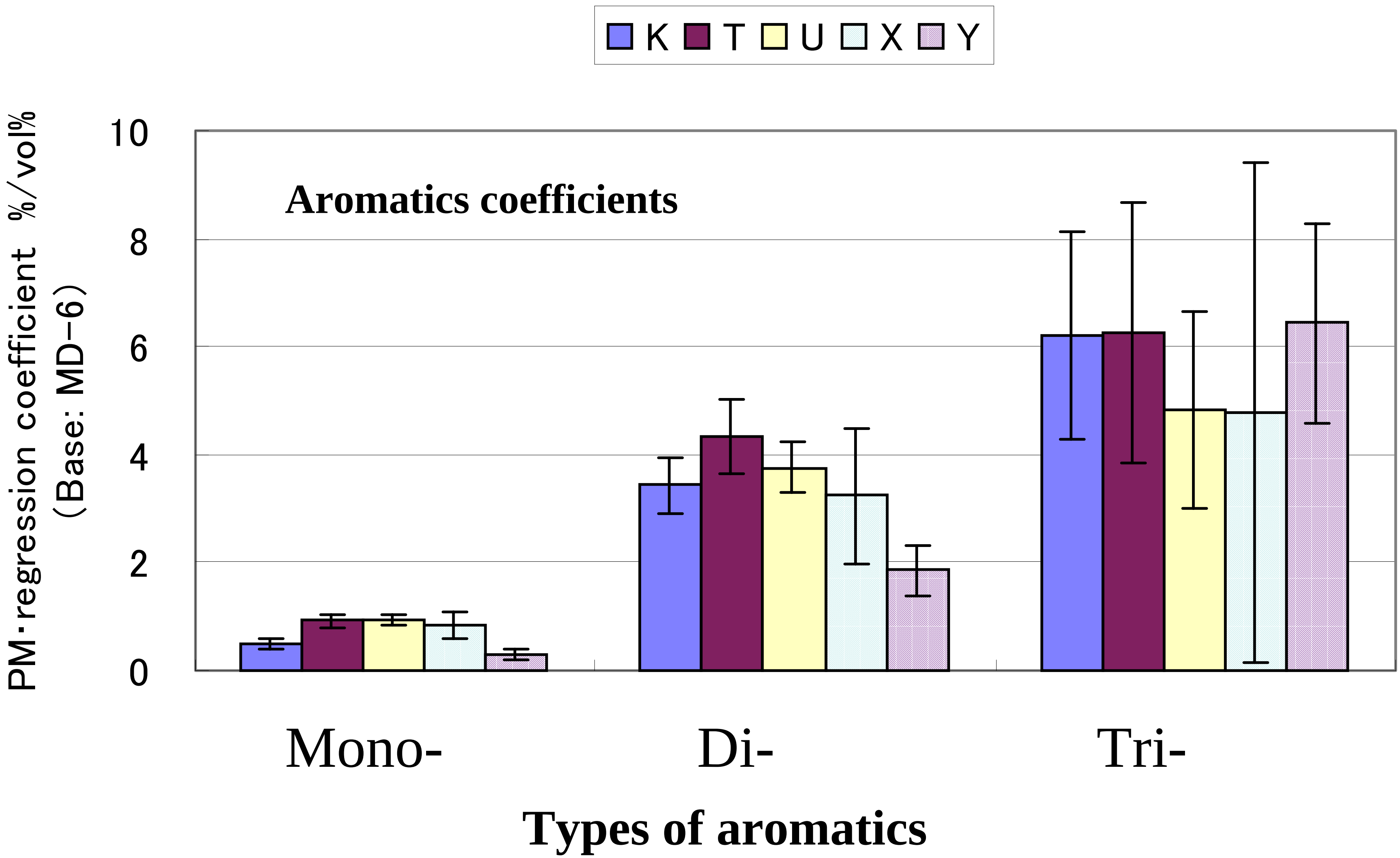
| | Mono- | Di- | Tri- | T90 | Sulfur |
|---|---|---|---|---|---|
| Mono-arimatichs | 1.00 | | | | |
| Di-aromatichs | -0.13 | 1.00 | | | |
| Tri-aromatichs | 0.02 | -0.16 | 1.00 | | |
| T90 | -0.31 | -0.07 | -0.17 | 1.00 | |
| Sulfur | 0.15 | 0.19 | 0.15 | -0.22 | 1.00 |

- Type of aromatics
  - mono:alkylbenzene/di-:methylnaphthalene/tri-:phenanthrene
- Other propaerties
  - **T90,sulfur**:independent/**C.N**.:around 55/ **density**:not controled.

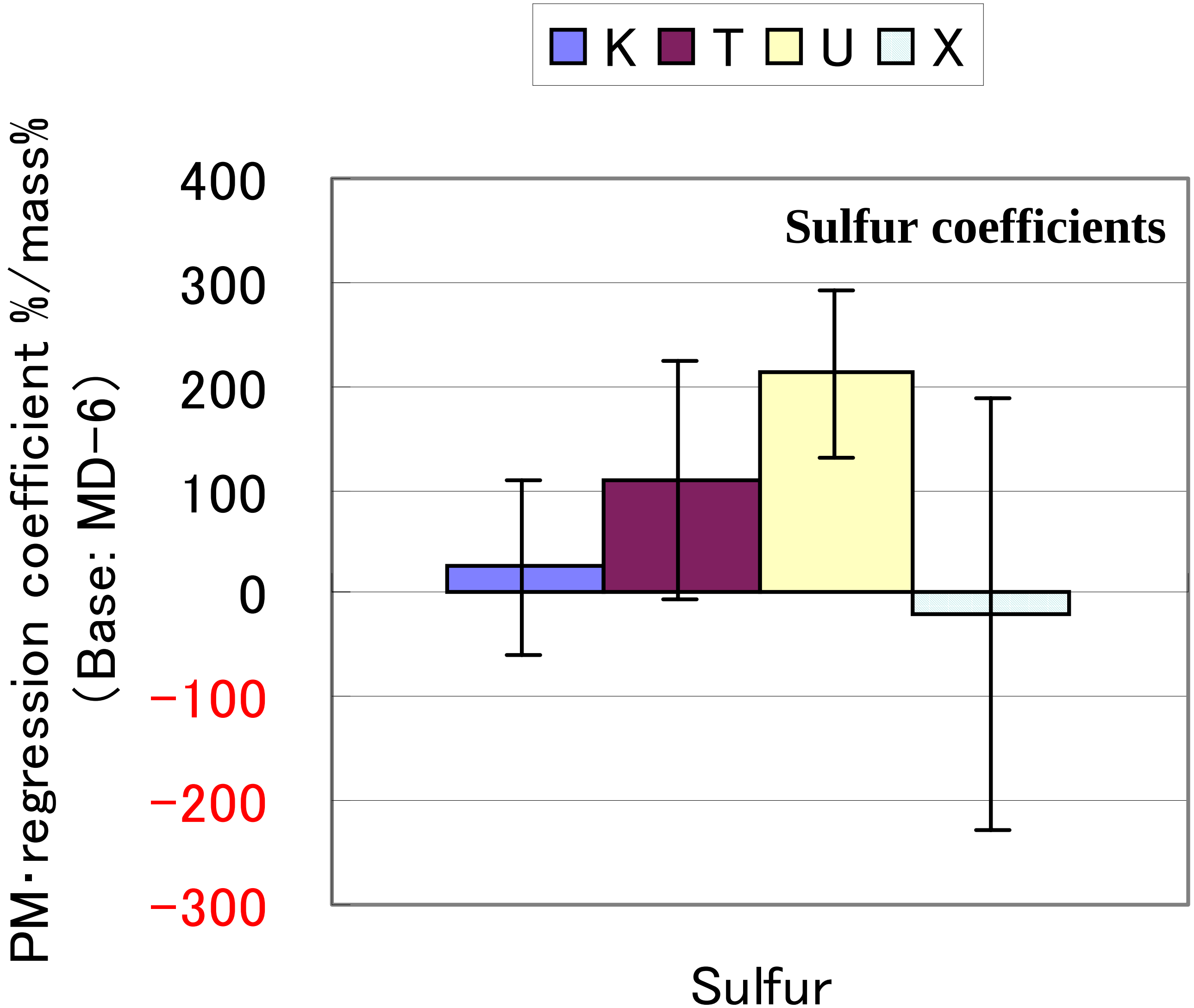
# *Multiple Regression Analyses of PM (1)*



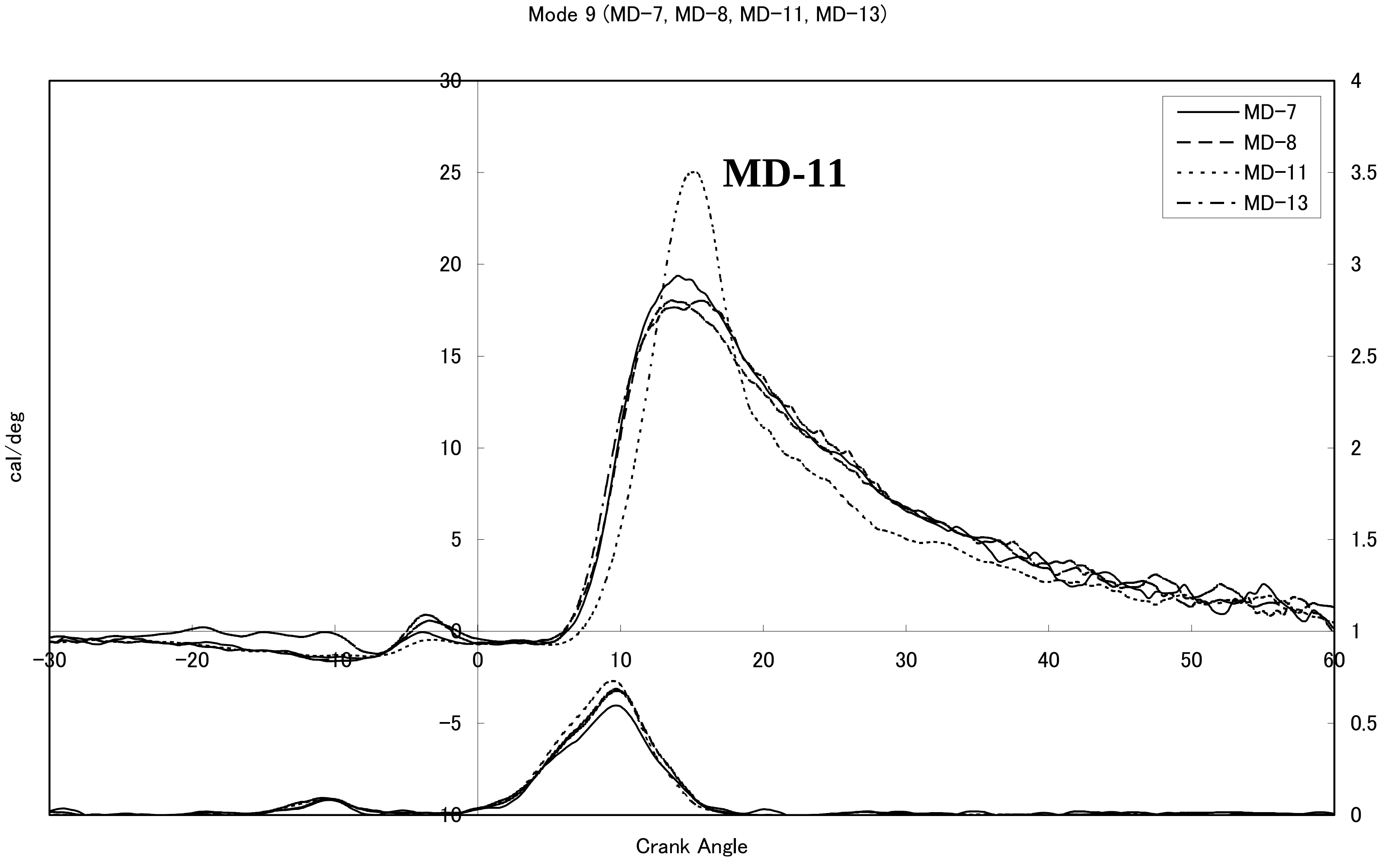
# ***Multiple Regression Analyses of PM (2)***



# Multiple Regression Analyses of PM (3)



# Analyses of Heat Release Rate (Engine X )




**MD-11: Low T90**

# *Exhaust Emission Reduction Effect of Vehicle S*

High performance catalyst:platinum(2.5g/L)

| 10・15-mode | Reduction ratio (%) | | | |
|---|---|---|---|---|
| | **PM** | **NOx** | **THC** | **CO** |
| **D-1(0.04%S)** | **-5.4** | **-3.0** | **95.8** | **99.7** |
| **MD-6(0.04%S)** | **-25.0** | **-13.7** | **96.4** | **99.5** |
| **MD-13(0.00%S)** | **15.0** | **-7.7** | **95.6** | **99.6** |

| 11-mode | Emission reduction ratio (%) | | | |
|---|---|---|---|---|
| | **PM** | **NOx** | **THC** | **CO** |
| **D-1(0.04%S)** | **40.8** | **3.9** | **84.8** | **94.3** |
| **MD-6(0.04%S)** | **34.7** | **4.1** | **85.1** | **94.4** |
| **MD-13(0.00%S)** | **22.2** | **8.0** | **85.8** | **96.2** |

(with the emissions using the dummy catalyst as the standard)

# ***Exhaust Emission Reduction Effect of Engines V and W***

V (catalyst): platinum(1.5g/L)    W(catalyst):base metal

| | Emission reduction ratio (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | PM | | NOx | | THC | | CO | |
| | V | W | V | W | V | W | V | W |
| D-1(0.04%S) | -76.3 | 31.7 | 2.6 | 0.4 | 82.6 | 35.1 | 92.4 | 18.9 |
| MD-6(0.04%S) | -110.8 | 25.5 | 3.1 | 2.1 | 83.2 | 34.3 | 92.9 | 20.1 |
| MD-13(0.00%S) | 29.8 | 43.3 | 1.2 | -1.6 | 88.1 | 41.6 | 99.4 | 49.7 |

•Comparing with the emissions using the dummy catalyst as the standard

# ***Exhaust Emission Reduction Effect of Engines Z (DPF)***

DPF: Cordierite

| | Emission reduction ratio (%) | | | |
|---|---|---|---|---|
| | **PM** | **NOx** | **THC** | **CO** |
| **D-1(0.04%S)** | **84.1** | **0.7** | **9.0** | **-3.6** |
| **MD-6(0.04%S)** | **87.0** | **-0.1** | **0.8** | **-7.4** |

# ***Conclusion of Step I***

- DPF is the most effective in reducing PM. In addition with a highly oxidative catalyst and reducing the sulfur concentration in the fuel, extremely low levels of PM, HC, CO and unregulated emissions can be expected.
- Fuel properties such as T90 distillation, aromatics and sulfur concentrations considerably affect PM emission, and the effects vary according to the vehicle and engine types and engine technologies.

# *Conclusion of Step I (continued)*

- Since the effect of fuel properties on NOx emission is fairly small, an innovative approach in engine technologies is necessary for the drastic reduction of NOx to meet the future emission regulation.
- Fuel properties affect unregulated emissions to some extent, but drastic reduction can be achieved by oxidation catalyst.

# ***Fin***

Thanks for your attention !