JCAP II
JAPAN CLEAN AIR PROGRAM

Further Challenge in
Automobile and Fuel Technologies
For Better Air Quality

5th JCAP Conference

Oil WG Report

February 22, 2007

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2. Influence of lubricating oil on diesel after-treatment devices
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   2.3 Influence of ash, S and P on Urea-SCR (NOx selective reduction catalyst)
   2.4 Feedback to lubricating oil specifications
3. Effects of lubricating oil on reduction of CO_2 emitted from gasoline vehicles
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Purpose of study

- **Influence of lubricating oil on diesel after-treatment devices**

  Acquire the knowledge necessary for taking countermeasures in oil formulation by determining the influence of SAPS(*) components in lubricating oil on the after-treatment devices （CR-DPF、NSR、Urea-SCR） which will be used widely when low sulfur diesel fuel becomes available in the market.

  ***SAPS：Sulfated Ash, Phosphates, Sulfur**

- **Effect of lubricating oil on reduction of CO_2 from gasoline vehicles**

  Evaluate the effect of energy-saving type lubricating oil on improvement in fuel economy in both Japanese and US fuel economy evaluation modes, and thereby grasp the potential of CO_2 reduction.

Overall plan

Items to be studied	Time schedule (FY)				
	2002	2003	2004	2005	2006
Conference				Interim report ★	Final report ☆
(1) Influence of lubricating oil on diesel after-treatment devices					
① Influence of ash on CR-DPF					
② Influence of S and P on NSR					
③ Influence of ash, S and P on Urea SCR					
2) Effect of lubricating oil on reduction of CO_2 emitted from gasoline vehicles					

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Contents of study

- **Engine running test**

  Determine the impact of ash coming from lubricating oil on pressure drop at the DPF.

- **Exhaust gas analysis test**

  Grasp the influence of various parameters on ash deposition, such as DPF specifications, operating conditions and oil additive formulation by analyzing ash components in the exhaust gases upstream and downstream of the CR-DPF.

Test conditions and matrix for engine running test

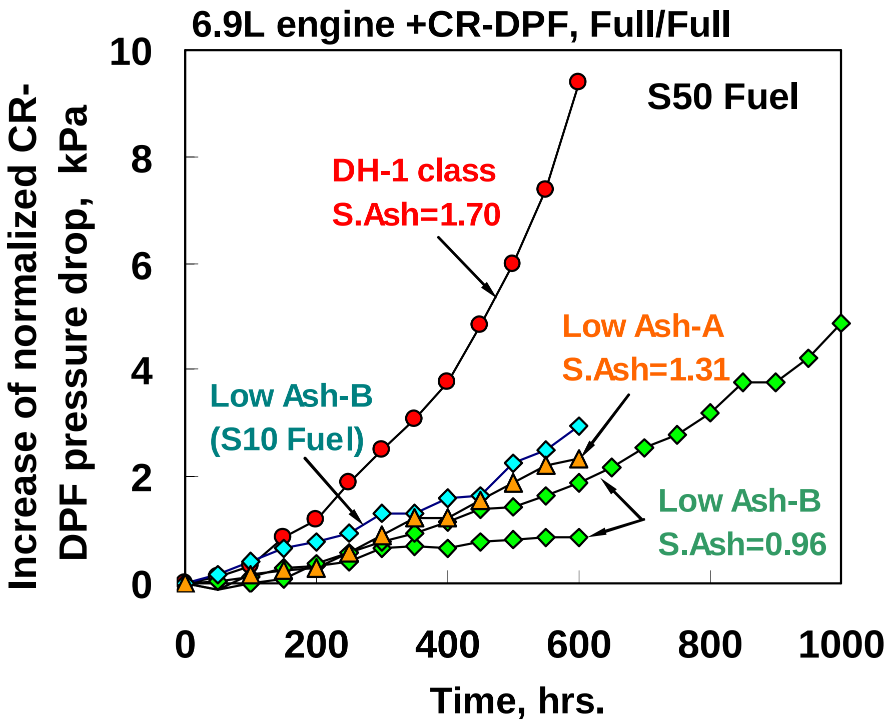
- Test engine: 6.9L DI engine meeting '98 regulations
- Continuous Regeneration DPFs (CR-DPFs) is comprised of upstream oxidation catalyst and downstream DPF coated with oxidation catalyst.
- Pressure drop caused by clogging of DPF is evaluated in steady-state operating condition (2700rpm/full load) at maximum engine output point.

Test No.	Oil	Fuel sulfur	Test duration
1	DH-1 class (S.Ash*=1.70)	S=50ppm	600h
2	Low Ash-A (S.Ash=1.31)	S=50ppm	600h
3	Low Ash-B (S.Ash=0.96)	S=50ppm	600h
4	Low Ash-B (S.Ash=0.96)	S=50ppm	1000h
5	Low Ash-B (S.Ash=0.96)	S=10ppm	600h

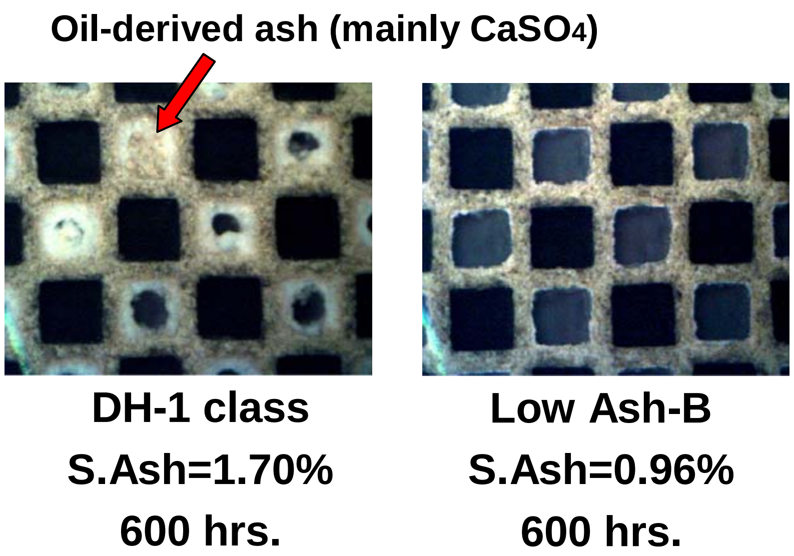
*Sulfated Ash

Results of engine running test

- **Reduction of sulfated ash in lubricating oil (index for ash quantity) reduces the ash deposits in the DPF and mitigates the increase in pressure drop.**
- **Reduction of fuel sulfur from 50ppm to10ppm has no influence on the pressure drop at the DPF.**



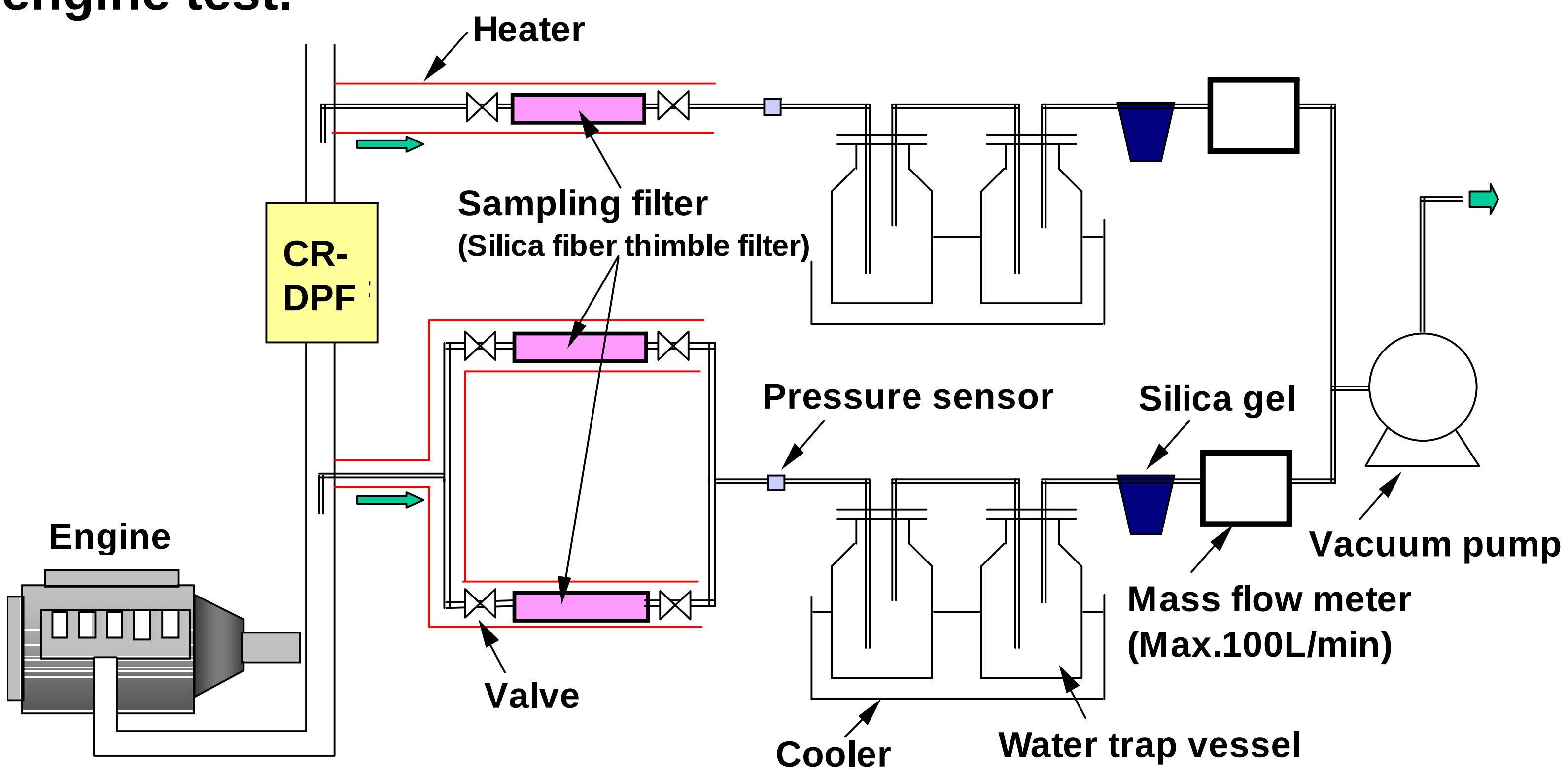
Cross section of DPF



Test method for exhaust gas analysis

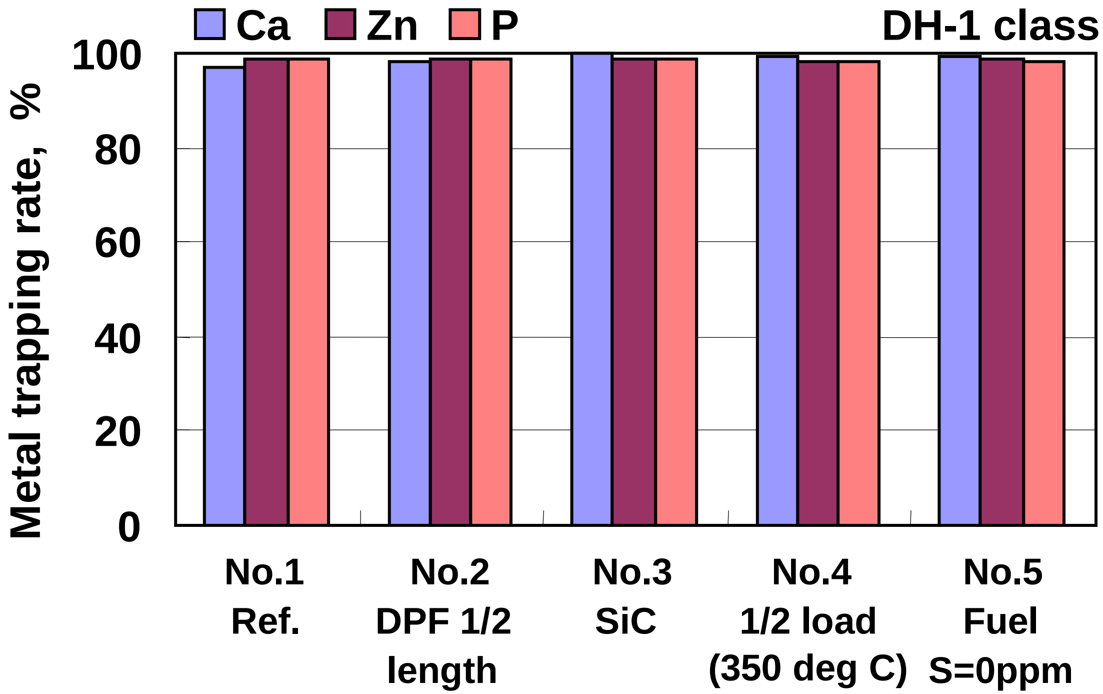
- **Measure the quantity of metal in exhaust gases, element by element, upstream and downstream of the CR-DPF. Using the difference in metal quantity, calculate trapping rate at the CR-DPF for each metal.**

  ➡ **Influence of various parameters can be evaluated in a short time.**
- **Specifications of engine and CR-DPF are basically the same as those for engine test.**



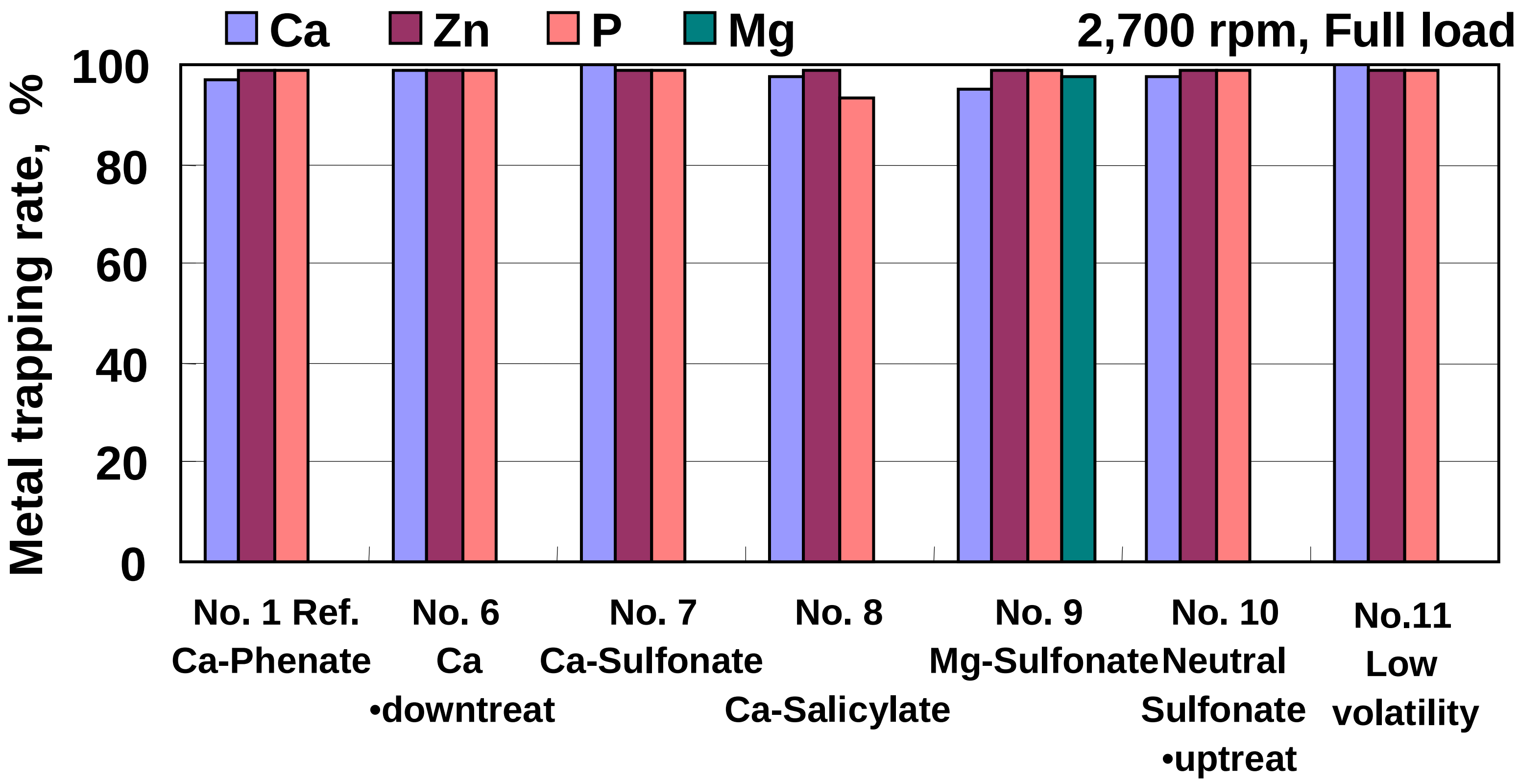
Exhaust gas analysis test results - No.1

- **Under the test conditions utilized at this time, almost all of the metals in the lubricating oil are captured by the CR-DPF regardless of the size/material of the DPF, exhaust temperature or the quantity of S in the fuel.**



Exhaust gas analysis test results - No.2

- **95% or more of the metal coming from the lubricating oil is captured by the DPF, even if lubricating oil formulation differs.**



Influence of ash on CR-DPF (summary)

- **Reduction of sulfated ash in lubricating oil reduces the ash deposits in the DPF and mitigate the increase in pressure drop, thereby contributing to prolongation of DPF maintenance interval.**

⇨ Vehicles equipped with the DPF require lubricating oil with reduced sulfated ash.

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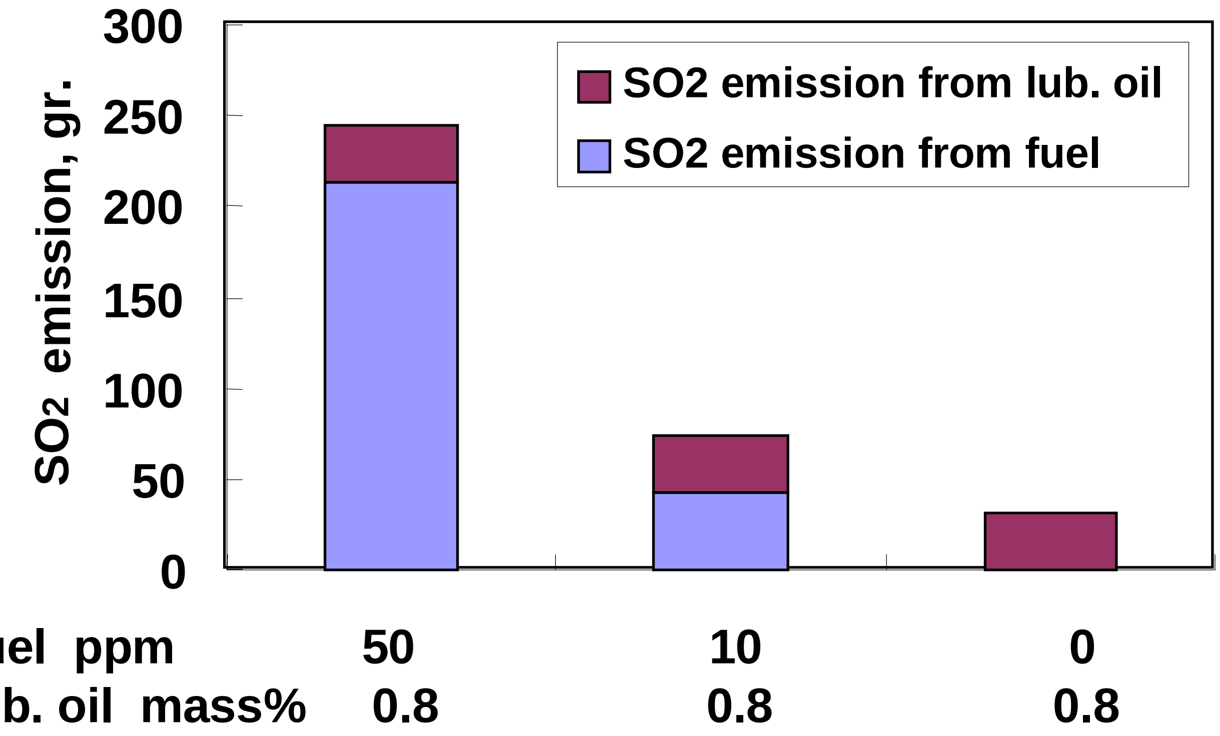
Contribution from S in lubricating oil to SO_2 emissions (estimated)

Influence of S in lubricating oil can not be neglected if S in fuel becomes less than 10ppm.

➡ **Influence of S in lubricating oil needs to be investigated.**



Note: The graph shown above is calculated assuming that all the S in the lubricating oil consumed is converted to SO2.

Contents of study

- **Engine running test**

  Determine the influence of S and P coming from lubricating oil on the NSR in the durability test without conducting fuel injection control for desulfation (S-purge).

- **Investigating emission characteristics**

  Analyze the quantity of S and P in exhaust gases under the same driving conditions and with the same test oil as in the driving test on test bench, and verify the results of driving test.

Test conditions and matrix for driving test on test bench

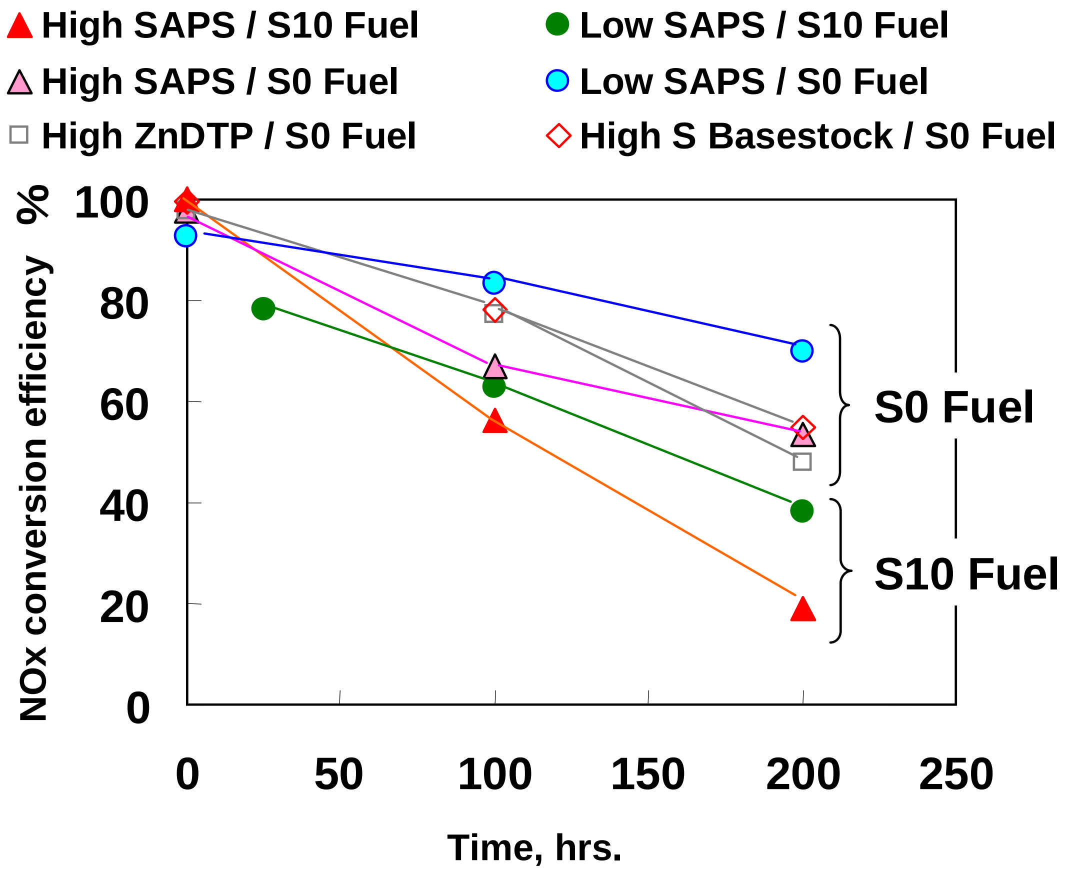
- Test engine is a 4.0L DI common rail engine meeting the ’02 regulations. This engine is equipped with a Diesel Particulate and NOx Reduction System (NSR+DPF).
- Conversion efficiency of NOx in exhaust gases is evaluated at 2,200rpm/ 115Nm steady state operation. In order to accelerate the influence of sulfur, the S- purge (fuel injection control for desulfation) is deactivated.

Test No.	Fuel	Lubricating oil			
		Name	S mass%	P mass%	S.Ash mass%
1	S10	High SAPS	0.76	0.11	1.7
2		Low SAPS	0.34	0.07	0.9
3	S0*	High SAPS	0.76	0.11	1.7
4		Low SAPS	0.34	0.07	0.9
5		High ZnDTP	0.69	0.28	1.4
6		High S Basestock	0.67	0.07	0.8

* Sulfur content <1ppm.

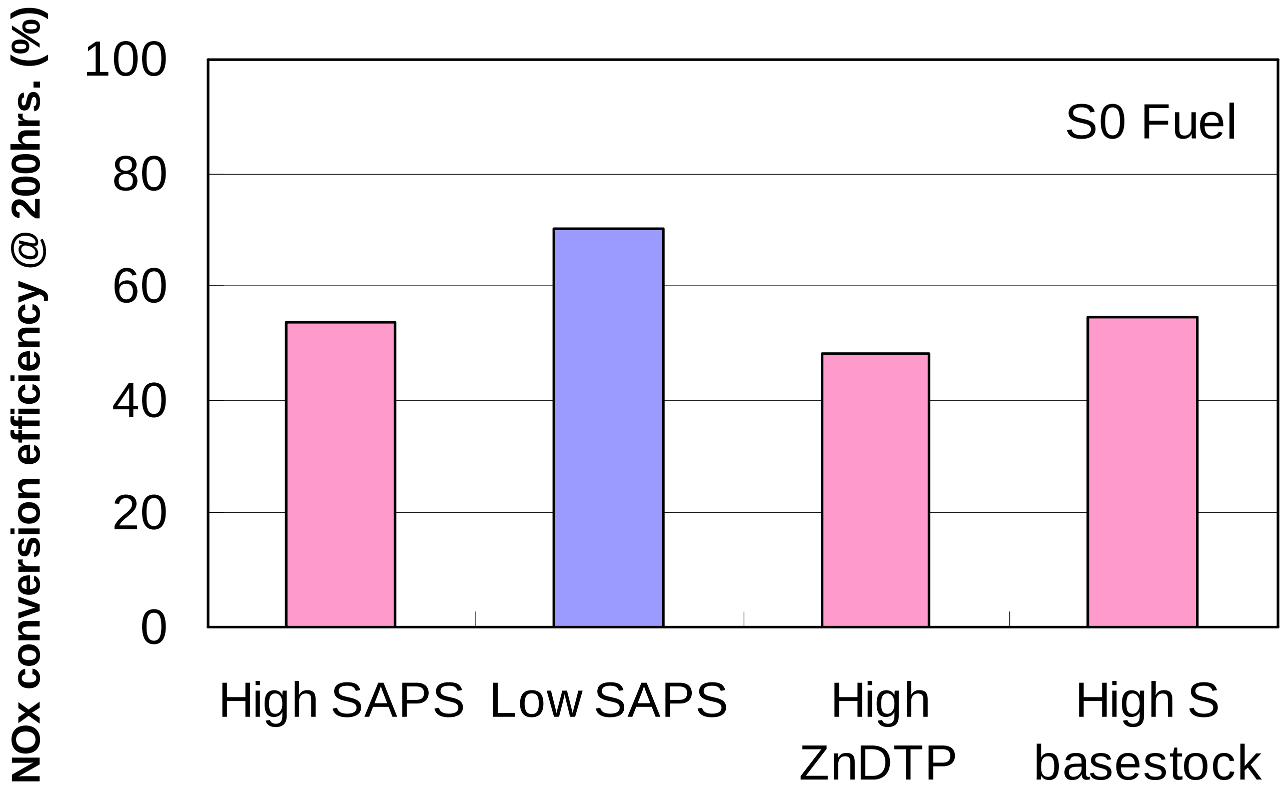
Change in NOx conversion efficiency during test

- As test time progresses, NOx conversion efficiency decreases.
- NOx conversion efficiency for High SAPS oil decreases more rapidly than that for Low SAPS oil in both cases of S0 and S10 fuels.



Comparison of NOx conversion efficiency

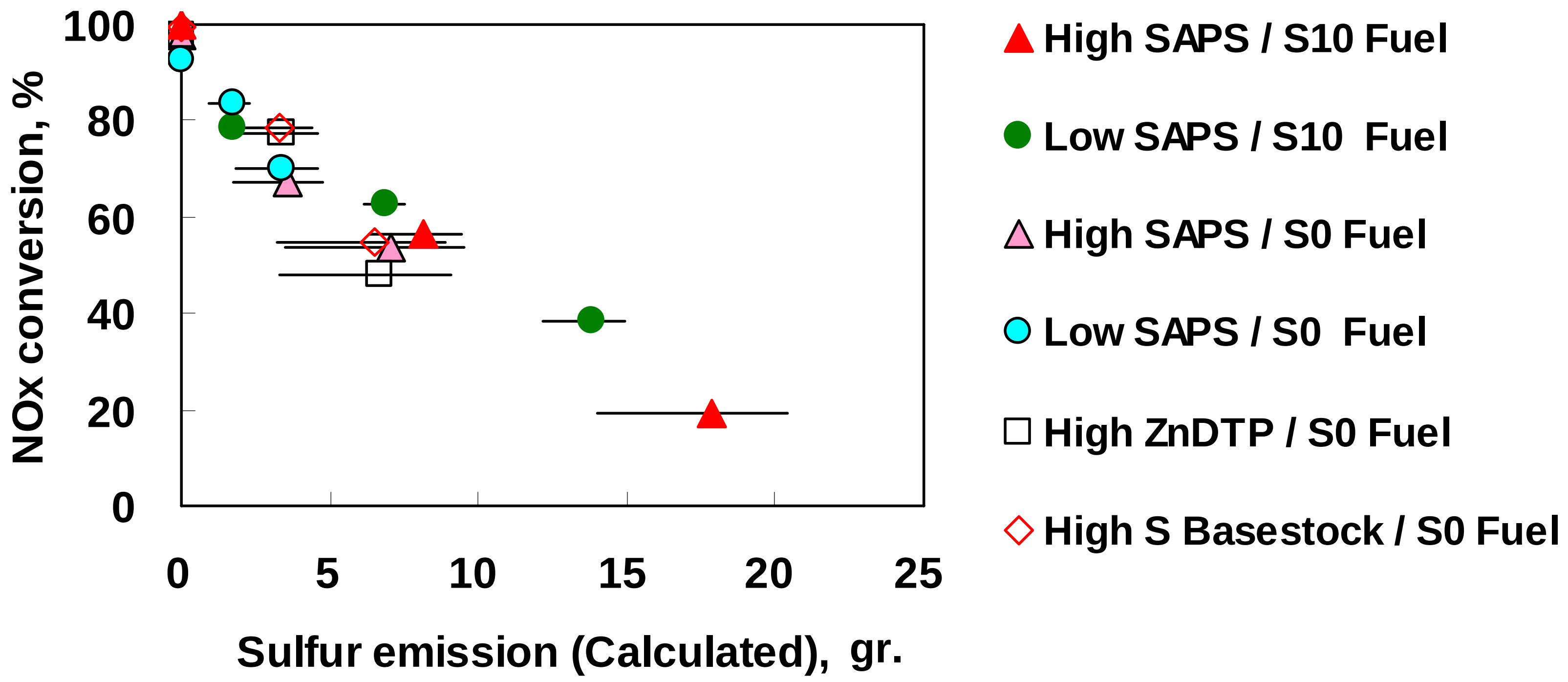
- **In the case of S0 fuel, S is more influential in the deterioration of NOx conversion efficiency than P.**



	High SAPS	Low SAPS	High ZnDTP	High S basestock
S cont. in lub. oil (%)	0.76	0.34	0.69	0.67
P cont. in lub. oil (%)	0.11	0.07	0.28	0.07

Relationship between S emissions and NOx conversion efficiency

- **If S-purge is not performed, NOx conversion efficiency decreases as S emissions coming from fuel and lubricating oil increase.**
- **In the tests conducted on this occasion, no influence of P coming from lubricating oil on catalyst poisoning is observed.**



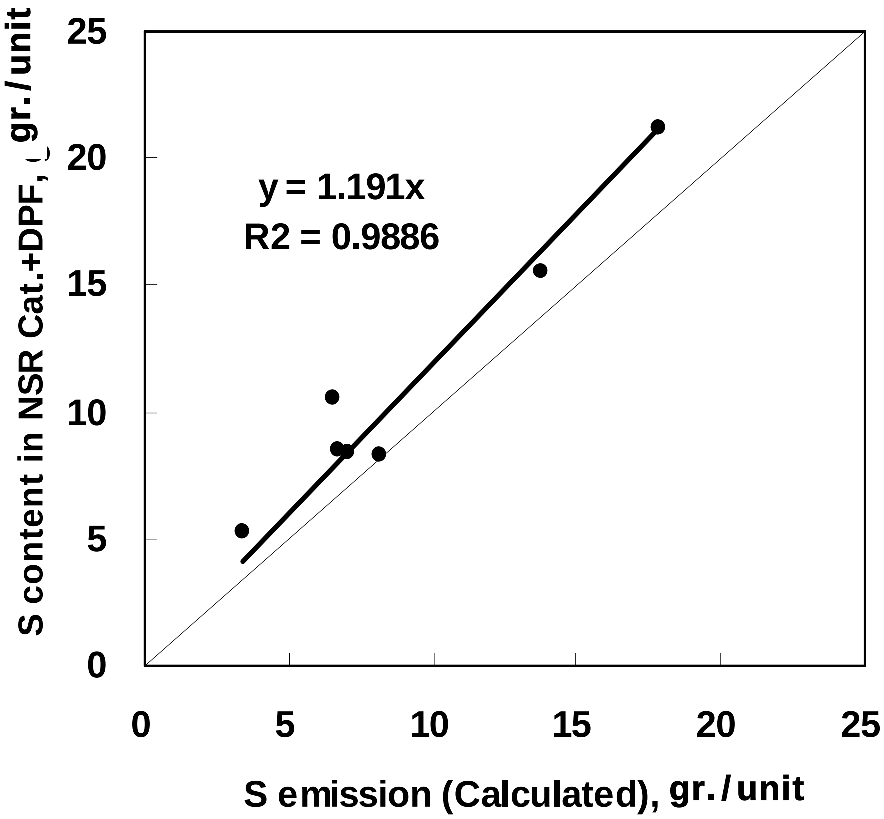
Element analysis for deposits on catalyst

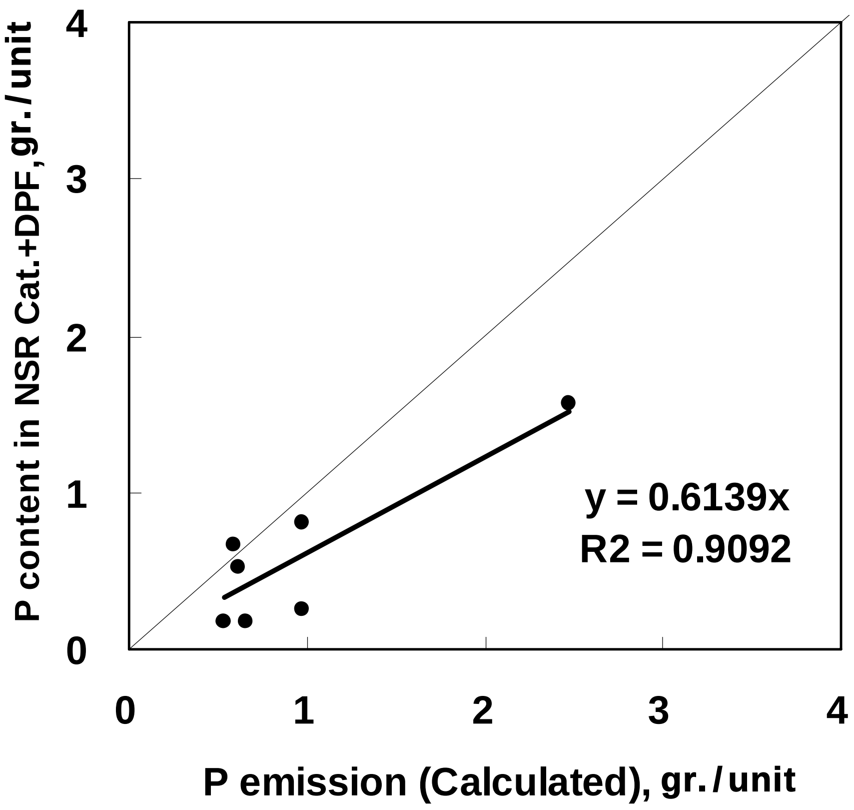
- **The ratio of P/S accumulated on catalyst is smaller than that of oil in every test, which suggests that P is not emitted as much as S.**

Test No.	Fuel	Oil				Elementary Deposits on NSR + DPF		
		Name	S (%)	P (%)	P/S	S (g/unit)	P (g/unit)	P/S
1	S10	High SAPS	0.76	0.11	0.14	21.2	0.80	0.04
2		Low SAPS	0.34	0.07	0.21	15.5	0.67	0.04
3	S0	High SAPS	0.76	0.11	0.14	8.4	0.25	0.03
4		Low SAPS	0.34	0.07	0.21	5.3	0.52	0.10
5		High ZnDTP	0.69	0.28	0.41	8.5	1.57	0.18
6		High S Basestock	0.67	0.07	0.10	10.5	0.17	0.02

Comparison of accumulated S and P with emitted S and P (calculated)

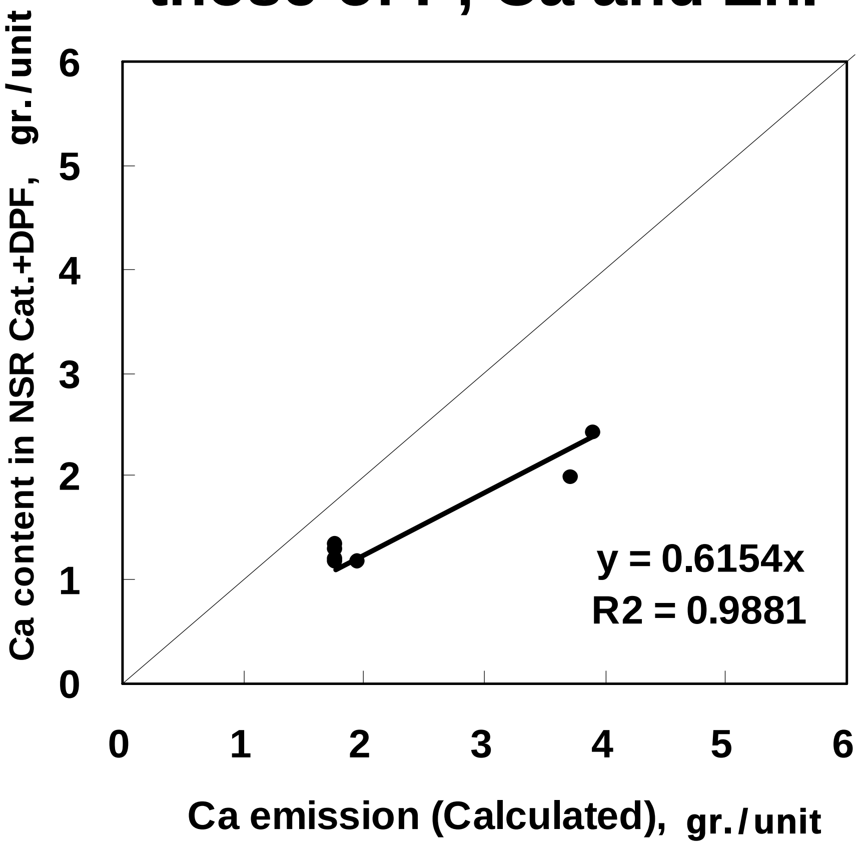
- **120% of S emissions calculated from oil consumption actually accumulates on the catalyst.**
- **60% of P emissions calculated accumulates on the catalyst.**

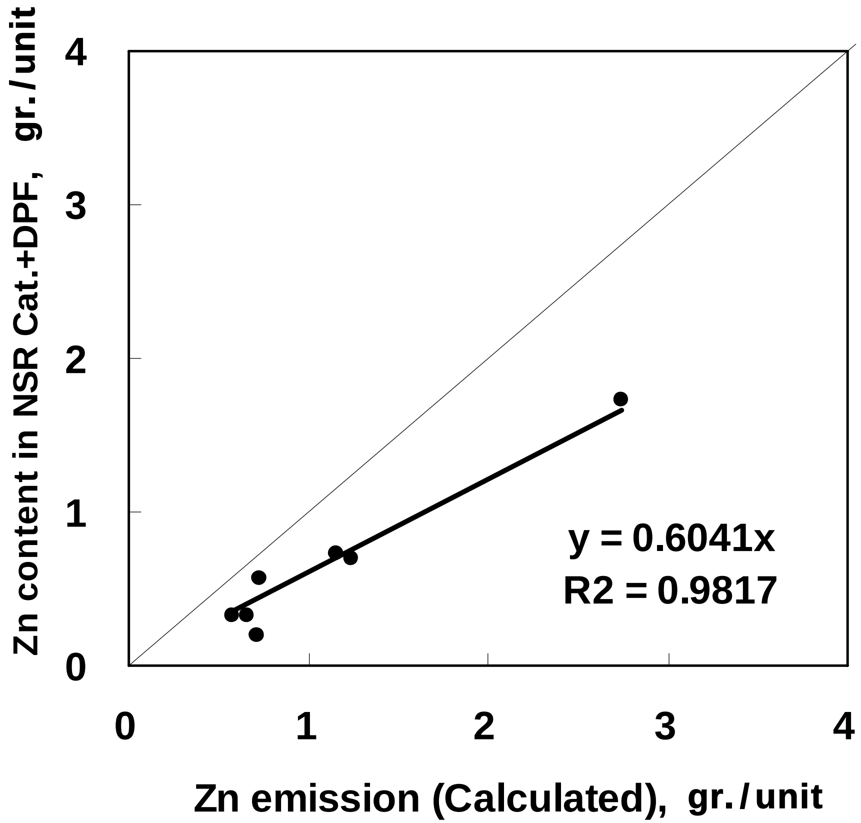




Comparison of accumulated Ca and Zn with emitted Ca and Zn (calculated)

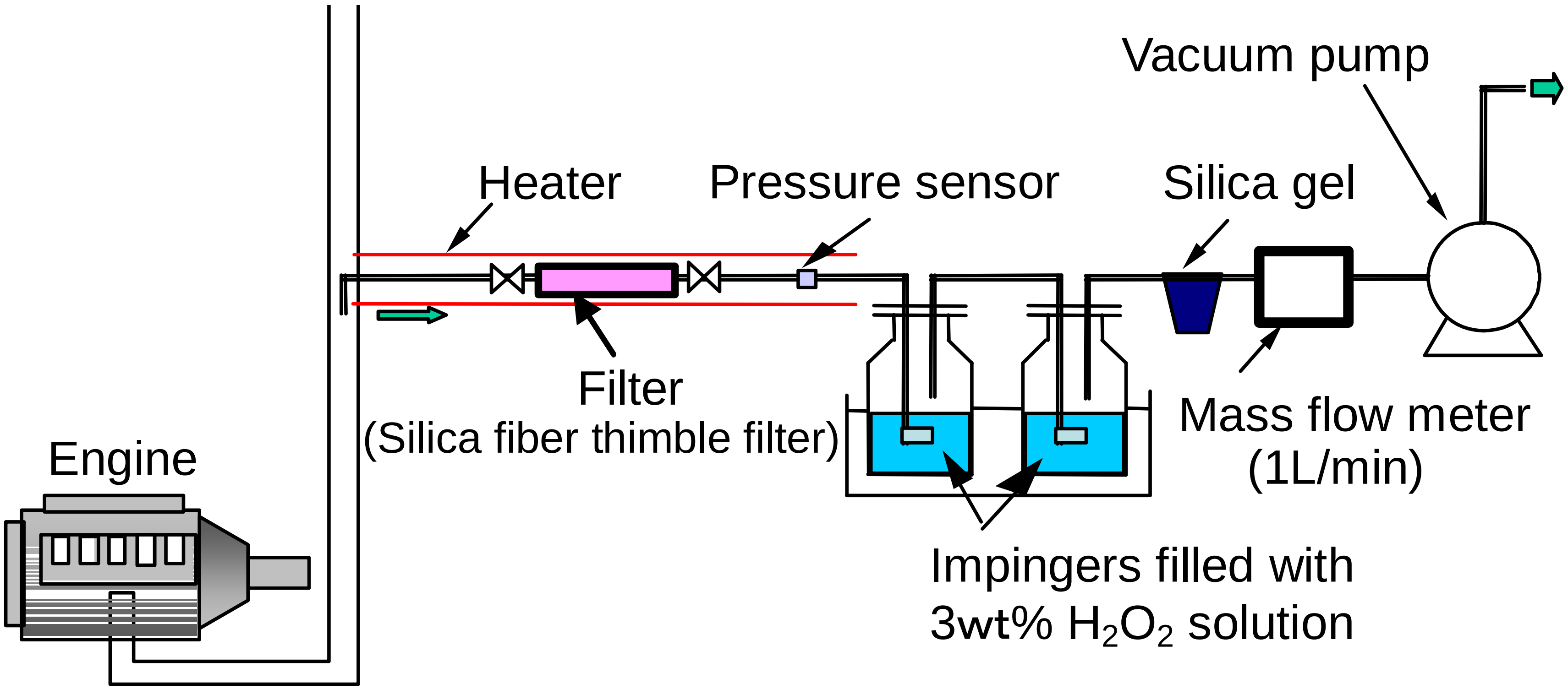
- **60% of Ca and Zn emissions calculated actually accumulate in the same way as P does.**
- **Emission mode of S is presumably different from those of P, Ca and Zn.**





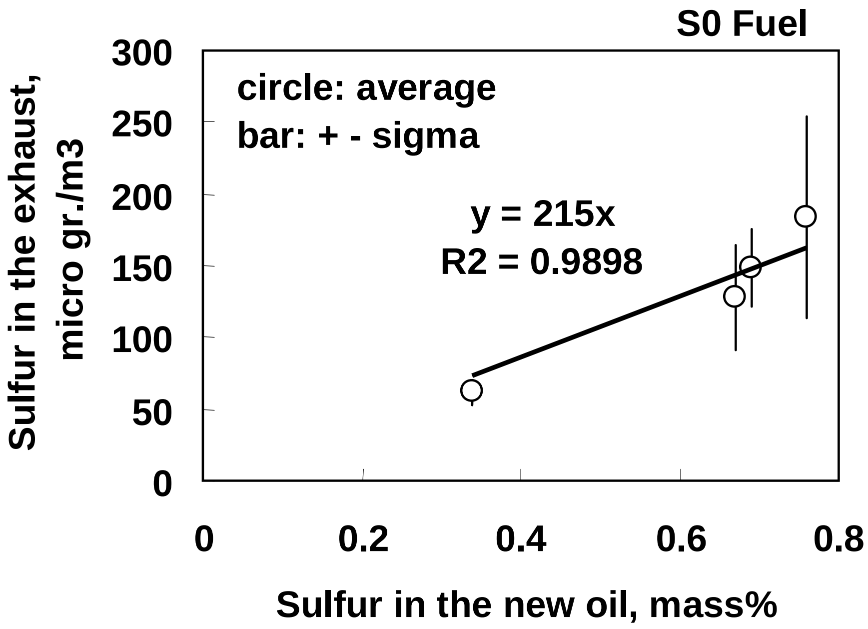
Test method for exhaust gas analysis

- **Test engine and operating conditions are identical to those in engine running test.**
- **Exhaust gases are sampled upstream of catalyst.**
- **PM is cut by thimble filter. Gaseous substances (oxidized S and P) caught in absorbing liquid are analyzed.**

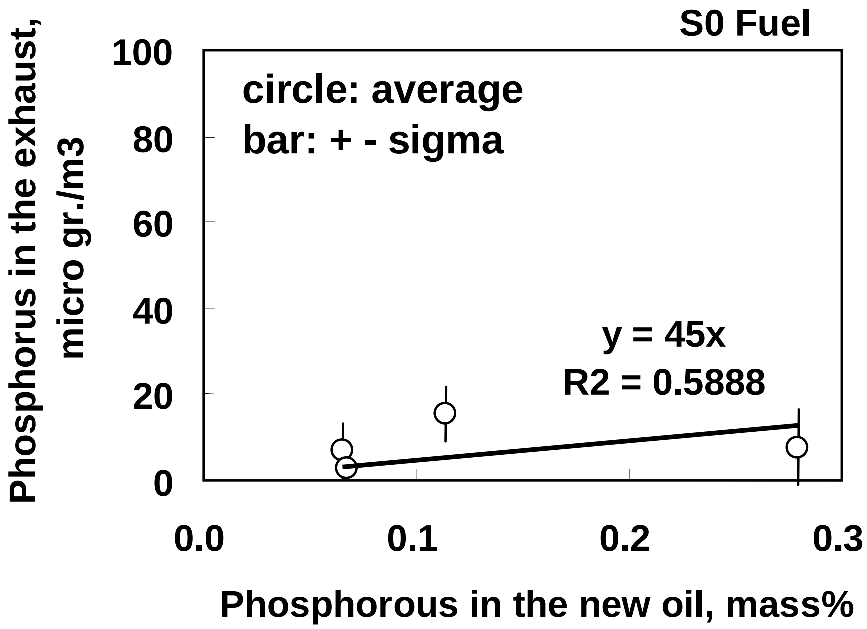


Relationship between quantities of S and P in oil and those in exhaust gases

- **S is emitted as gaseous substances (presumably as SOx), while almost no P is emitted.**



(a) Sulfur

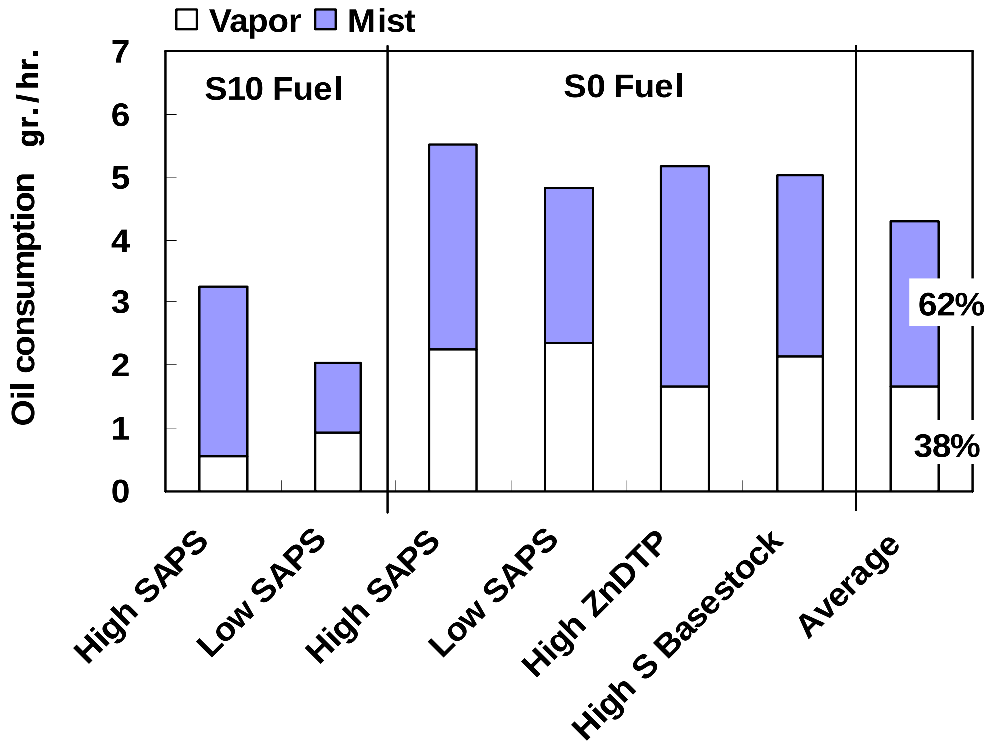


(b) Phosphorous

Analysis for causes of oil consumption

- **Oil consumption due to oil mist is 62% on average.**
- **This ratio agrees with the ratios of P, Ca and Zn deposits on the catalyst.**

Oil consumption
- **① Evaporation: Light components in base oil and additives**
  Light components such as gases generated by heat oxidative pyrolysis
- **②Dispersion of oil mist**



Influence of S and P on NSR (Summary)

- In the tests conducted without performing S-purge (control for desulfation), NOx conversion efficiency of the NSR is affected by the poisoning by S in the oil and decreases as S emission from the oil increases.
- P is emitted to a lesser degree than S. Also, catalyst poisoning by P is not so clearly recognized under these test conditions.

⇨ **It is preferable to use lubricating oil containing less S in the vehicles equipped with the NSR.**

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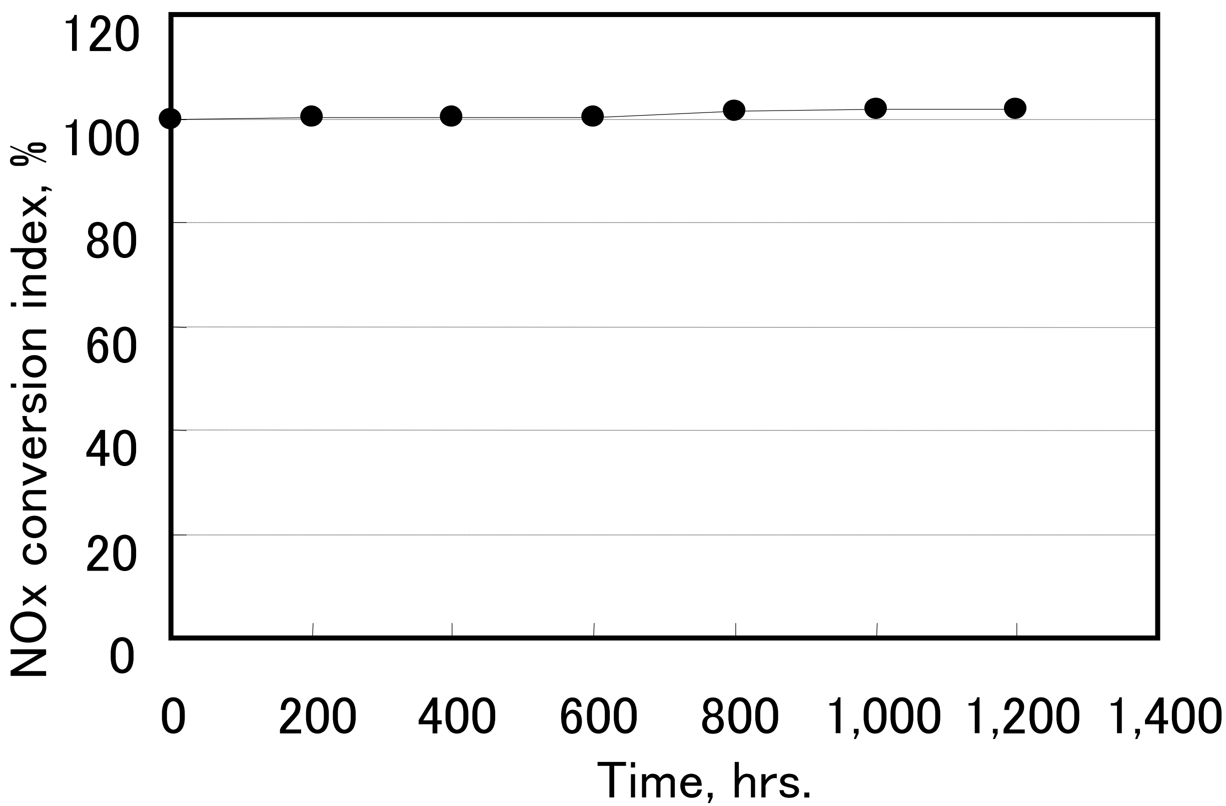
Outline of test

➤ **Conduct a long time durability test to confirm the influence of ash, S and P coming from oil on the Urea SCR.**

- **Test: Long time engine durability test**
  - **Operating conditions: 100% engine speed /60% load**
    （Keep SCR inlet temperature at 400 deg C or lower to prevent deterioration by heat)
  - **Testing period: 1270 hrs.**
    (equivalent to 150,000 km driving on the road)
- **Engine: 9.2L common rail DI engine meeting '05 regulations**
- **After-treatment system**
  : Oxidation catalyst + Urea SCR + Oxidation catalyst
- **Fuel: S10 diesel fuel available in the Japanese market**
- **Test oil: High SAPS oil (Upper limit level in the Japanese market)**

Change in NOx conversion efficiency during test

- **No deterioration of NOx conversion efficiency is observed throughout testing period.**
- **Although Ca, Zn, S and P tend to accumulate on the upstream oxidation catalyst, the level of accumulation does not affect catalyst performance.**



Influence of ash, S and P on Urea-SCR (Summary)

- **There is no deterioration in NOx conversion efficiency throughout the long time durability test using conventional high SAPS oil equivalent to DH-1. It is estimated that the influence of ash, S and P coming from lubricating oil on the Urea-SCR is small, even when the durability of the device is taken into consideration.**

⇨ **If SAPS components is DH-1 level, the reduction in SAPS components is not necessary for vehicles equipped with Urea-SCR.**

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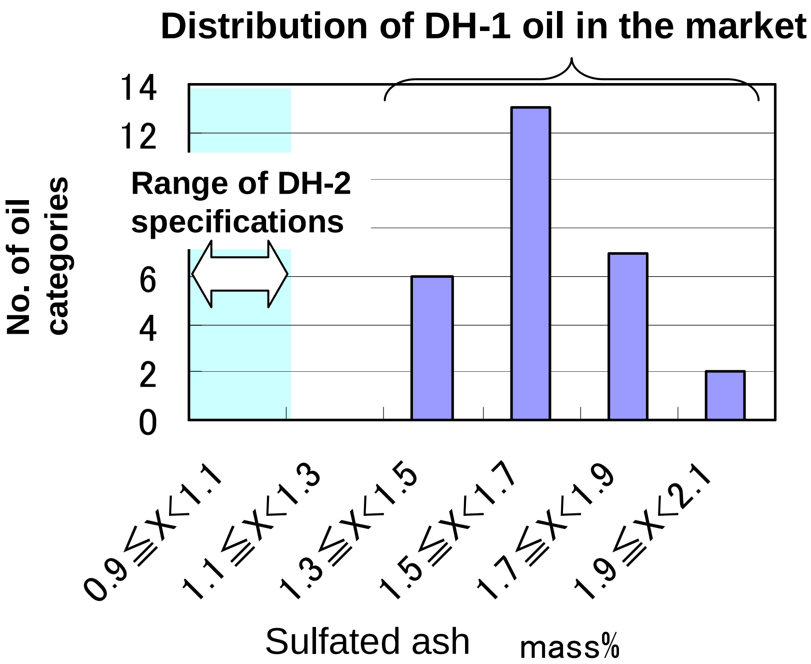
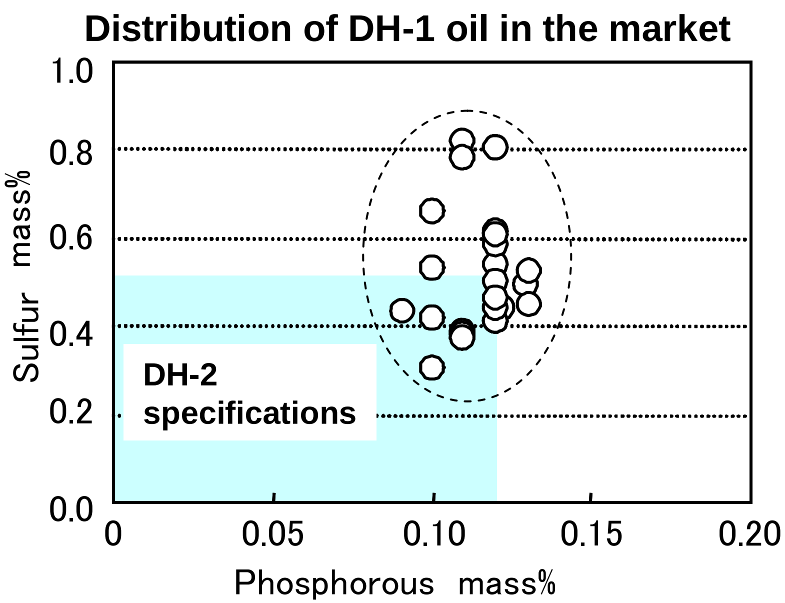
Feedback to JASO Specifications

- **The results obtained at this time were fed back to the JASO DH-2 specifications for diesel engine lubricating oil for heavy duty vehicles such as trucks and buses equipped with DPF.**

	DH−2 (New specifications)	DH−1 (Old spec/for reference)
Sulfated ash	Within 1.0±0.1mass%	No specification
Sulfur	0.5mass% or lower	No specification
Phosphorous	0.12mass% or lower	No specification





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Outline of test

- Determine the effect of energy-saving type lubricating oil on fuel economy in both Japanese and US evaluation test modes and grasp the potential for CO_2 reduction.

- Testing: Vehicle fuel economy test using chassis dynamometer
  - Evaluation test mode: 10･15 Mode (Japan) and FTP Mode (US)
  - Fuel economy to be evaluated at both initial（3200km) and after-aging（10400km) stages.

- Test vehicle: Passenger car (2.5L, MPI, 2WD, sliding valve-train type)

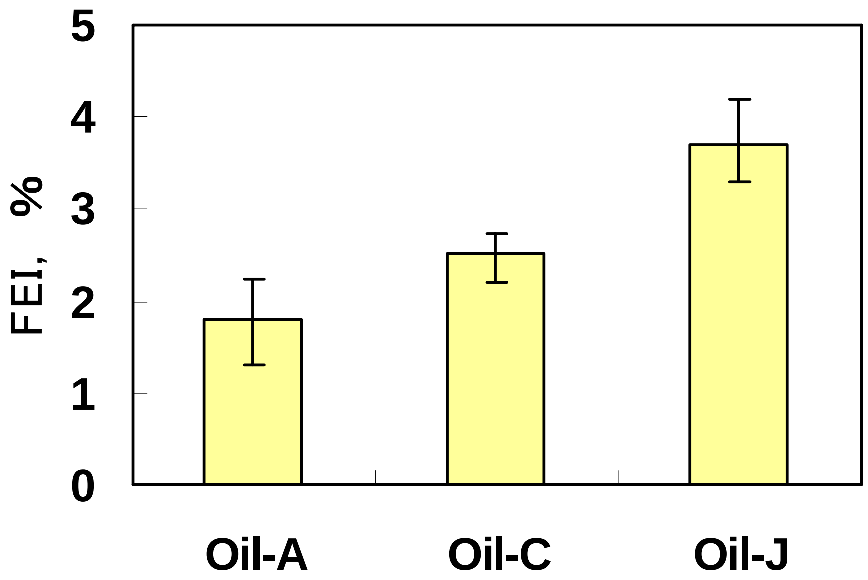
Test oil properties

- **Energy-saving type lubricating oils (three kinds of them) of low viscosity and with Mo friction modifier (Mo FM) mixed are evaluated.**
- **Calculated as fuel economy improvement % against baseline oil**

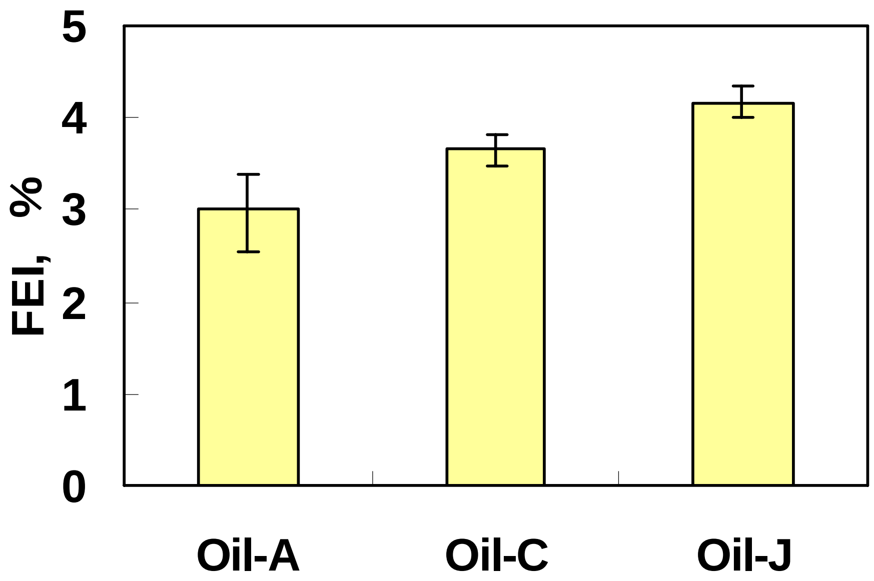
		Oil-A	Oil-C	Oil-J	Baseline Oil
Vis. grade		5W-20	5W-20	0W-20	20W-30
FM formulation		None	Yes	Yes	None
KV mm^2/s	40℃	45.12	45.22	41.4	103.5
	100℃	8.023	8.067	8.945	12.13
VI		151	152	205	108
HTHS vis., mPa･s		2.6	2.6	2.6	3.7
Mo content, mass%		<0.001	0.02	0.10	<0.001

Fuel economy improvement at initial stage

- **Owing to the low viscosity and the Mo FM mixed in, fuel economy improvement (FEI) ratio increases and reaches 4% at maximum in the case of most effective oil (Oil-J).**
- **The effect of Mo FM on fuel economy improvement is believed to be 0.5 to 1.0%.**
- **FTP Mode exhibits greater fuel economy improvements due to low viscosity than 10・15 Mode.**



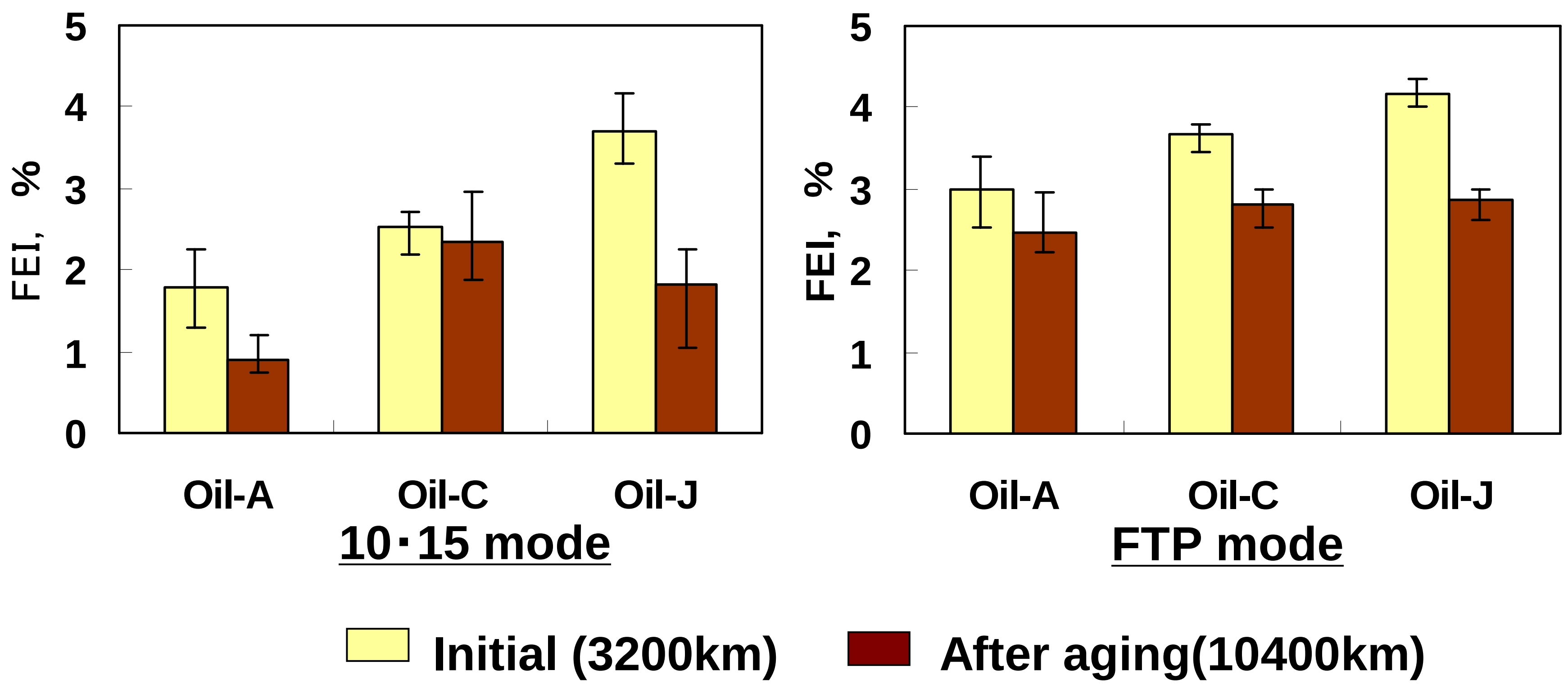
10・15 Mode



FTP Mode

Fuel economy improvement after aging

- **Fuel economy improvement ratio reduces through aging on all test oils. However, 1 to 3% improvement still remains after 10,000 km driving.**



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Summary

- As a result of the study of the influence of lubricating oil on diesel after-treatment devices, it has been found that the reduction of ash in oil is necessary for the DPF and the reduction of S is effective for the NSR. This result was fed back to the JASO Diesel Engine Oil Specifications.

- The effect of lubricating oil to reduce CO_2 emitted from gasoline vehicles depends on the evaluation mode being used in Japan or in the US. However, the maximum improvement reaches approximately 4% over the 20W-30 baseline oil. The data obtained on this occasion is expected to be utilized for developing the ASTM Test Method which is designed to evaluate the performance of oil on fuel economy.