Further Challenge in Automobile and Fuel Technologies For Better Air Quality

JCAP1 Diesel WG Results

Oct. 9-10.2002

ＪＣＡＰ **Diesel** ＷＧ
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for Joint Meeting ; APBF-DEC,CAFE,JCAP

Objectives

Examine future direction of automobile and fuel technologies by evaluating exhaust emissions and reliability for advanced types of fuel and vehicles/engines

Outline

·Matrix test: Clarify the fuel effect for future exhaust emissions control technologies.

Fuels; sulfur , distillation and others

Modes; Japan 10/15 mode for vehicles

Japan D13, WHDC, Japan MOT/JARI for engines

3 vehicles/ 3 engines/ 11 fuels matrix

·Mileage accumulation test: Clarify the fuel sulfur effect on after-treatment device performance and reliability

Fuels; sulfur 100, 50, 10ppm

Modes; Japan 11 Lap (average speed 46km/h) for vehicles

JARI engine test cycle (average speed 26km/h) for engines

-2 vehicles/ 2 engines/ 3 fuels

Vehicle/Engine Specification for STEP II

All of the listed are turbocharged intercooled and direct injection engines

	Code	Emission Control Technologies	E. I. W.(kg)	Type	Engine Type	Displ. L	Power kW	F.I.E	EGR
Vehicle	XA	NSR cat.-A	1250	Passenger Car	In-line4	2.0	81	Common-Rail	Cooled EGR
	XB	CR-DPF-B	2000	Passenger Car	In-line4	2.5	110	Elec. Distributer type	Hot EGR
	XD	NSR cat. + CR-DPF	1500	Passenger Car	In-line4	2.0	———	Common-Rail	Cooled EGR
Engine	YB	LPL-EGR ＋CR-DPF	———	Small Truck	In-line4	4.9	132	Elec. Distributer type	LPL Cooled EGR
	YC	CR-DPF-A +Urea SCR	———	Large Truck	In-line6	15.7	272	Common-Rail	No
	YD	NSR cat.-B	———	Small Truck	In-line4	3.8	———	Common-Rail	Cooled EGR

NSR cat.: NOx Storage and Reduction catalyst / **CR-DPF:** Continuous Regeneration Diesel Particulate Filter
LPL Cooled EGR: Low Pressure Loop Cooled Exhaust Gas Recirculation
Urea SCR: Urea Selective Catalytic Reduction / **E.I.W.:** Equivalent Inertia Weight

The latest technologies which systematized those of after treatment, combustion, and control were provided for testing.

Japan Clean Air Program

Fuel Properties for STEP II

		Matrix test											Mileage accumulation test		
	NO.	2D-01	2D-02	2D-03	2D-04	2D-05	2D-06	2D-07	2D-08	2D-09	2D-10	Class1	2D-21	2D-22	2D-23
	Symbol	D500	D300	D100	D50	DK50	K50	K10	K10 LCN	D50 oxy	K10 oxy	Class1	MDK10	MDK50	MDK100
	Sulfur target(max)	S500	S300	S100	S50	S50	S50	S10	S10	D50+ DGM10%	K10+ DGM10%	Sweden Class1	S10	S50	S100
	Distillation	Diesel	Diesel	Diesel	Diesel	Diesel /kerosine	Kerosine	Kerosine	kerosine w/o CNI						
Density (g/cm³ @15℃)		0.8320	0.8312	0.8316	0.8312	0.8120	0.7932	0.7932	0.7930	0.8404	0.8068	0.8132	0.8028	0.8026	0.8025
Kinetic Vis. (mm²/s @30℃)		3.926	3.922	4.140	4.104	2.241	1.380	1.407	1.384	3.108	1.270	2.220	1.704	1.694	1.695
Distillation ℃	IBP	172.0	173.0	179.0	179.0	155.0	153.0	152.0	152.0	158.0	148.5	178.5	158.0	158.0	158.0
	10 vol%	221.0	218.0	225.0	221.0	180.0	165.5	166.0	166.0	182.5	160.0	195.0	175.0	175.0	175.0
	50 vol%	286.0	286.0	288.0	287.5	237.5	194.0	194.0	194.0	282.5	187.0	233.0	206.5	206.0	206.0
	90 vol%	**324.5**	**327.0**	**332.5**	**334.0**	**317.0**	**239.0**	**239.5**	**239.5**	**331.5**	**238.5**	**272.0**	289.0	288.0	289.0
	95 vol%	334.0	338.0	344.0	346.0	334.0	248.0	250.0	250.0	344.0	249.0	281.0	323.5	324.0	325.0
	EP	344.0	347.5	354.0	355.0	347.5	261.0	261.5	263.0	354.5	262.0	296.0	355.0	354.0	353.5
Cetane Number		57.2	57.4	58.4	58.8	54.1	54.2	54.2	47.2	61.7	59.7	54.4	53.8	54.6	53.4
Cetane Index		58.2	58.4	59.2	58.8	53.2	47.0	47.1	47.2	−	−	−	48.2	48.2	48.2
Aromatic (HPLC) (vol%)	mono	19.4	18.4	16.5	16.0	16.4	16.6	16.7	16.7	15.4	16.4	3.3	17.3	17.4	17.4
	di	2.0	1.6	1.4	1.4	0.8	0.4	0.4	0.4	1.2	0.3	0.1	0.6	0.8	0.7
	tri+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
S	(massppm)	**443**	**298**	**94**	**46**	**36**	**48**	**0**	**0**	**43**	**0**	**0**	**9**	**44**	**95**
C	(mass%)	85.7	85.9	85.7	86.1	85.8	85.8	85.8	86.1	81.7	81.1	85.4	85.5	85.4	85.4
H	(mass%)	14.3	14.1	14.3	13.9	14.2	14.2	14.2	13.9	14.5	15.1	14.6	14.5	14.6	14.6
O	(mass%)									3.8	3.8				
Low Heat Value (kJ/kg)		43210	43240	43280	43280	43360	43340	43350	43350	41160	41140	43180	43340	43340	43340
HFRR (μm @60℃)		363	332	300	306	528	452	452	454	565	664	232	315	325	330

- **·Oxygenate：DGM（di-ethylene glycol di-methyl ether)**
- **·Test fuel:10 fuels + Sweden class1 fuel**
- **·Mileage accumulation test fuel:3 fuels**

STEP II Tests Performed

Code	Matrix Test	Mileage Accumulation Test
Vehicle XA：NSR cat.	9 fuel	30,000km
Vehicle XB：CR-DPF	10 fuel	30,000km
Vehicle XD：NSR cat.+ CR-DPF	6 fuel	
Engine YB：CR-DPF	6 fuel	30,000km
Engine YC：CR-DPF ＋ Urea-SCR	4 fuel	10,000km
Engine YD：NSR cat.	4 fuel	

Vehicle XA : NSR cat.

·Engine Spec.

E. I. W.(kg)	Type	Engine Type	Displ. L	Power kW	Intake Air	Comb.	F.I.E	EGR
1250	Passenger Car	In-line4	2.0	81	T/C+I/C	DI	Common-Rail	Cooled EGR

·Emission control technologies

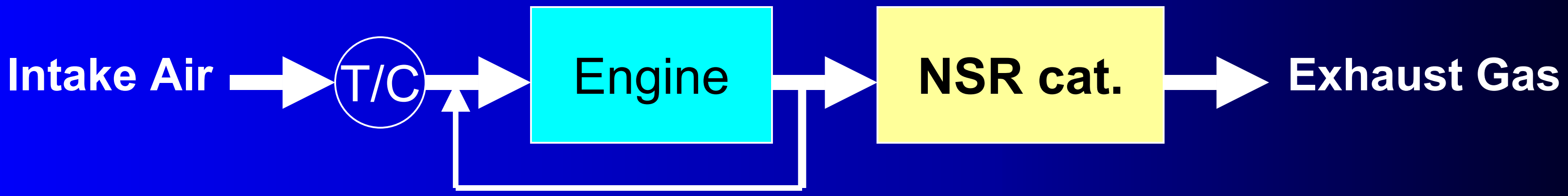
-NOx Storage Reduction Catalyst

-Rich spike by Smokeless-Rich combustion,which increases catalyst bed temperature

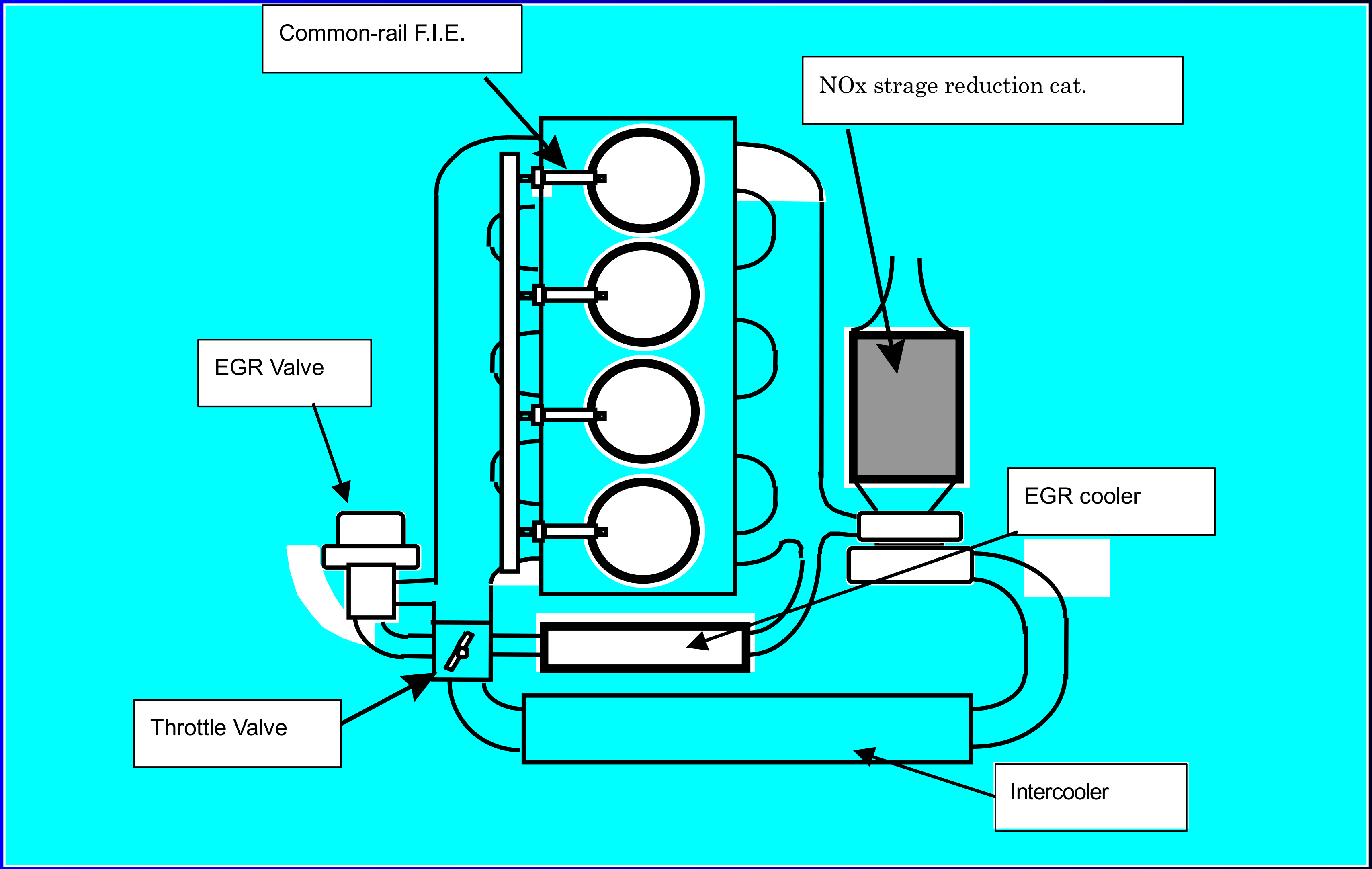
·Test items

-Matrix test: 9 fuels / 10.15 mode

-Mileage accumulation test: 30,000km

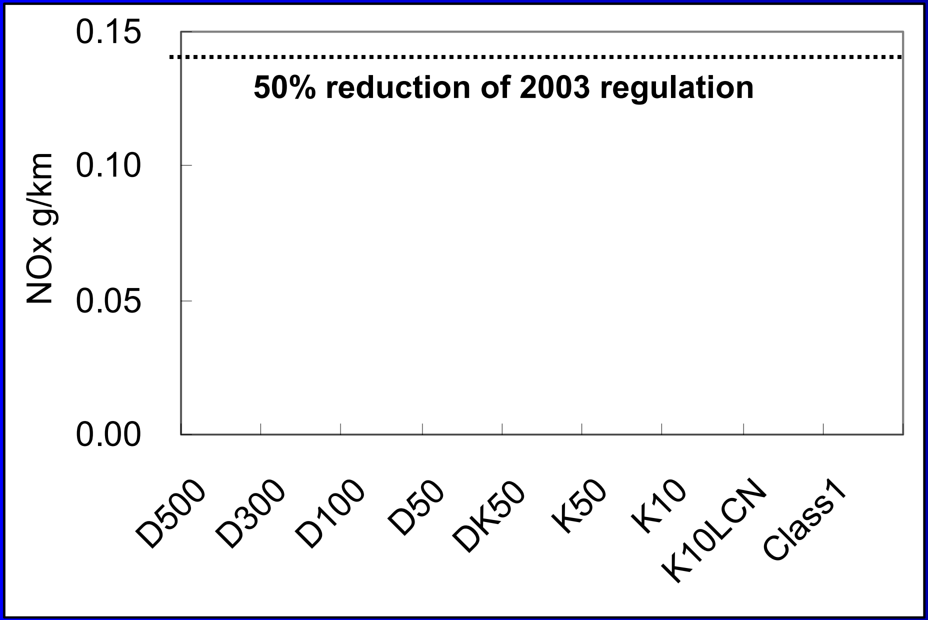


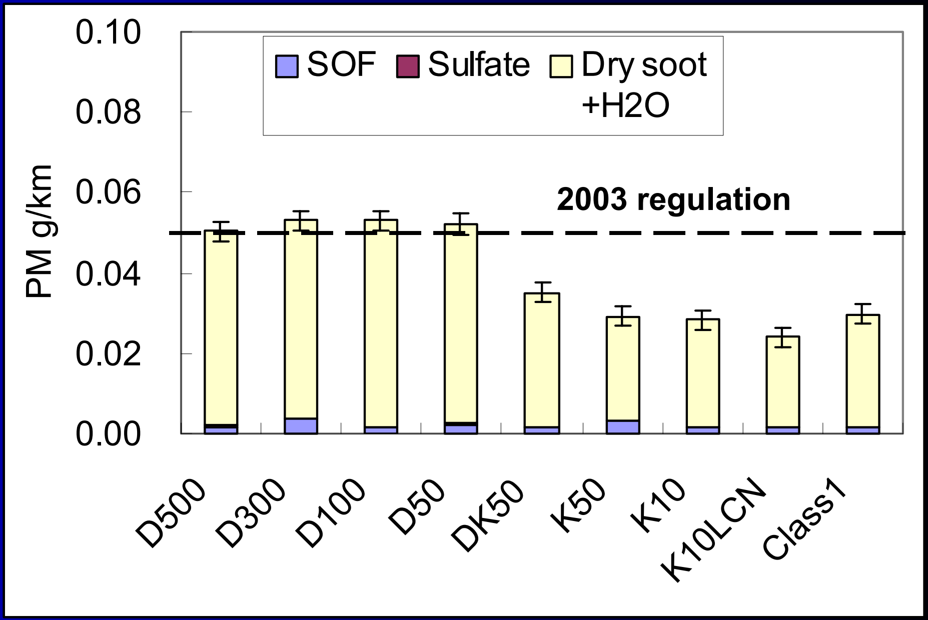
Schematics of Engine for Vehicle XA



NOx/PM Emission of Matrix test for Vehicle XA

10.15 mode exhaust emission





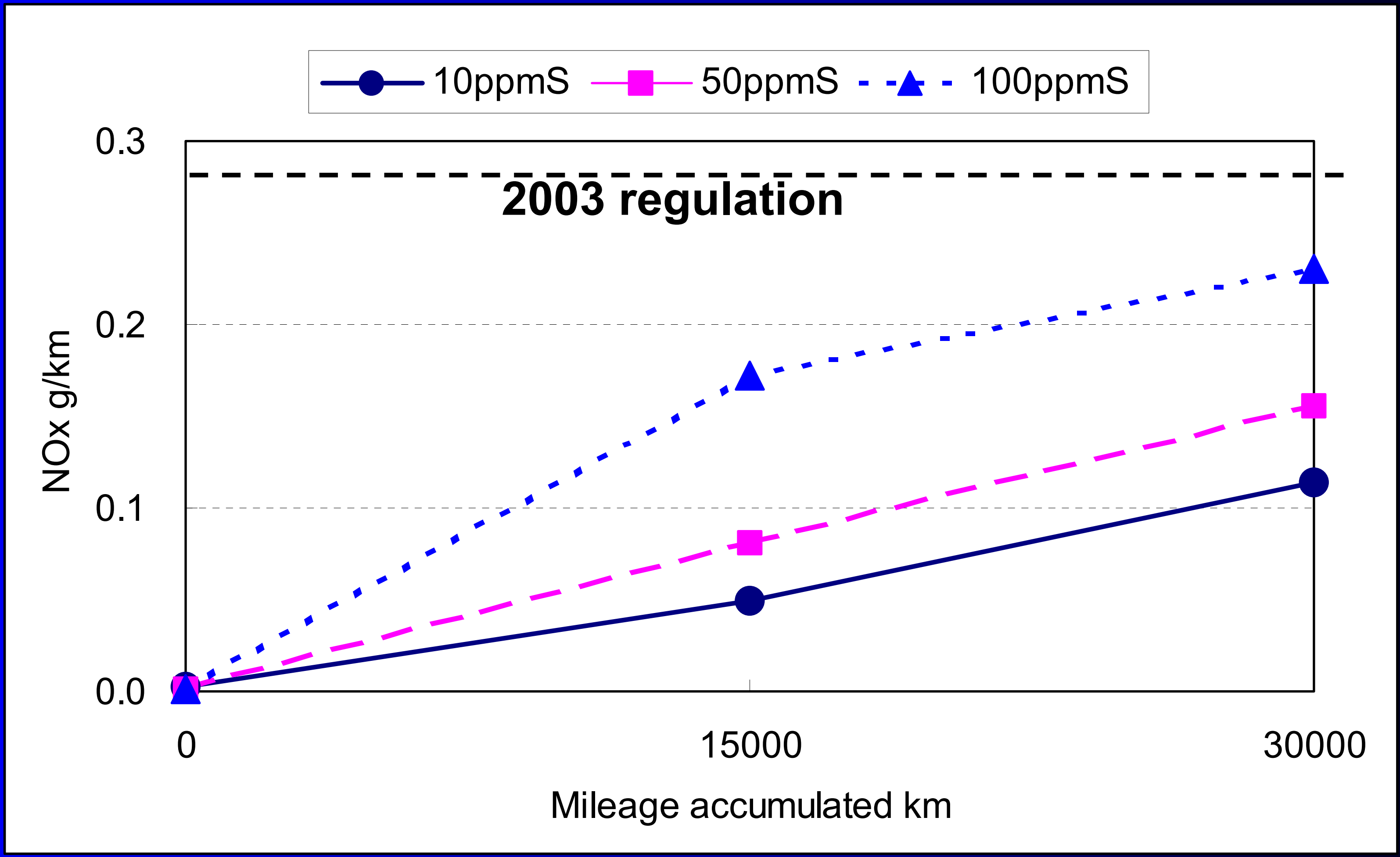
·NSR catalyst is proved to be highly effective NOx reduction technology

·Fuel effect on NOx; Not observed(Considering the fact that PM composition result shows little sulfate discharge, catalyst are fresh and have sufficient NOx storage capacity).

·Fuel effect on PM ; Distillation affect PM.

Vehicle XA

Mileage Accumulation Test of Vehicle XA



NOx increases as fuel sulfur increases and as mileage increases.

Vehicle XA

Vehicle XB : CR-DPF

·Engine Spec.

E. I. W.(kg)	Type	Engine Type	Displ. L	Power kW	Intake Air	Comb.	F.I.E	EGR
2000	Passenger Car	In-line4	2.5	110	T/C+I/C	DI	Elec. Distributer type	Hot EGR

·Emission control technologies

-DPF: Woven Ceramic Fiber ; improve NOx/PM ratio by decreasing trapping efficiency. Oxidation catalyst before DPF.

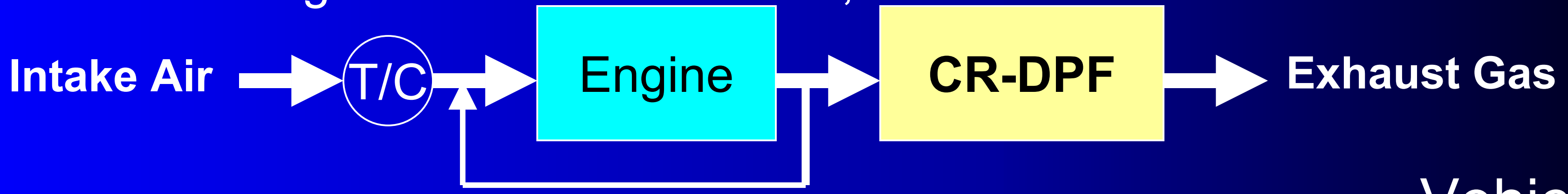
-Pre-mixed low temperature combustion method; improve NOx/PM ratio by reducing PM discharge.

-High Pressure Loop Electronically controlled EGR system with Exhaust Back Pressure Compensation.

·Test Items

-Matrix test: 10 fuels/ 10・15 mode

-Mileage accumulation test: 30,000km



Vehicle XB

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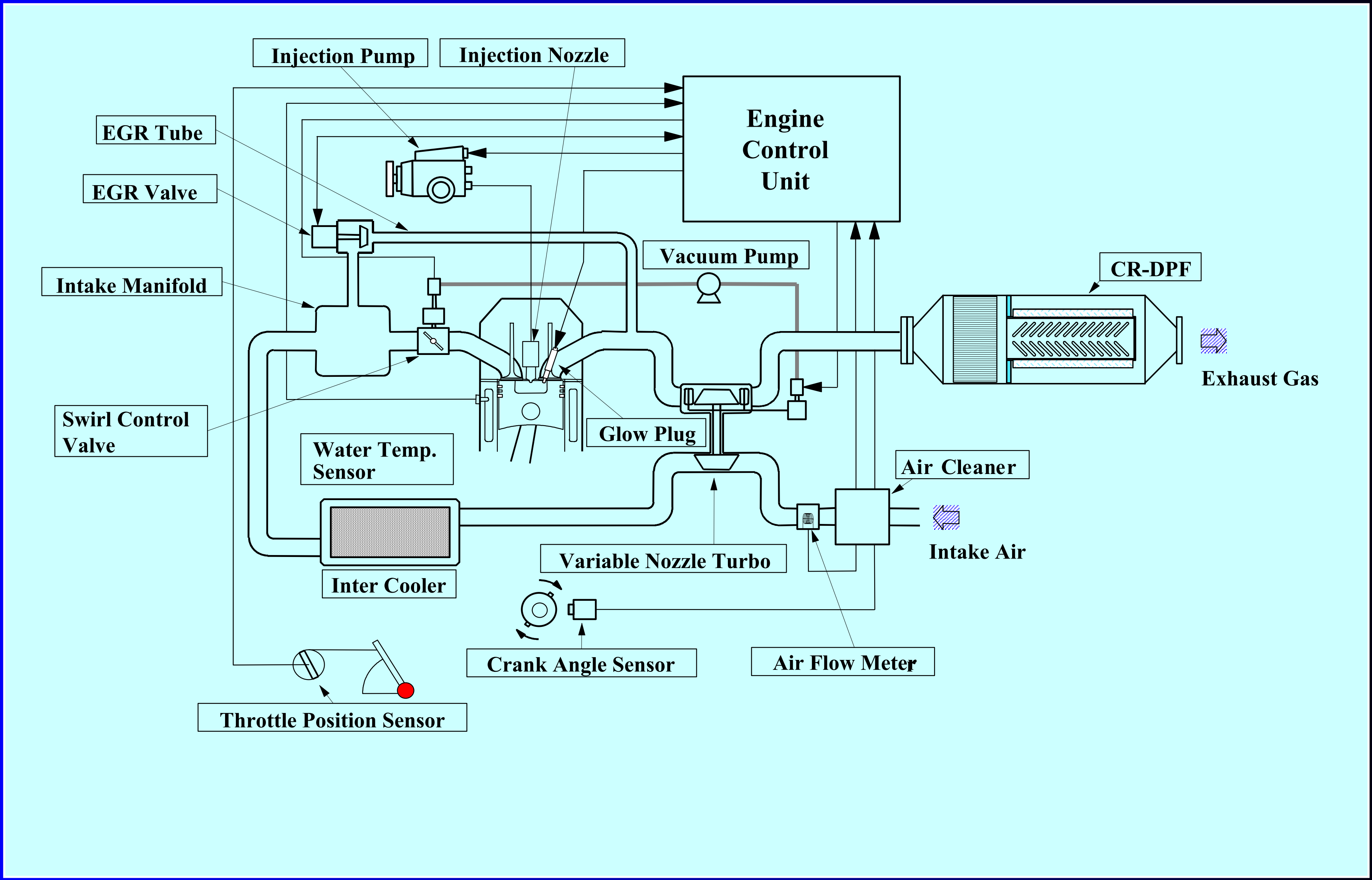
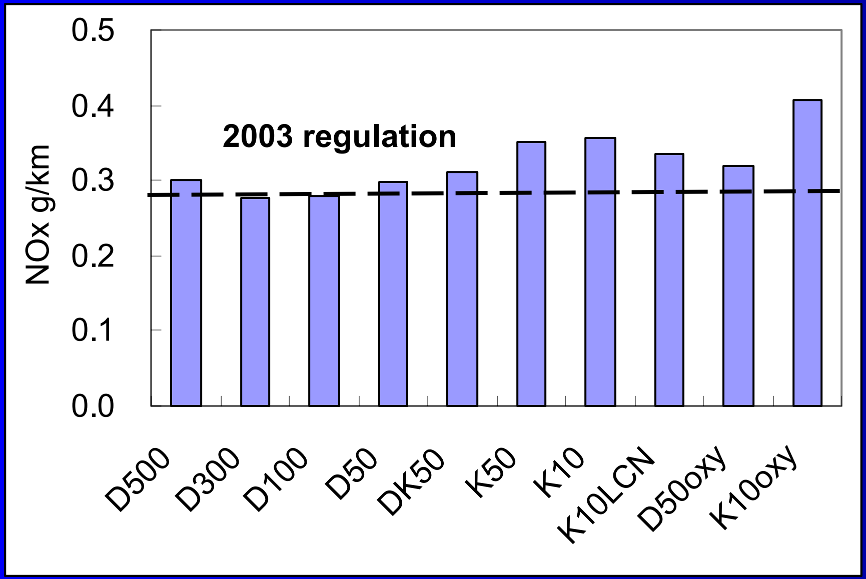
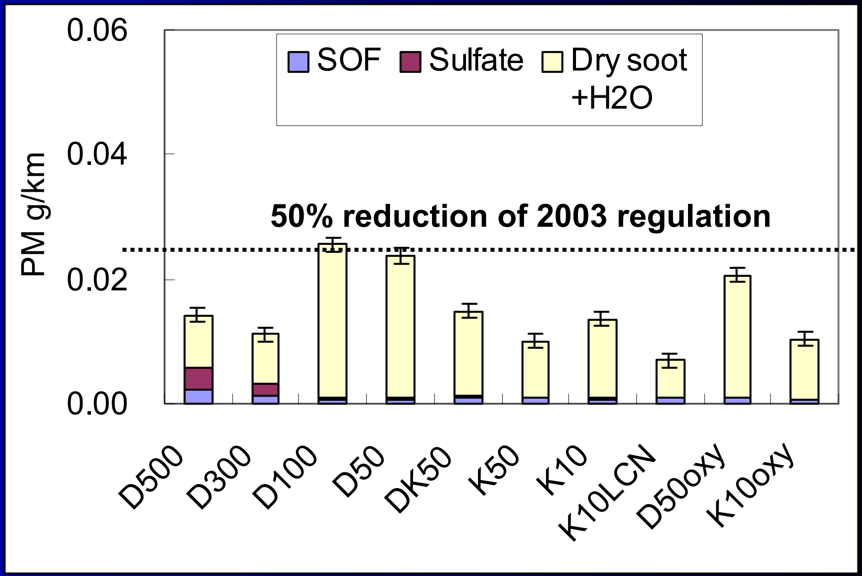
Schematics of Engine for Vehicle XB



NOx/PM Emission of Matrix test for Vehicle XB

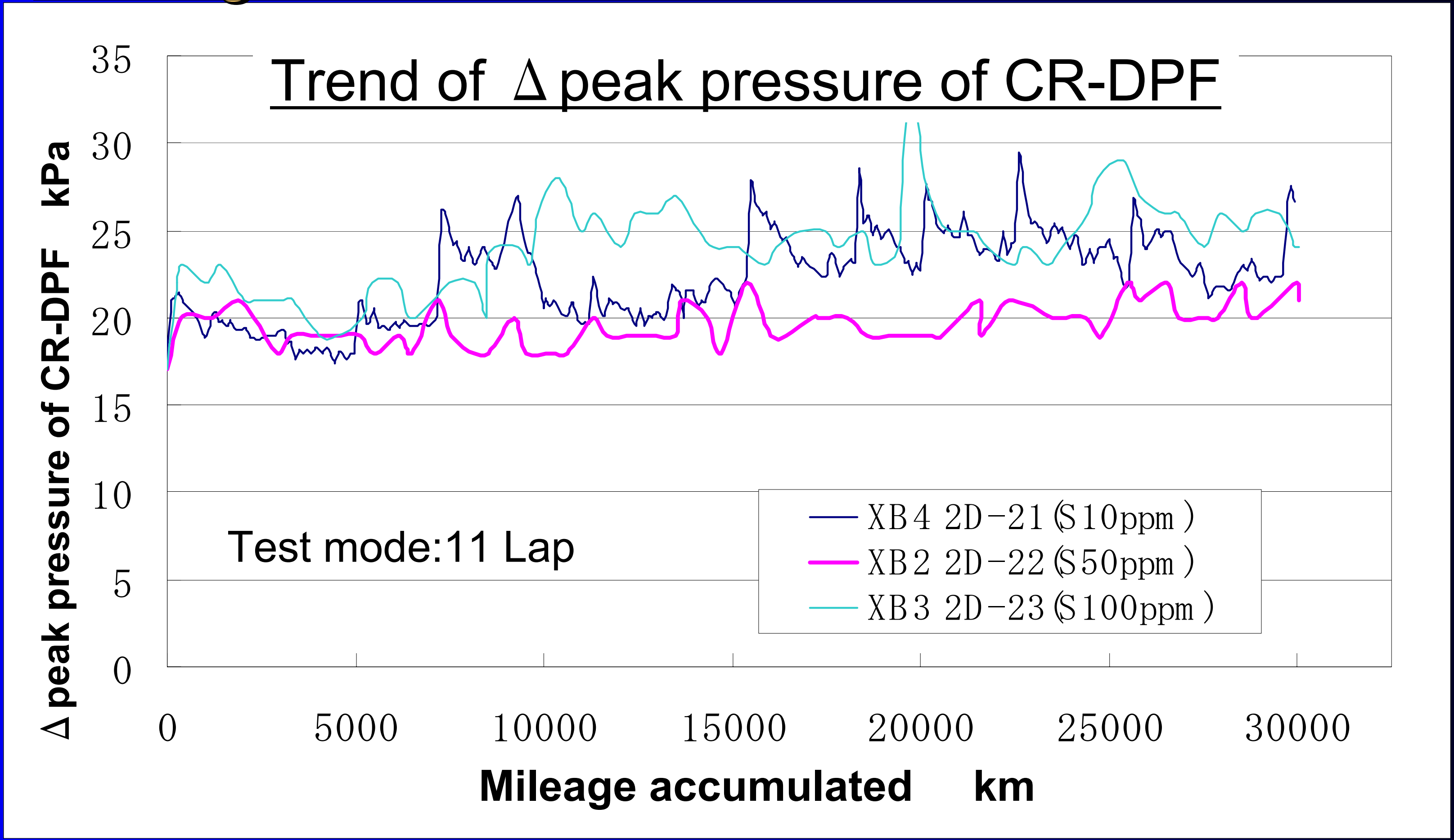
10.15 mode exhaust emission





- Drysoot trapping efficiency fairy low.
- Fuel effect on PM ; Low distillation decrease PM. Sulfur effect is not clarified.
- Fuel effect on NOx; Low distillation increase NOx. This is due to increased accell position, resulting change in EGR valve position.

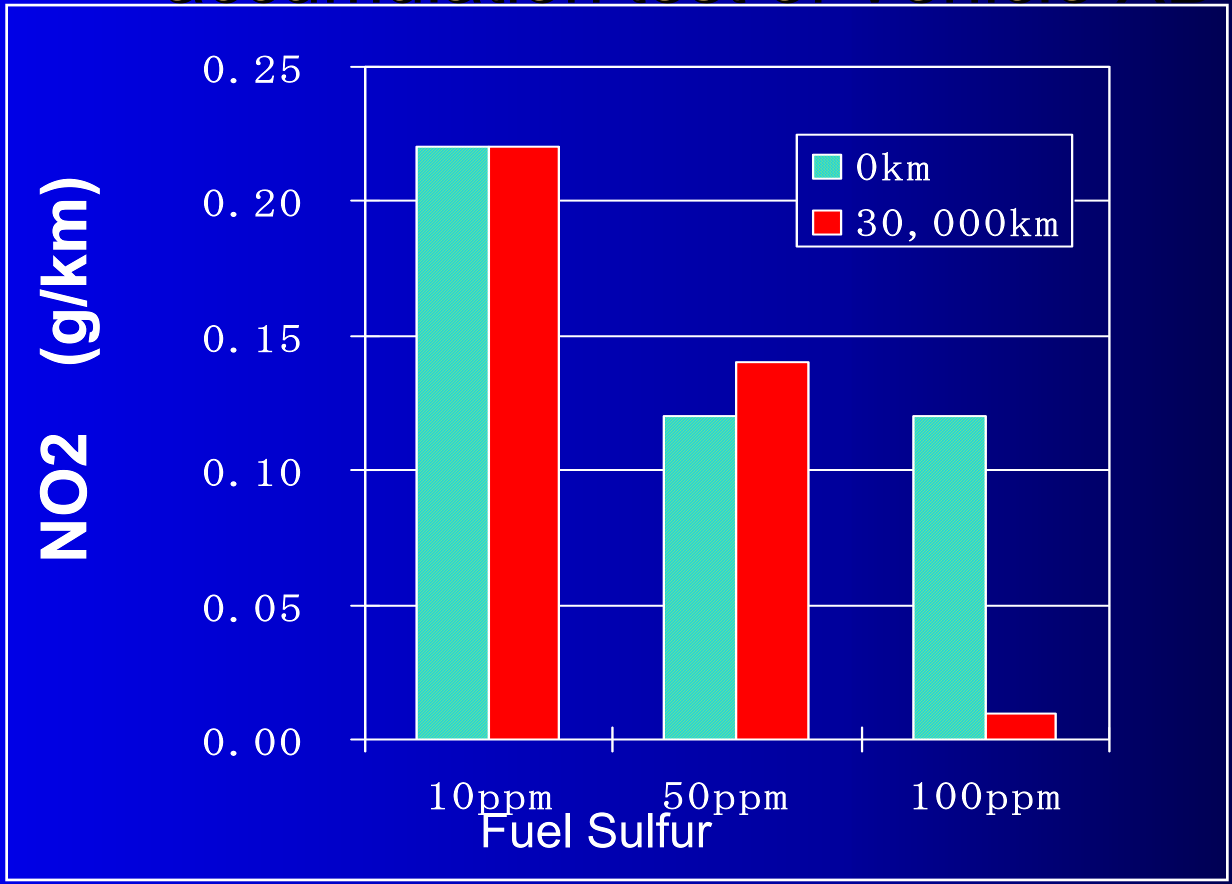
Mileage Accumulation Test of Vehicle XB



All 30,000km-mileage accumulation tests using 3 fuels (100ppmS, 50ppmS, and 10ppmS) were completed successfully. When running on 10ppmS fuel, more back pressure increase was observed than 50ppmS fuel. We presume that intake air temperature during the test effects the results.

Vehicle XB

Change in NO2 emissions before and after mileage accumulation test of Vehicle XB



When compared NO2 emissions before and after mileage accumulation test, no change was observed for 10ppmS fuel and 50ppmS fuel respectively. The result of 100ppmS fuel showed a significant reduction in NO2. There is a possibility of the oxidation catalyst being poisoned with sulfur.

Vehicle XB

Vehicle XD : NSR cat.+CR-DPF

·Engine Spec.

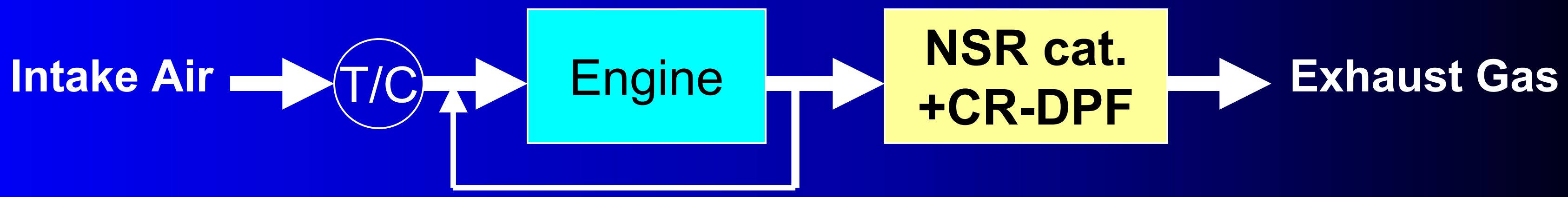
E. I. W.(kg)	Type	Engine Type	Displ. L	Power kW	Intake Air	Comb.	F.I.E	EGR
1500	Passenger Car	In-line4	2.0	———	T/C+I/C	DI	Common-Rail	Cooled EGR

·Emission control technologies

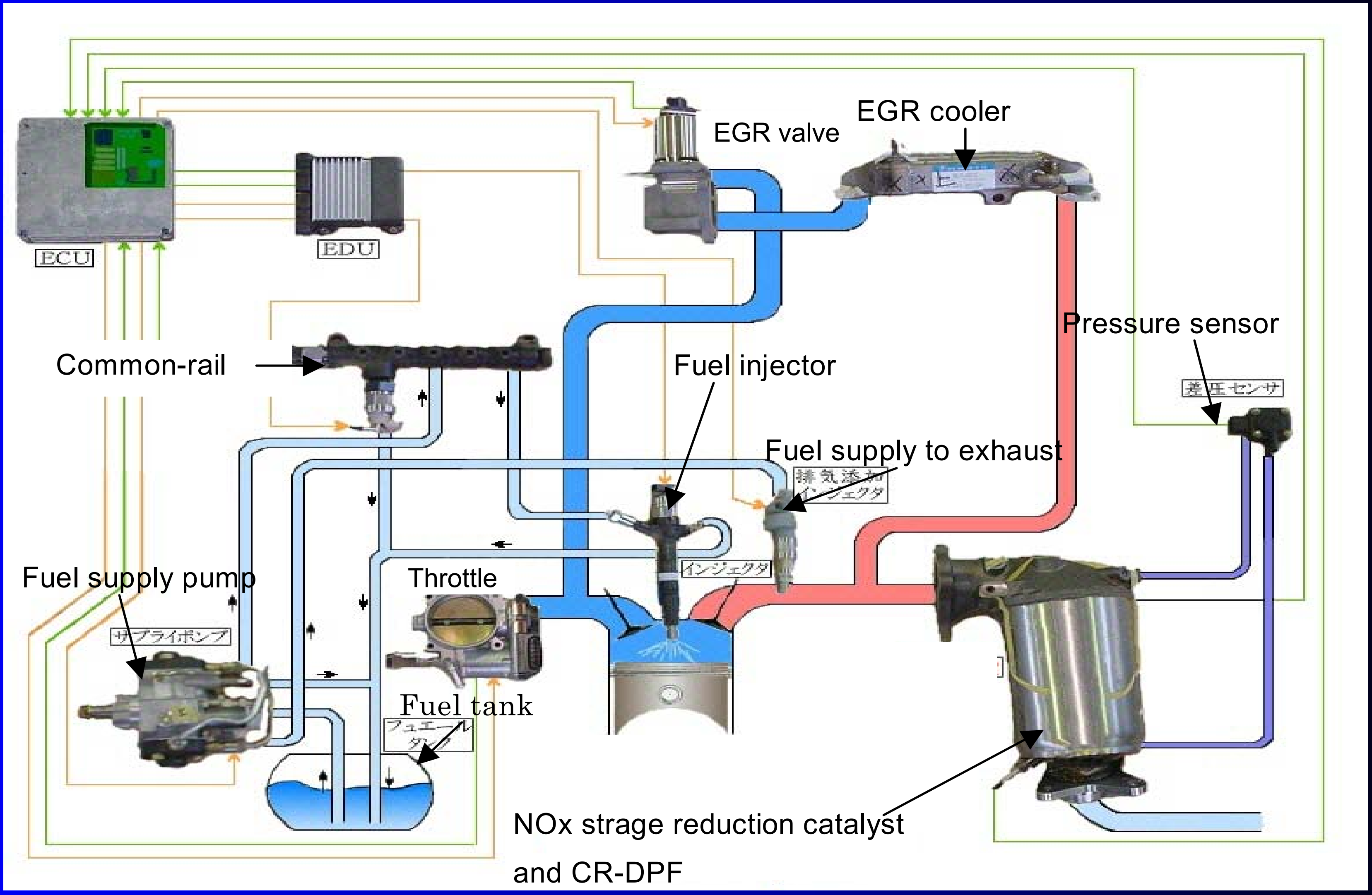
-To reduce NOx and PM simultaneously with NSR catalyst + CR-DPF.

·Test Items

-Matrix test: 6 fuels / 10・15 mode

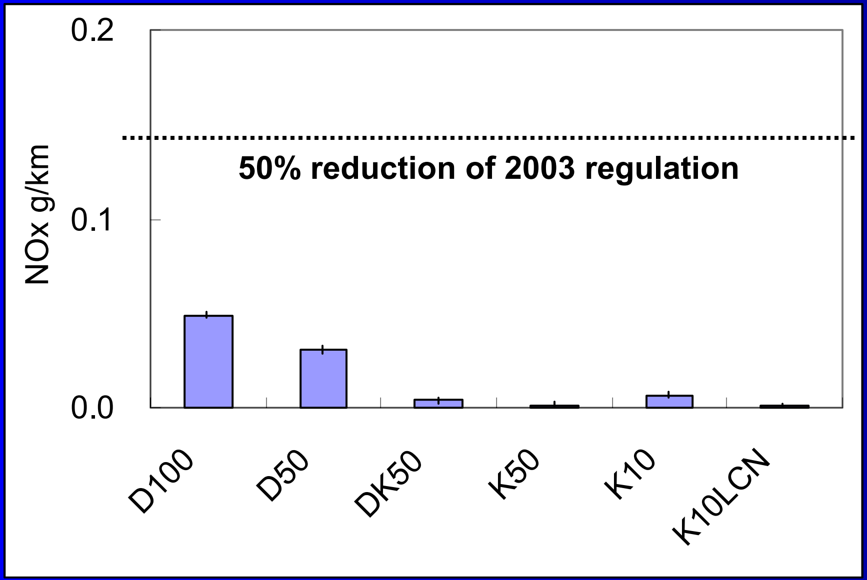


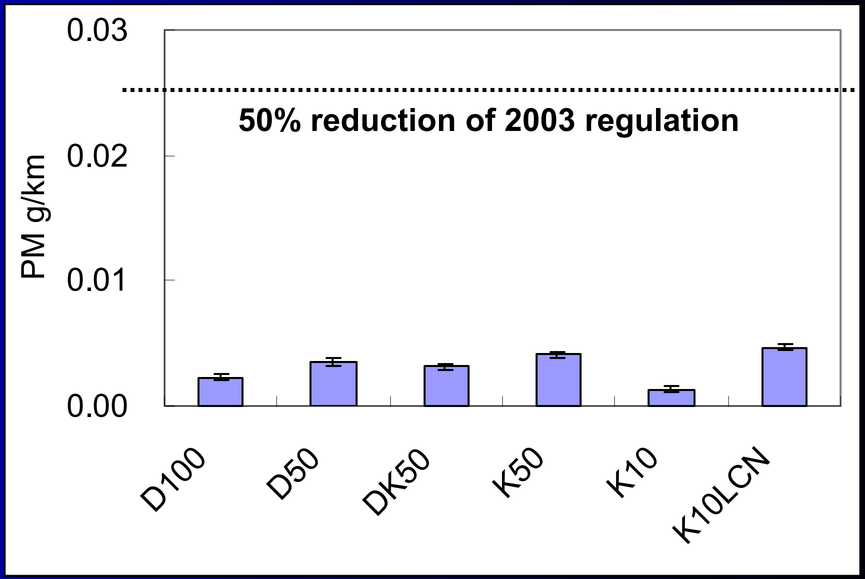
Schematics of Engine for Vehicle XD



NOx/PM Emission of Matrix test for Vehicle XD

10.15 mode exhaust emission





-The after-treatment system (NOx storage reduction catalyst + CR-DPF) is proved to be a highly effective simultaneous reduction technology of NOx and PM, which means it has a high potential as emission control technology for future regulations.

-Mileage accumulation test will be necessary for clarifying fuel effects.

Vehicle XD

Engine ＹB:CR-DPF

·Engine Spec.

E. I. W.(kg)	Type	Engine Type	Displ. L	Power kW	Intake Air	Comb.	F.I.E	EGR
―――	Small Truck	In-line4	4.9	132	T/C+I/C	DI	Elec. Distributer type	LPL Cooled EGR

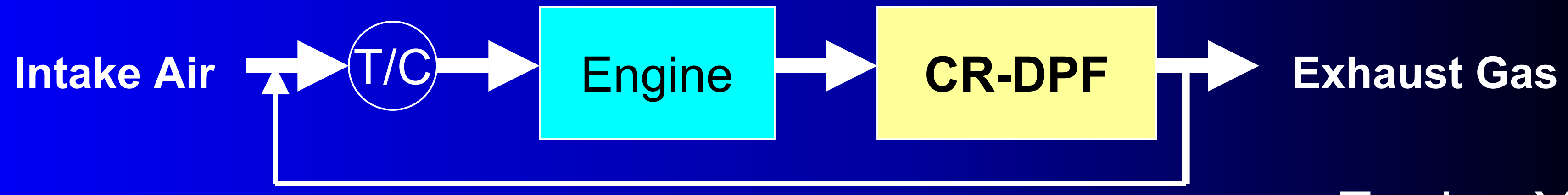
·Emission control technologies

-CR-DPF ; Precious metal oxi. cat. + ceramic monolith DPF

- Low Pressure Loop-EGR; suppress change of EGR ratio by DPF back pressure change

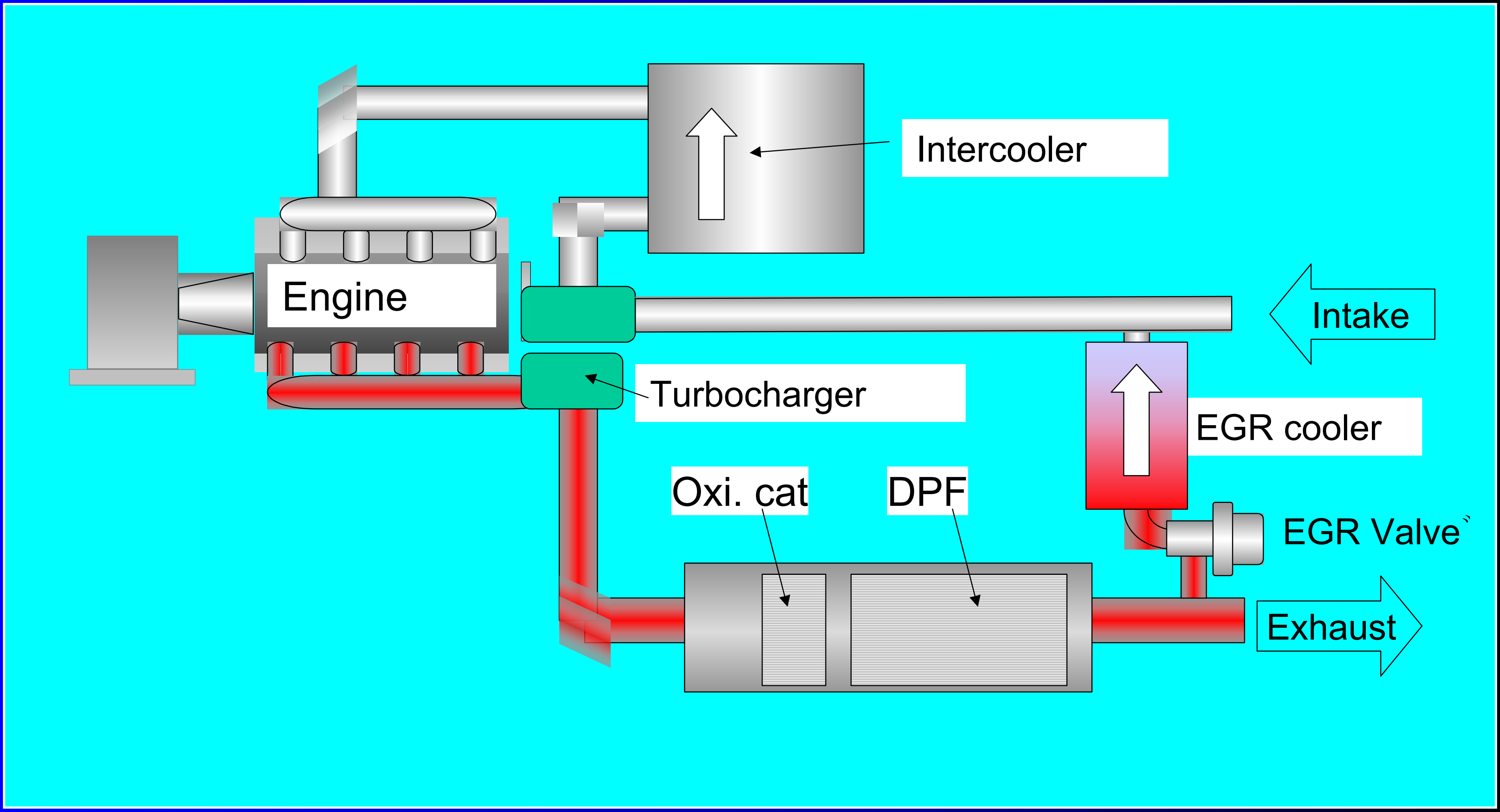
·Test Items

-Matrix test: 6 fuels / D13 mode,WHDC mode, MOT/JARI mode
-Mileage accumulation test: 30,000km



Engine YB

Schematics of Engine YB (CR-DPF Engine)



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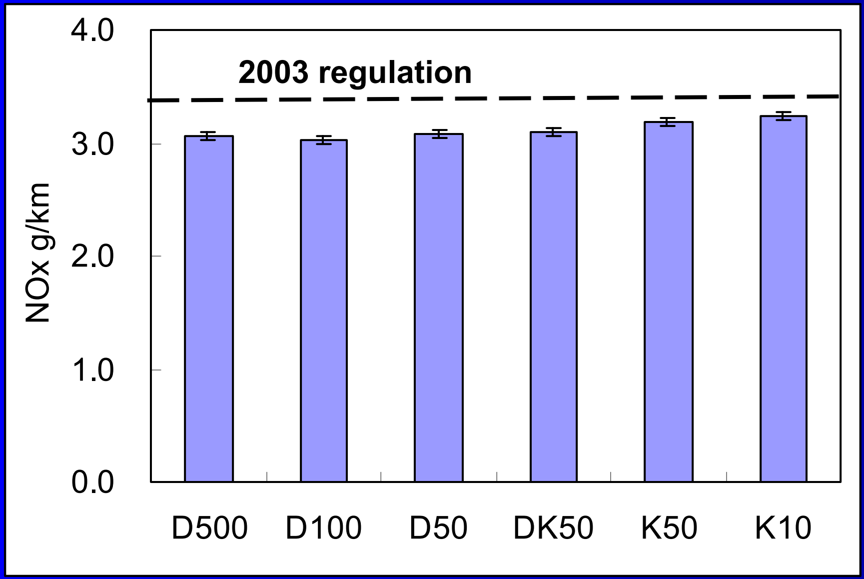
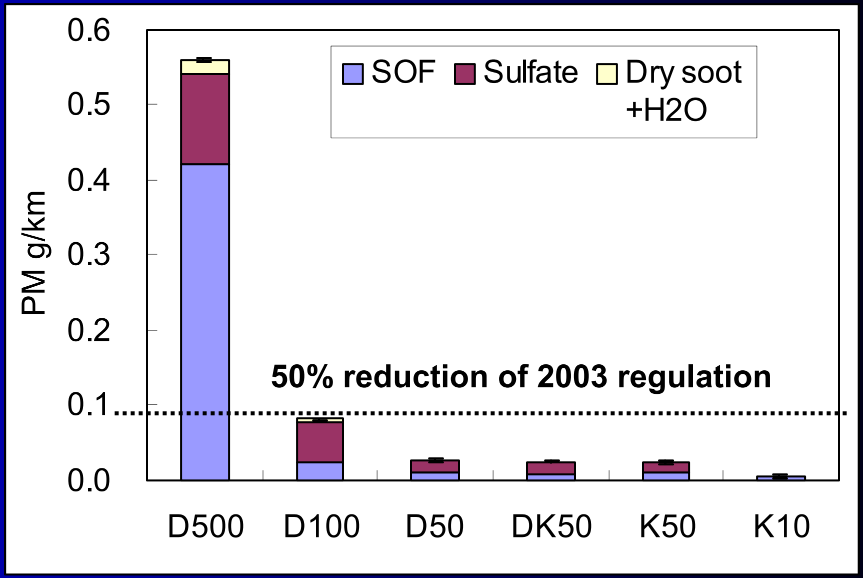
NOx/PM Emission of Matrix test for Engine YB

D13 mode exhaust emission



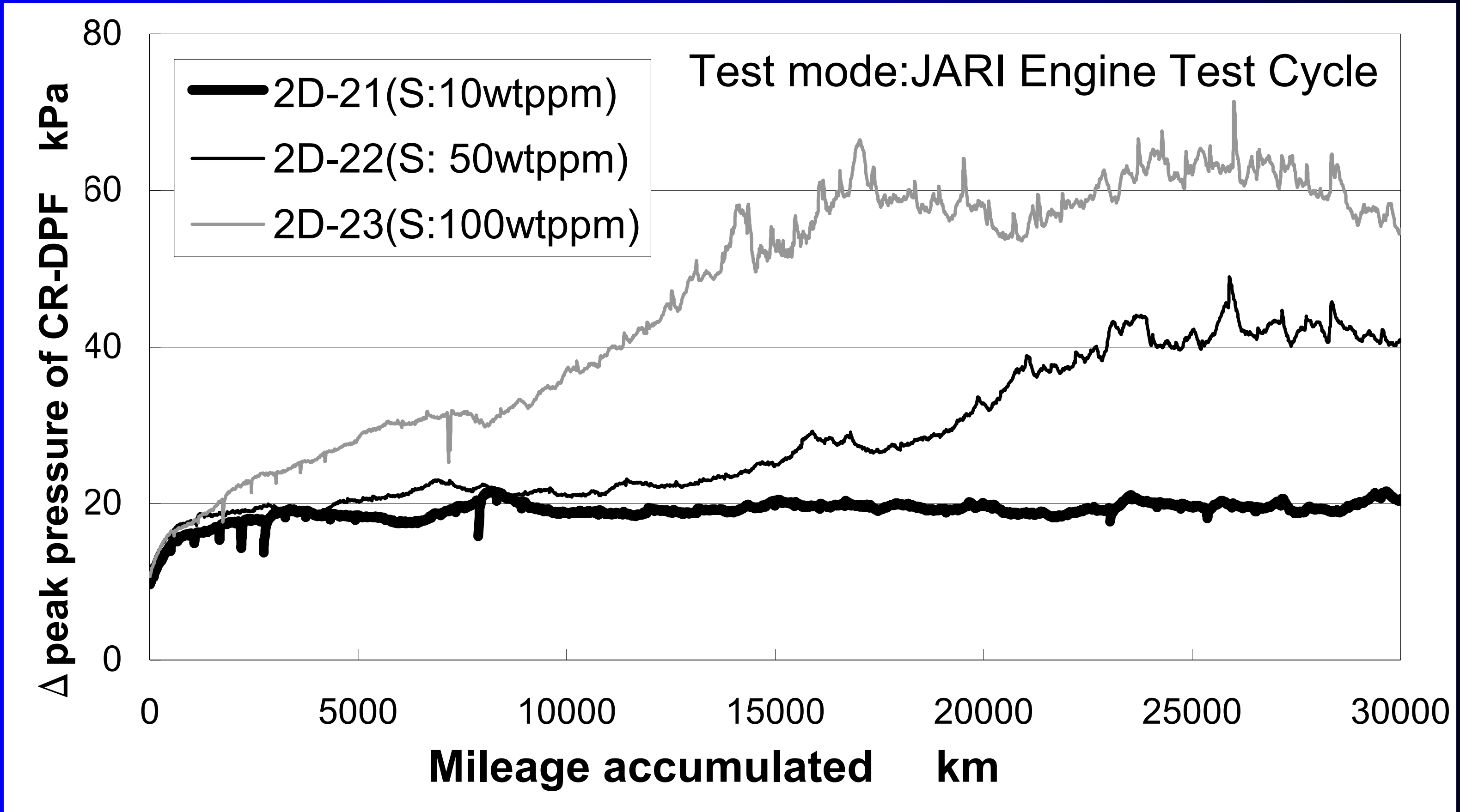


-CR-DPF technology is very effective for PM reduction when using low sulfur fuel.
-Fuel effect on PM; Sulfur is dominant.
-Fuel effect on NOx; small

Engine YB

Mileage Accumulation Test of Engine YB

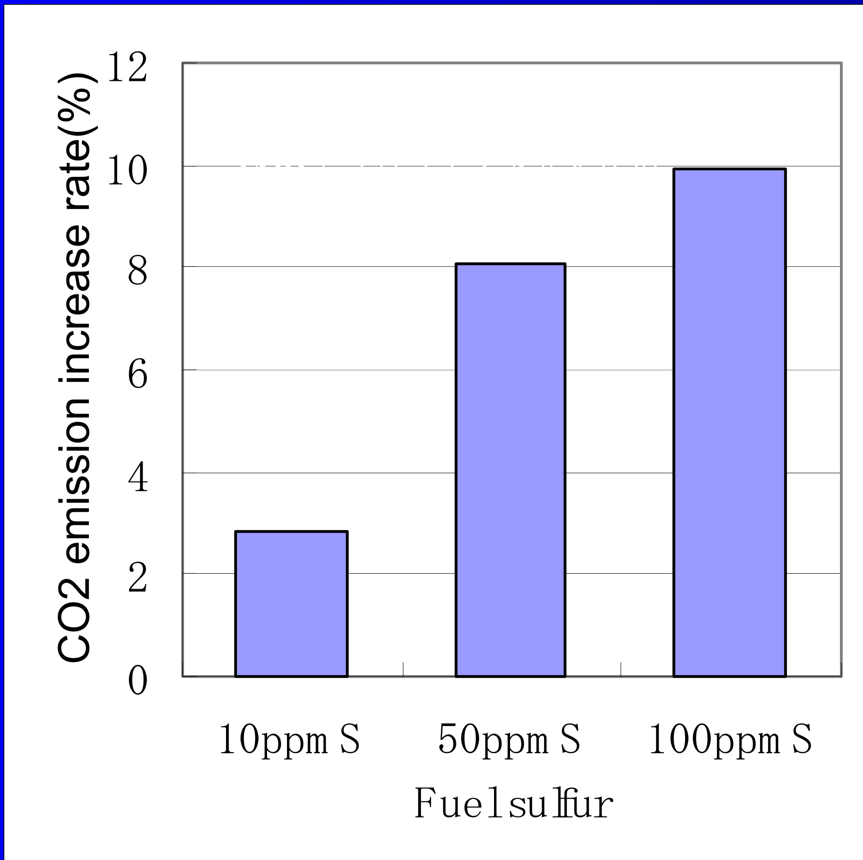
Trend of Δ peak pressure of CR-DPF

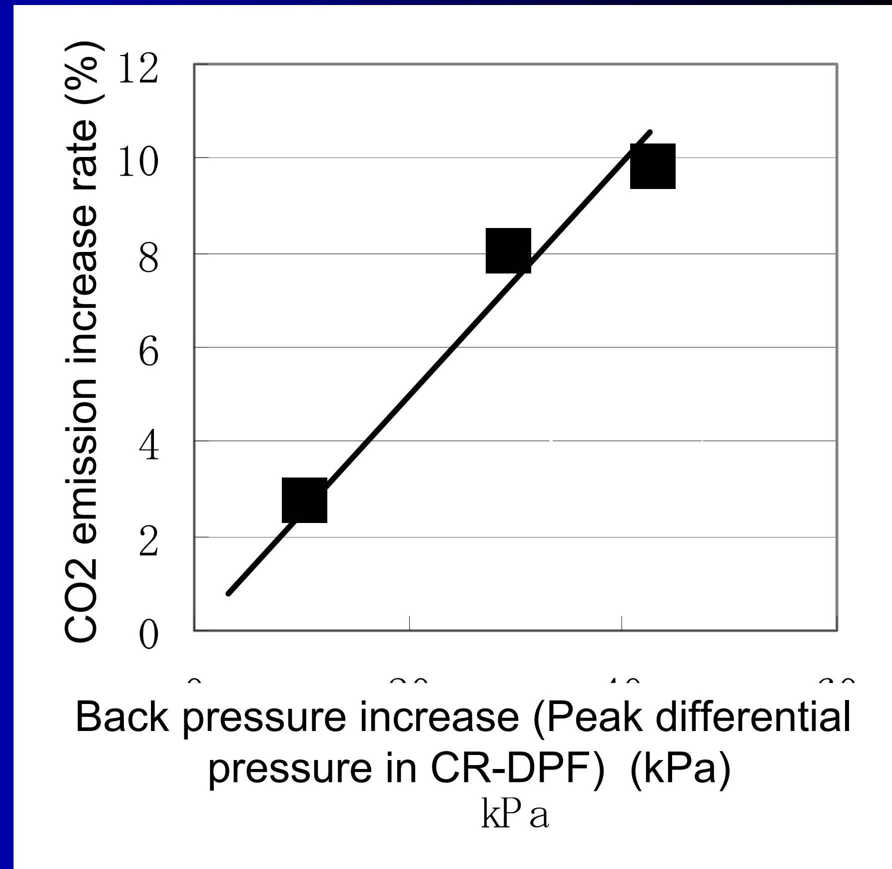


Increase of sulfur content results in filter plugging. → Increase of back pressure → Deteriorate fuel economy as well as engine reliability

Engine YB

Fuel sulfur effect on CO2 emission after mileage accumulation for Engine YB





·Fuel sulfur affect CO_2 emission due to back pressure increase

Engine YB

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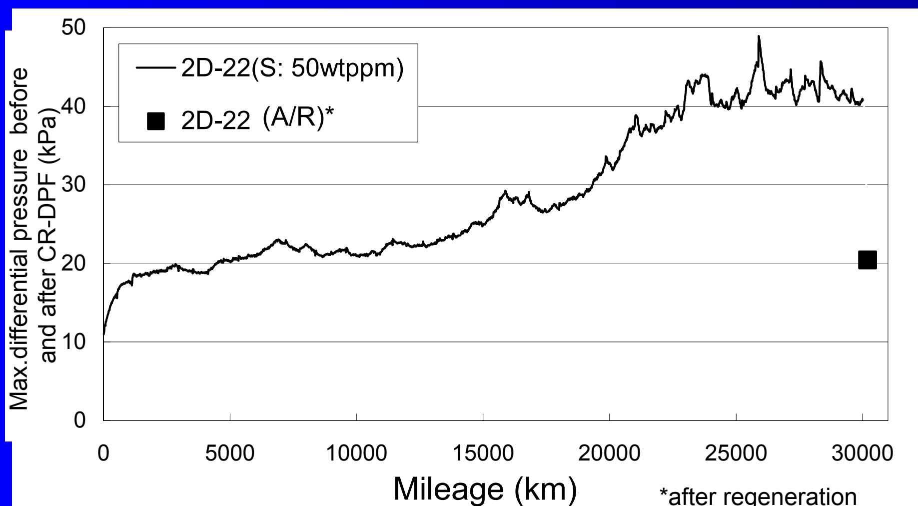
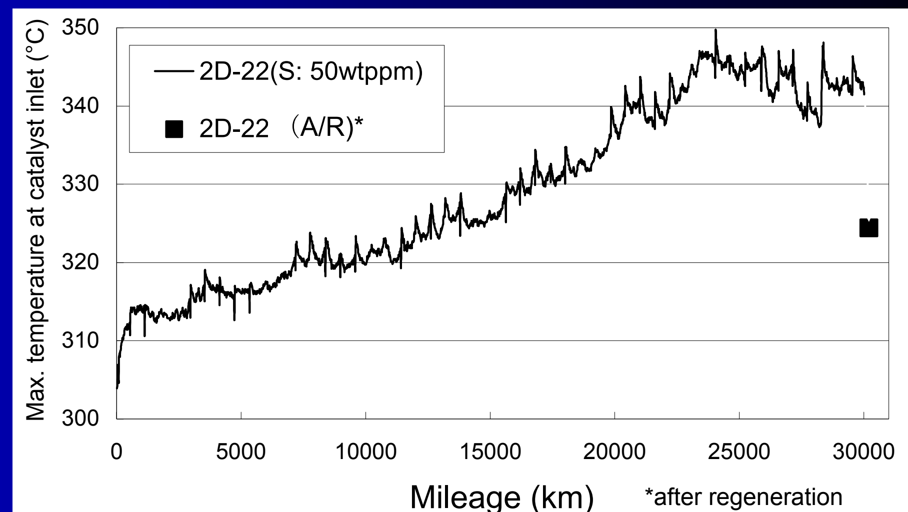
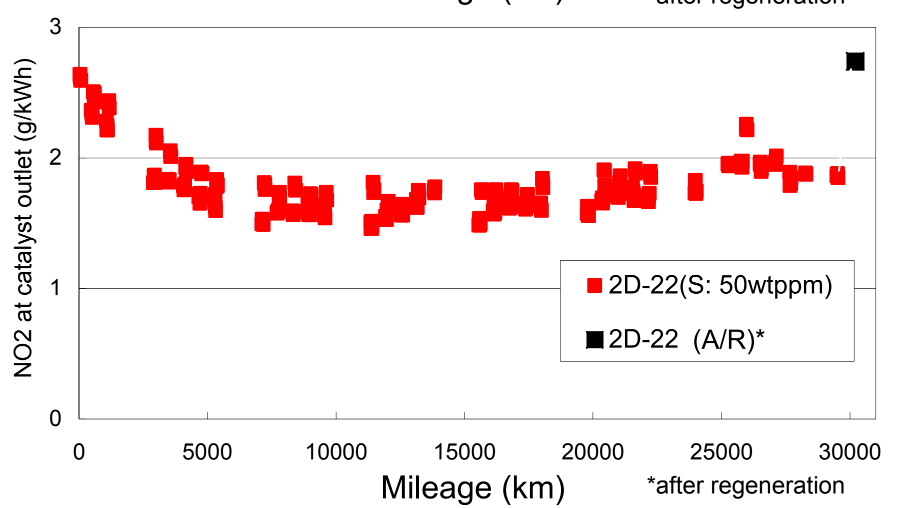
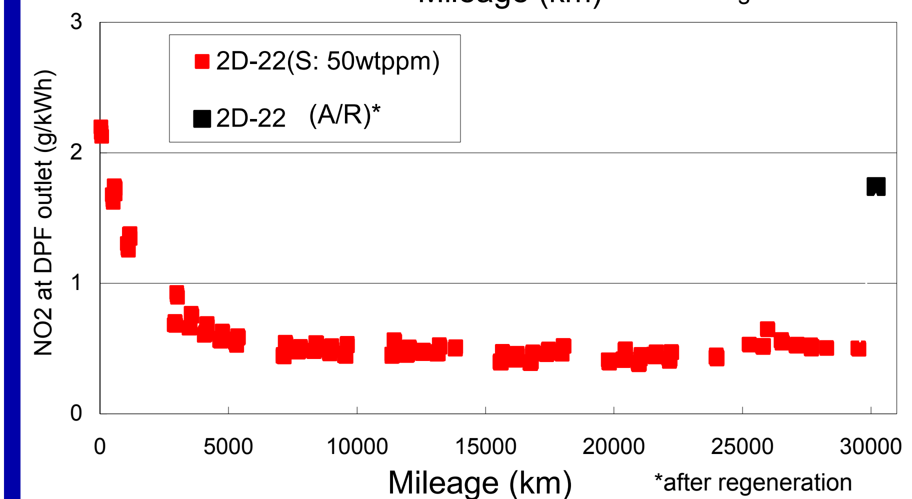
NO2 Generation and Consumption During Mileage Accumulation and Oxidation Catalyst Regeneration Effect

Oxi. Cat. NO2 generation performance can be recovered by regeneration(1 hour driving with 60% engine speed (350 deg. C cat. bed temp.) and w/o EGR operation) to a certain level









Engine ＹC : CR-DPF＋Urea SCR

·Engine Spec.

E. I. W.(kg)	Type	Engine Type	Displ. L	Power kW	Intake Air	Comb.	F.I.E	EGR
———	Large Truck	In-line6	15.7	272	T/C+I/C	DI	Common-Rail	No

·Emission control technologies

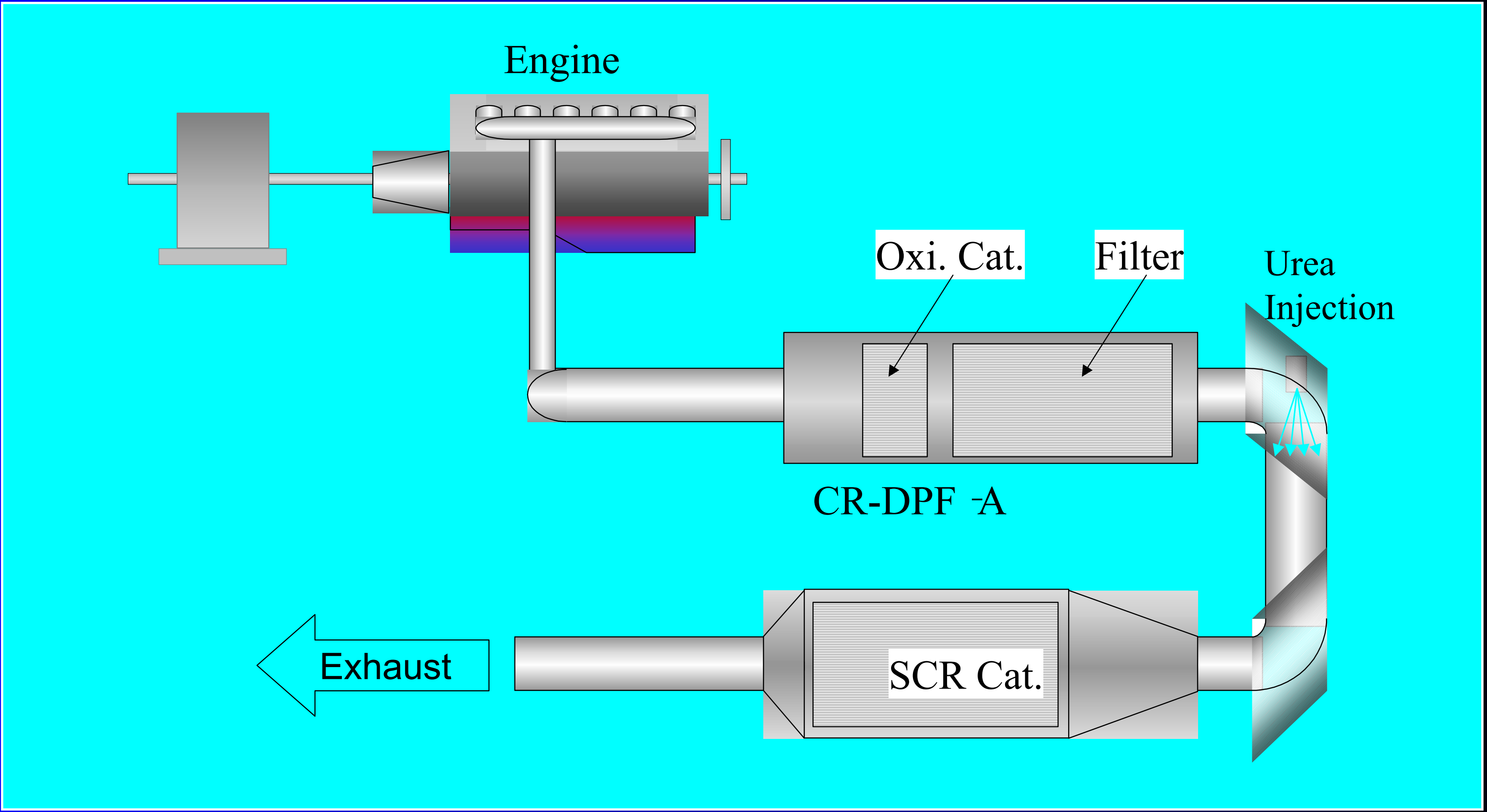
-CR-DPF; precious metal oxi. cat. + ceramic monolith DPF

- Urea SCR; 40 liter catalyst size

·Test items

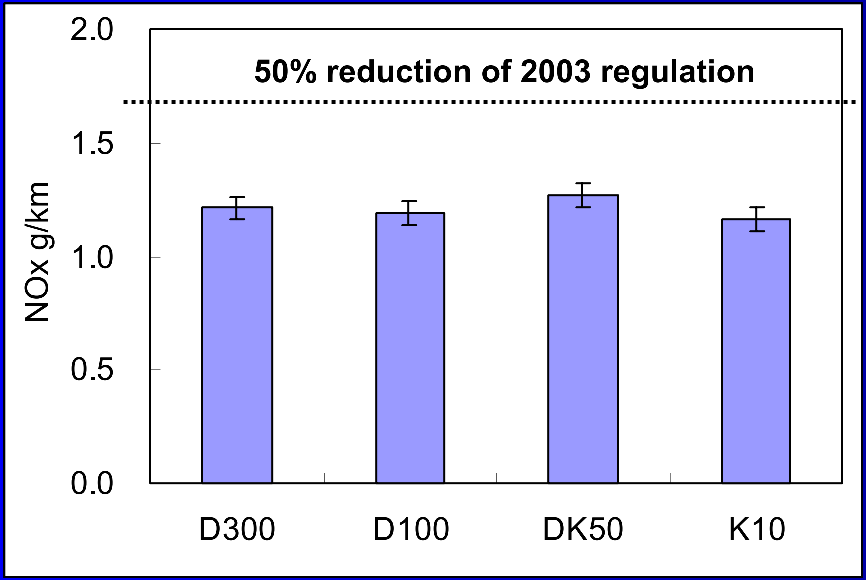
-Matrix test: 6 fuels / D13, WHDC, ETC, MOT/JARI
-Mileage accumulation test: 10,000km

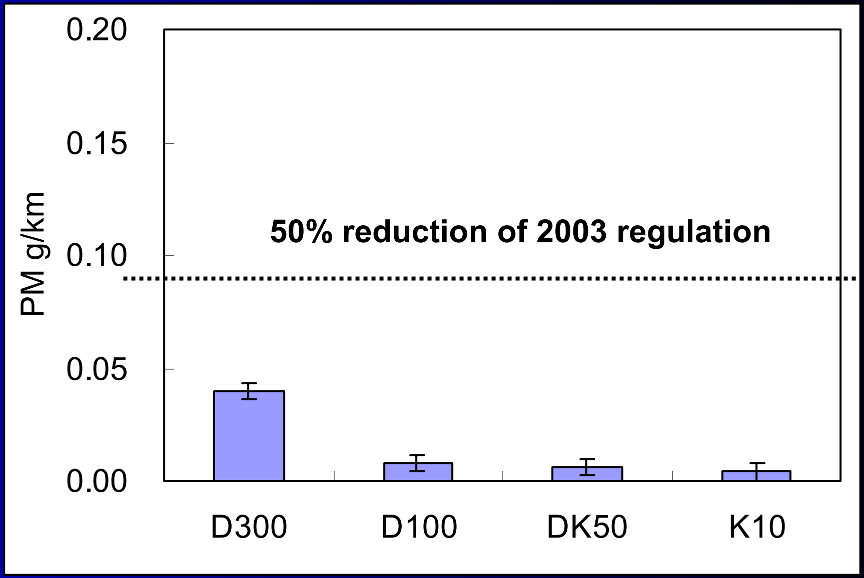
Schematics of Engine YC (Urea SCR+CR-DPF Engine)



NOx/PM Emission of Matrix test for Engine YC

D13 mode exhaust emission





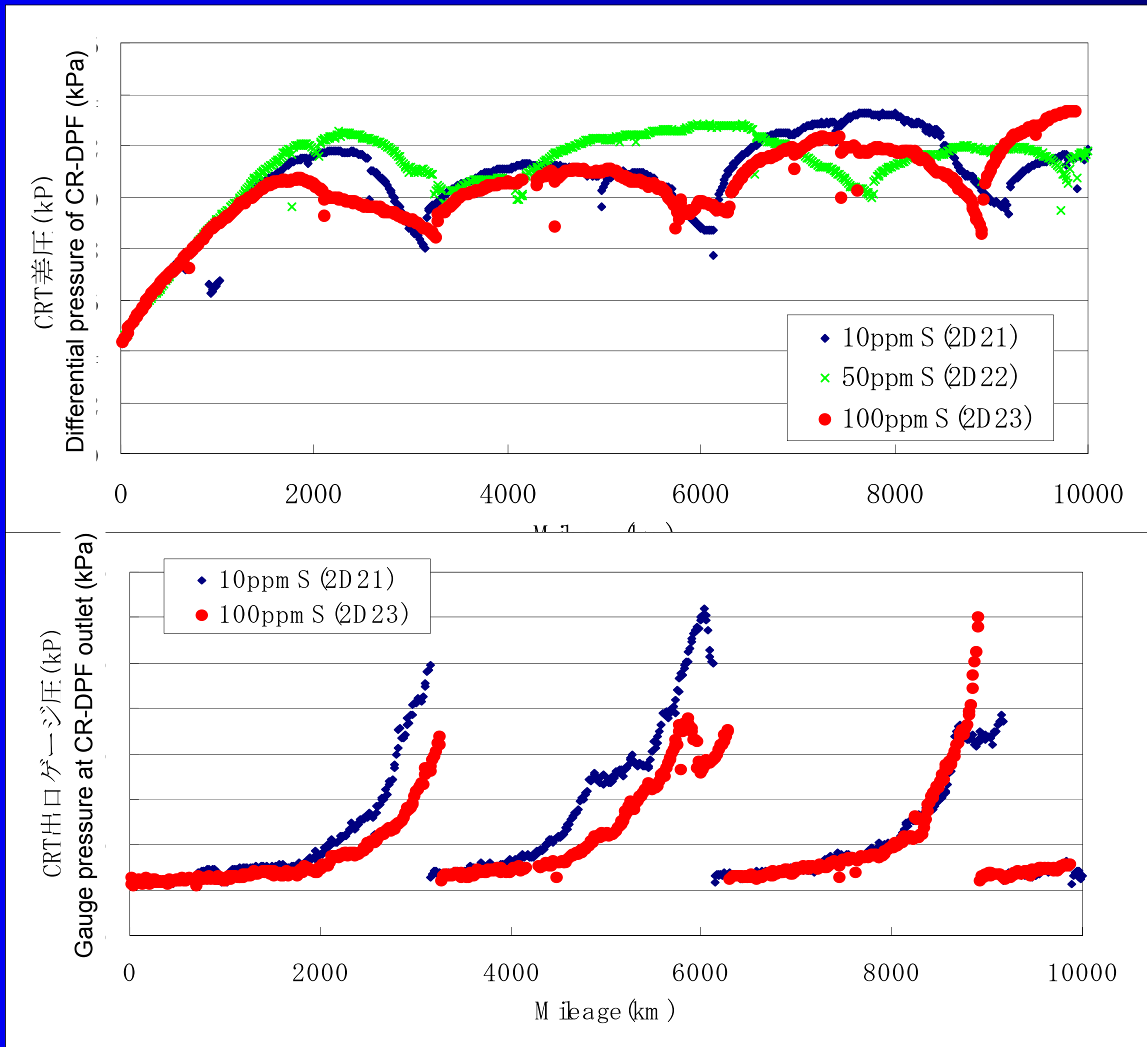
CR-DPF + Urea SCR technology is very effective for simultaneous reduction of NOx and PM when using low sulfur fuel.

-Fuel effect on PM; Sulfur is dominant.

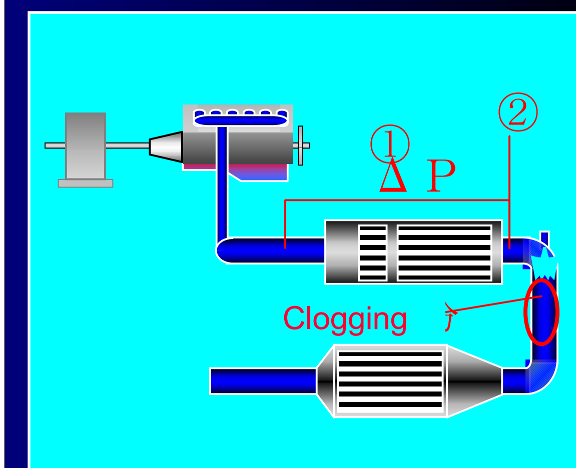
-Fuel effect on NOx; small

Engine YC

Mileage Accumulation Test of Engine YC



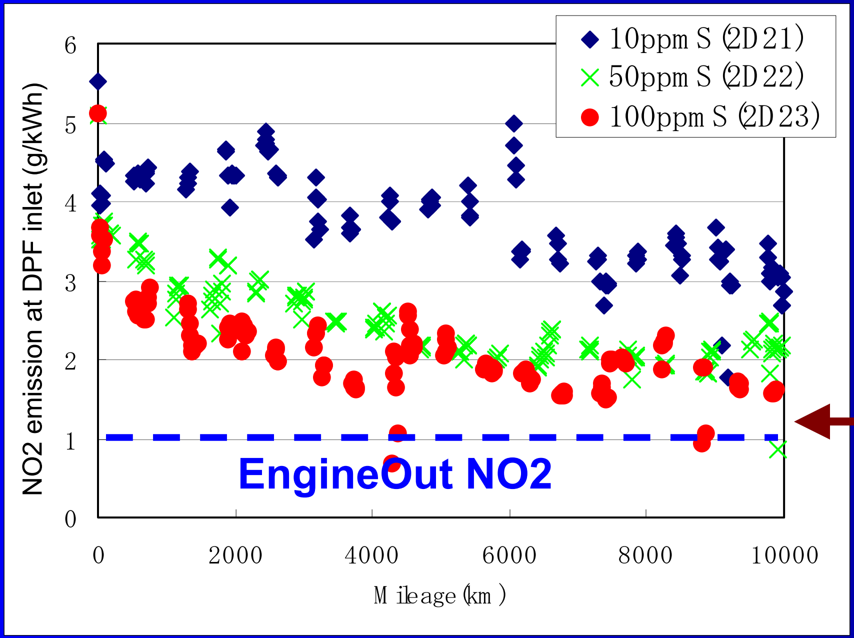
Layer of urea metamorphic compound in exhaust pipe caused back pressure increase. Manual removal of the layer was performed every 3000km during the test.

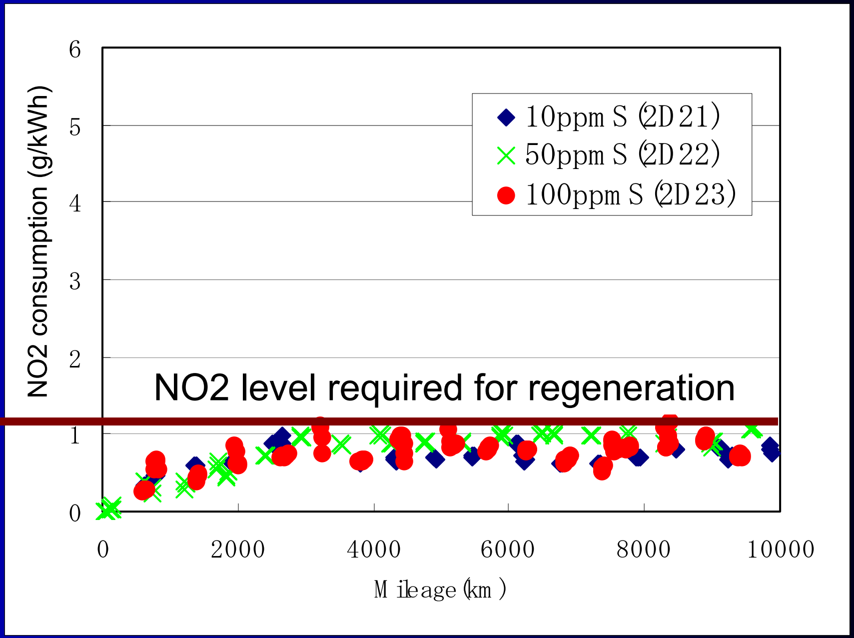


·Fuel sulfur effect on back pressure increase is small.

Engine YC

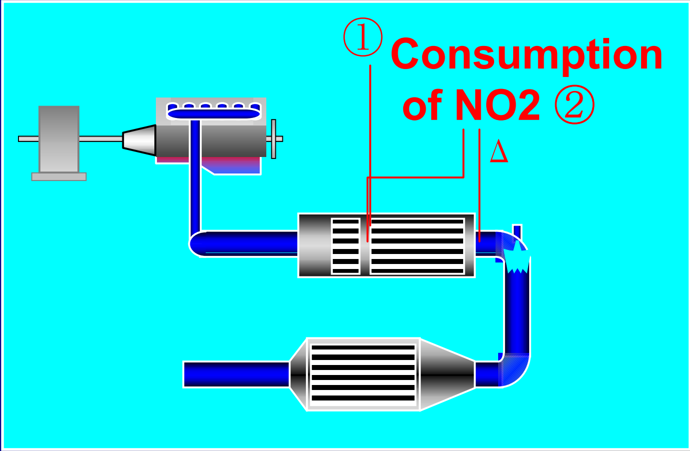
NO2 Generation and Consumption during Mileage Accumulation





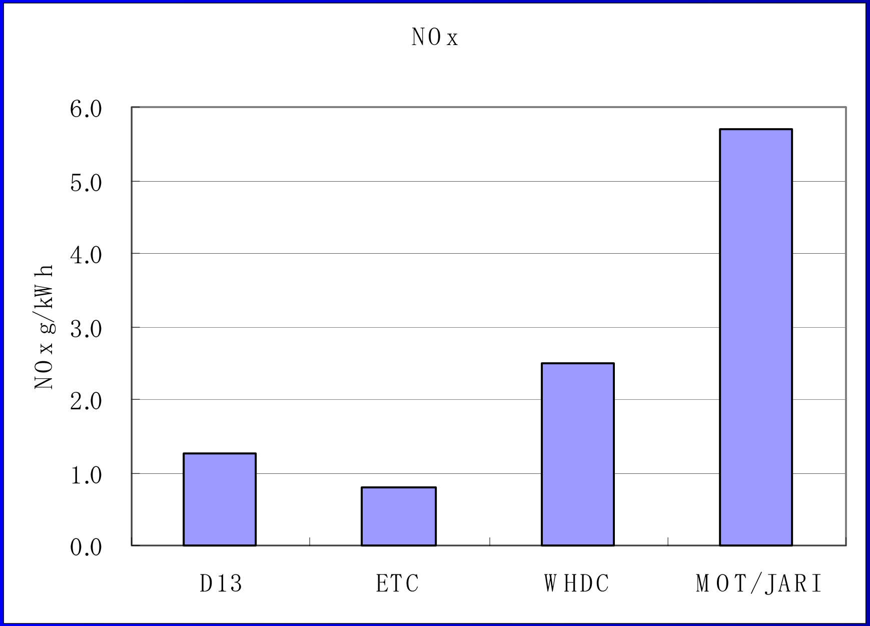
·NO2 generation is affected by fuel sulfur level,indicating sulfur poisoning of precious metal oxi. cat..

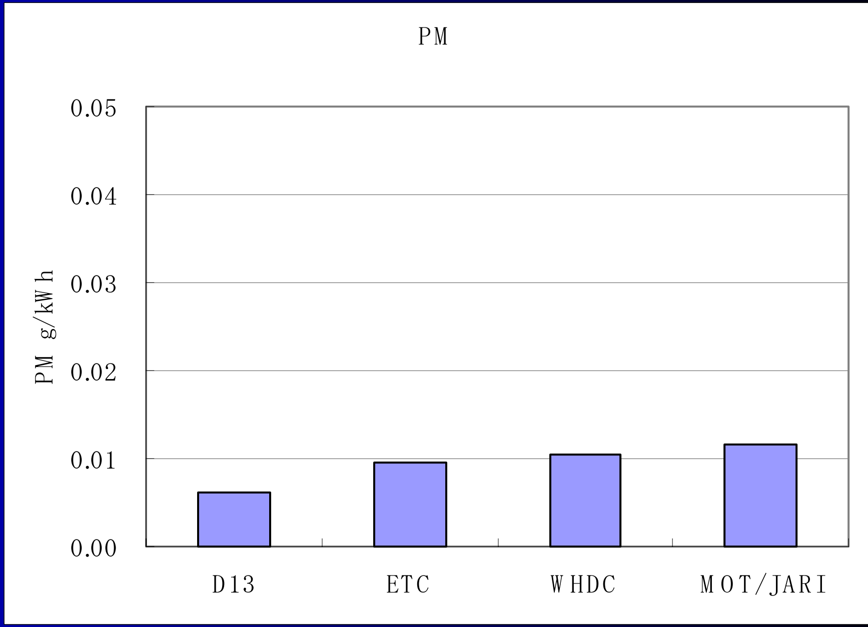
·The reason that sulfur did not affect back pressure is estimated that engine-out NO2 is higher than that required for DPF regeneration



Engine YC

Effect of Test Mode on Emissions





·Effect of emission test mode are evaluated, and results are

NOx… MOT/JARI > WHDC > D13 > ETC

PM … MOT/JARI > WHDC > ETC > D13

·Effect of test mode on NOx is high, due to the fact that exhaust temperature varies much by mode,and test engine does not have exhaust temperature control technologies to improve catalyst performance.

Engine YC

Engine YD : NSR cat.

·Engine Spec.

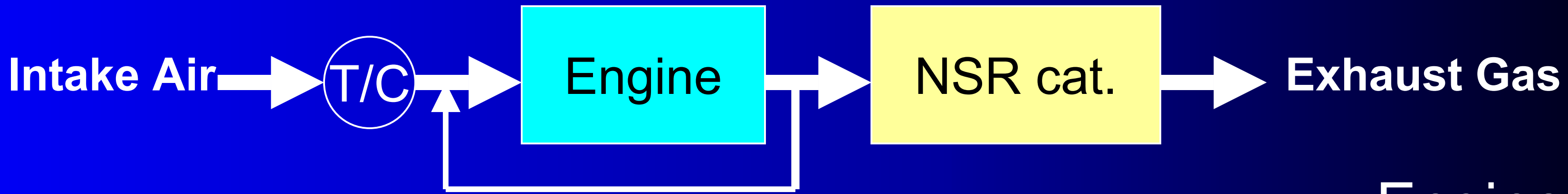
E. I. W.(kg)	Type	Engine Type	Displ. L	Power kW	Intake Air	Comb.	F.I.E	EGR
―――	Small Truck	In-line4	3.8	―――	T/C+I/C	DI	Common-Rail	Cooled EGR

·Emission control technologies

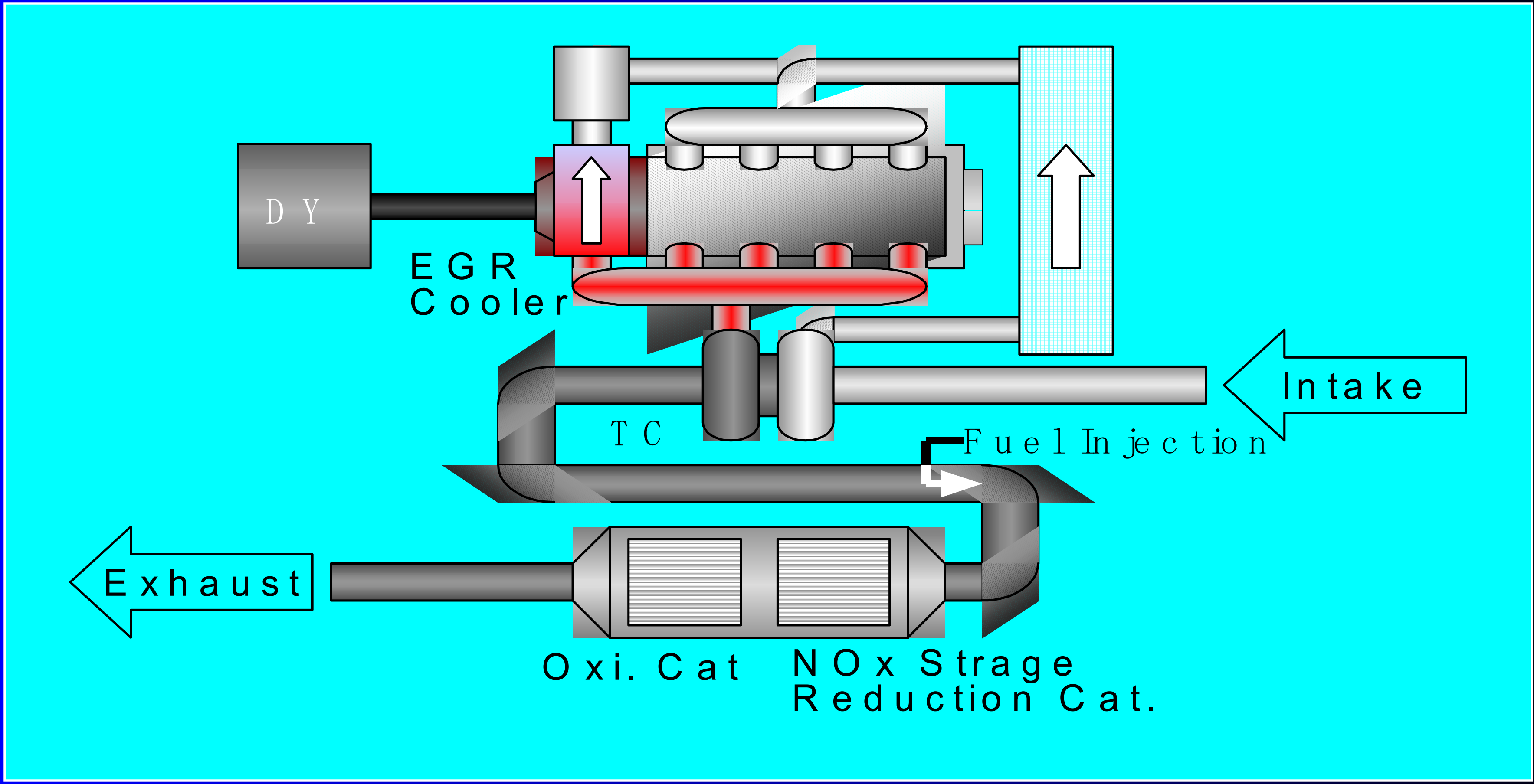
- -NSR catalyst with Oxi. cat. downstream
- -Rich spike by fuel supply to exhaust
- -Semi-premixed combustion

·Test items

- -Matrix test: 5 fuels / D13 ,WHDC, MOT/JARI

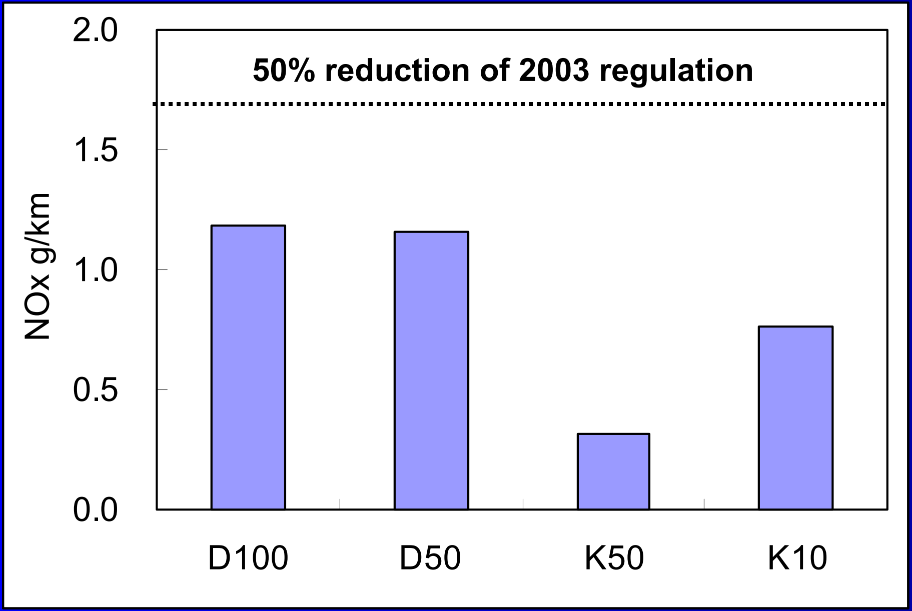


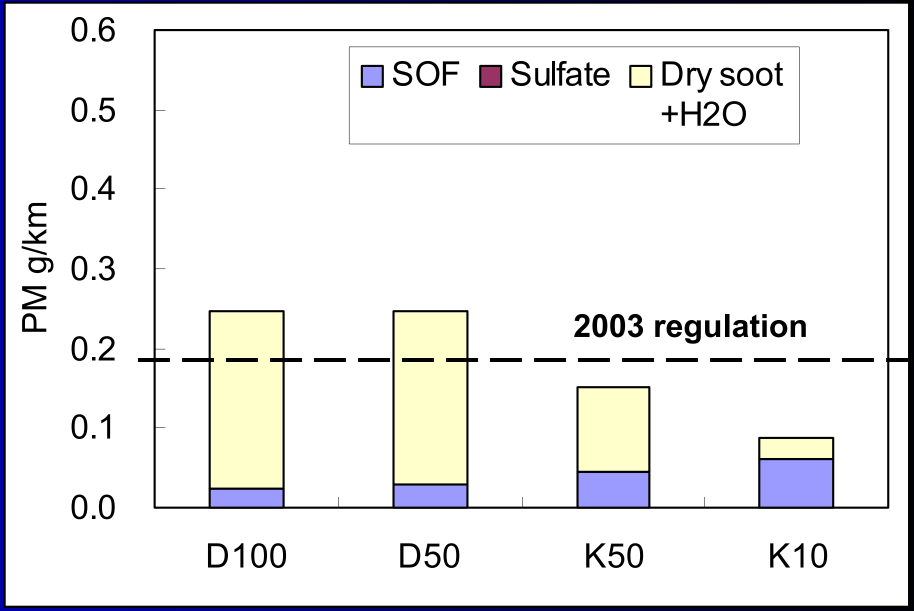
Schematics of Engine YD (NOx Storage Reduction Catalyst Engine)



NOx/PM Emission of Matrix test for Engine YD

D13 mode exhaust emission





NSR cat. is very effective for reduction of NOx .

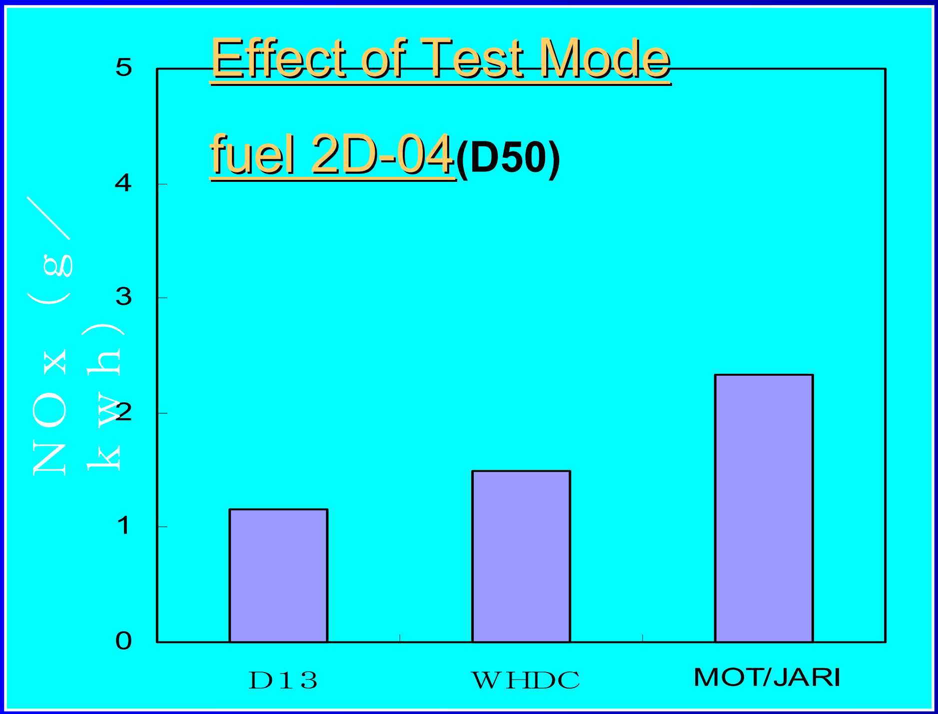
-Fuel effect on PM; Distillation is dominant.

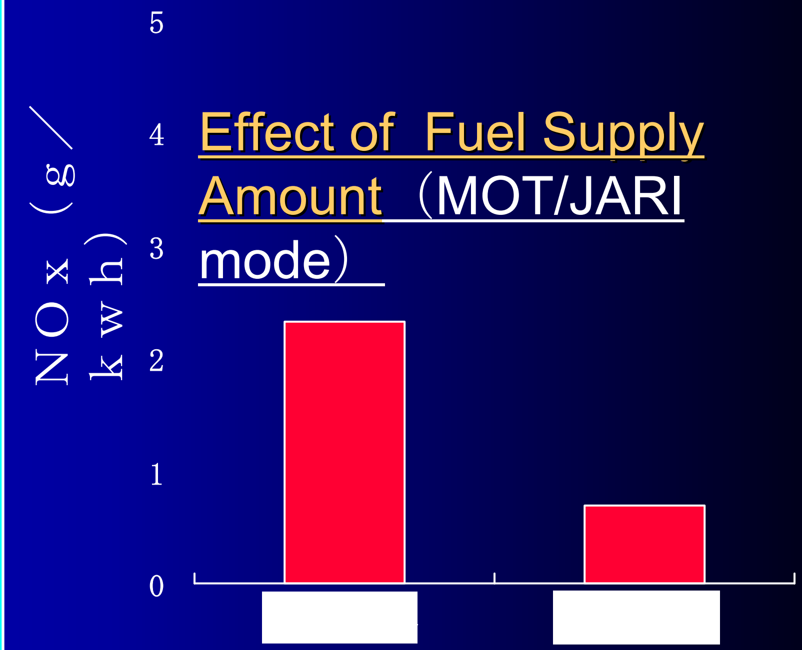
-Fuel effect on NOx; Distillation is dominant (Rich spike by fuel supply to exhaust, and low distillation fuel can easily vaporize and create better fuel-rich circumstances.)

-Mileage accumulation test is necessary for clarifying fuel sulfur effect.

Engine YD

NSR Catalyst Engine-Effect of Test Mode and Fuel Supply Amount for NOx Emission





- NOx emission level is high in low exhaust temperature MOT/JARI mode.
- Increasing fuel supply amount is effective to increase catalyst performance in MOT/JARI mode.

Summary-1

- · NSR catalyst : In the matrix test, high NOx reduction efficiency was obtained. Especially in the two vehicles case, almost zero level. In the mileage accumulation test NOx tend to increase as fuel sulfur increased.
- · CR-DPF ; In the matrix test, PM tend to increase as fuel sulfur increased. In the mileage accumulation test DPF back pressure tend to increase as fuel sulfur increased.
- ·Urea SCR:In the matrix test,high NOx reduction efficiency was obtained without fuel economy penalty. Further improvement is necessary for stable injection of urea, and high NOx reduction efficiency in low exhaust temperature operation.

Summary-2

- Fuel properties ; Both sulfur level and distillation characteristics affected the emissions. Sulfur effect was bigger and decreasing fuel sulfur level can, suppress generation of sulfate and SOF, and improve performance deterioration of those after-treatments after driving mileage accumulation.
- For 2005 regulation ; Fuel suppliers are expected to develop technologies to further reduce fuel sulfur level concurrently with the preparation of 50ppm fuel supply. Automobile suppliers are expected to develop technologies of after-treatments and their sulfur poisoning recovery.

JCAP2 Background

- Strict emission regulation will start from 2005
  for HD engine; 2g/kwh NOx, 0.027g/kwh PM
  for Passenger Car; 0.15g/km NOx, 0.014g/km PM

- 50ppmS fuel now start production, and so-called "sulfur free" level under discussion.

- A marked decline of diesel vehicle sales, especially in big cities .

Outline of JCAP2

- To evaluate potentials for reductions of both pollutants and CO_2 emissions by combining advanced emission control and advanced fuel technologies.
- 6 vehicles and engines with advanced after-treatments, combustion technologies and electric control.
- Using 9 fuels matrix having different specifications in sulfur(50,10,1ppm), aromatic(20,10,5%) contents, and distillation characteristics.
- Basic research with single cylinder engine, under discussion.