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Size-resolved nano-particle and hazardous air pollutants emissions characteristics with low, medium, and high proportion of ethanol content fuels from a direct injection spark ignition vehicle

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Introduction

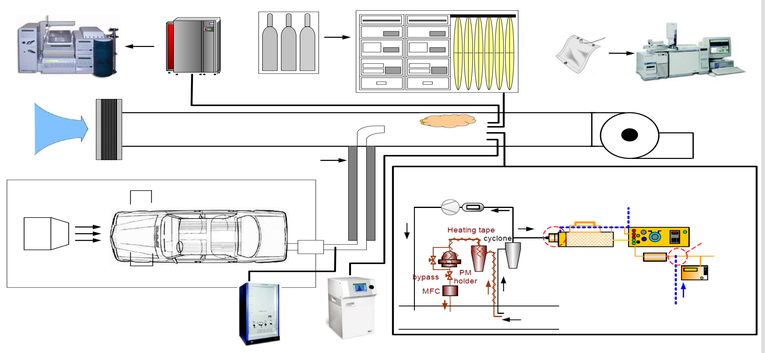
➢ **Main issue about modern GDI vehicle ; PN**
- Locally rich A/F mixture
- Wall-wetting phenomena
- PN Emission Limit : 6 X 10^{11} #/km
- RDE PN regulation : CF 1.5
  → Advanced Engine & FIE & ECU, GPF

➢ **Ethanol as an automotive fuel**
- Clean Combustion
  – Oxygenated fuels, Higher Octane rating
  – Lower PN/PM mass
- Worldwide markets
  – Brazil, United States
  – Japan(E10), EU(E10), Korea(E3)

➢ **Chassis dynamometer Experiments (FTP-75) with Ethanol blended fuel**
- Using Application ECU for Target Air-to-Fuel ratio(Non-FFV)
- Meet the test protocol by the particle measurement program(PMP)

Experimental Apparatus

Vehicle test schematic diagram



Gaseous Emission Analyzer	MEXA-7200H (HORIBA)
Constant Volume Sampler	CVS-7200S and DLT-1230 (HORIBA) using HEPA filter to minimize the background PM at CVS tunnel
PN Analyzer	Thermal Diluter (MD19, Matter-Engineering) TSI Condensation Particle Counter (CPC) 3790 A TSI Engine Particle Sizer (EEPS) 3090 spectrometer
PM Analyzer	Using Fluorocarbon-coated glass filter (TX40, Pallflex) Using an analytical balance (CPA2P-F, Sartorius)
HAPs Analyzer	Gas Chromatography-mass spectroscopy Selective detector (HP6890-HP5973N, Agilent) Fourier Transform Infrared analyzer (FTIR, AVL)

Test vehicle specifications

Engine Type	Wall-guided, Stoichiometric Direct Injection
Displacement	2,359 cc
Compression ratio	11.3 : 1
After-treatment system	Three-way catalytic converter
Regulation category	ULEV2, PZEV

Properties of tested ethanol-gasoline blended fuels

Fuel		E0	E10	E50	E85	E100
Ethanol (%wt.)		>0.01	13.12	53.63	87.80	99.89
Oxygen content (%wt.)		2.02	6.34	19.60	30.77	34.69
Stoichiometry		14.56	13.97	11.69	9.79	9.00
Density (kg/m^3 @15 °C)		712.1	719.8	752.9	782.6	794.3
Octane rating (RON)		92	94	100	106	109
LHV (kJ/kg)		43,966	42,142	35,085	29,206	26,766
Distillation	10% (°C)	44.3	43.6	51.5	72.9	78.0
	50% (°C)	72.6	62.4	74.1	78.0	78.0
	90% (°C)	147.8	145.8	79.4	78.5	78.1
	FBP (°C)	187.4	189.7	166.5	79.7	79.6
	Distillation index	954	917	978	1,139	1,188
DVPE (kPa @37.8 °C)		80.2	82.8	67.4	35.7	15.1
Aromatics (%vol.)		14.3	12.3	7.1	1.9	>0.1
Olefins (%vol.)		13.9	12.2	6.6	>0.1	>0.1
Benzene (%vol.)		0.5	0.4	0.3	0.1	>0.1
Sulfur (ppm)		10	5	3	1	>1

Regulation Emissions, CO_2

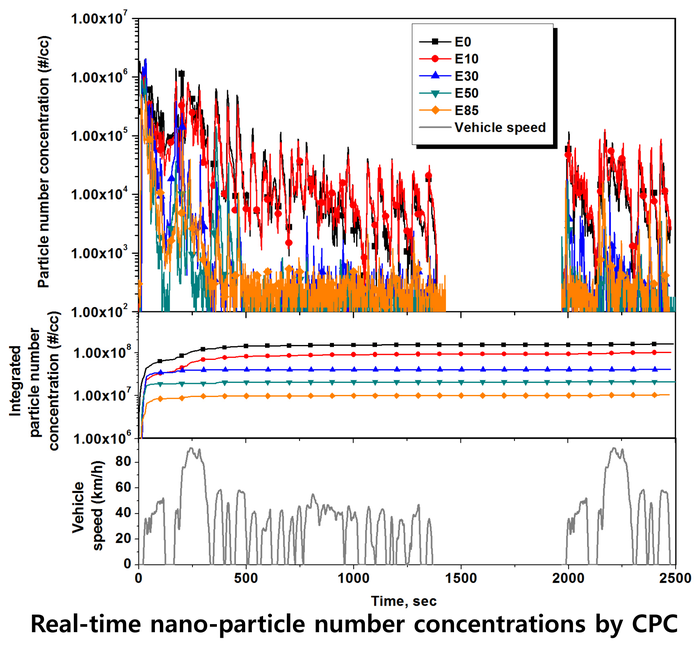
➢ **Regulation gaseous emissions for the FTP-75**

Fuel	THC [g/km]	NMHC [g/km]	CO [g/km]	NOx [g/km]	CO_2 [g/km]	Fuel economy [km/l]
E0	0.013	0.011	0.275	0.002	190	12.3
E10	0.015	0.013	0.292	0.005	189	11.9
E30	0.013	0.011	0.220	0.003	187	11.2
E50	0.021	0.016	0.200	0.004	188	10.2
E85	0.034	0.025	0.147	0.003	187	8.7

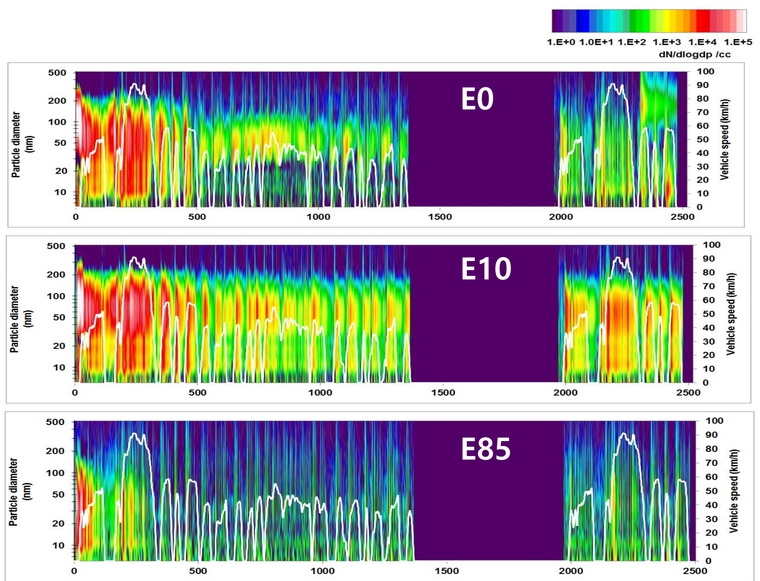
➢ THC : increasing trend as the ethanol content in the fuel increased
➢ CO : decreasing trend as the ethanol proportion increased
➢ NOx : minor change
➢ CO_2 & F.E: decrease slightly with higher ethanol ratio

Oxygenated Fuels, Low Heating Value, Induced clean burning

Nano-particle emissions



Real-time nano-particle number concentrations by CPC



Real-time particle concentration and size distribution with ethanol-gasoline blended fuels by EEPS

➢ PN emissions associated with cold-start and cold-transient within 25 sec
➢ The sub-23nm particles occupied more of the total PN concentration
➢ After cold-start phase (300-505 sec), PN peaks shows slightly reduction and further PN reduction occurred during the engine warm-up phase (505-1372 sec)
➢ Both nucleation and accumulation mode particles were simultaneously produced in the P1
➢ Hot restart (P3) shows similar trends to P1, but PN concentration was much lower than P1

Particle Number and Mass

➢ **PN & PM emissions of ethanol-gasoline blended fuels**

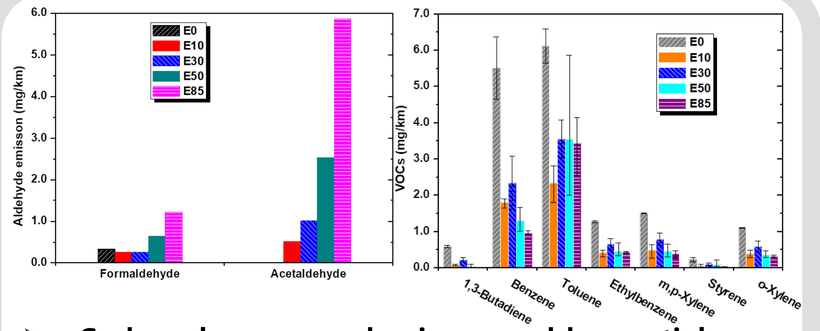
Fuel	Particle Number (#/km)				Particle Mass (mg/km)
	Phase 1	Phase 2	Phase 3	FTP-weighted	FTP-weighted
E0	6.67E+12	3.34E+11	2.54E+11	1.62E+12	1.847
E10	4.65E+12	4.98E+11	5.27E+11	1.37E+12	1.298
E30	2.78E+12	1.01E+10	2.77E+10	5.89E+11	1.168
E50	1.17E+12	7.31E+09	1.26E+10	2.50E+11	0.898
E85	6.30E+11	7.68E+09	2.20E+10	1.40E+11	0.337

➢ E10
- P1 emissions exhibited slightly lower levels than E0
- P2 and P3 emissions presented higher levels than those of E0 fuel
  → azeotropic mixture characteristics of E10

➢ E30
- Most PN emissions above 95% were emitted within 123 sec of P1

➢ High ethanol blended fuel(E50, E85)
- Strong reduction in the cold-stabilized and warm-start phase
  → high oxygen content in the fuel
- PM mass : 1.847(E0) → 0.337 (82% reduced)
  → improvement of the shift in fuel toward lighter HC

Hazardous Air Pollutants



➢ Carbonyl compounds : increased by partial oxidation of ethanol and incomplete burning
➢ BTEX emissions : produced by unburned aromatic HCs → high ethanol blended fuel has lower aromatic HCs → BTEX emissions decreased substantially
➢ E10 : lower than E30 → physical properties of distillation and vapor pressure behaviors of azeotropic characteristics

Conclusion

■ **Nano-particle emission evaluation**
- ○ Blending ratios of 30 – 85% fuels showed strong PN and PM reduction performance relative to that of E0 – E10 blended fuels
- ○ The PN emissions from E85 were only 10% that of E0 fuel, a reduction achieved simply by changing the supplied fuel to a GDI engine
- ○ The maximum PM reduction of 82 % was obtained by adding ethanol 85% to the gasoline (E85)

■ **Regulated and Unregulated emission characteristics**
- ○ THC emissions were increased by the ethanol contents and incomplete combusted fuel
- ○ CO emissions were decreased by oxygen component in ethanol
- ○ NOx emissions were reported that NOx could either increase or decrease with high ethanol blends
- ○ Carbonyl compounds were increased by partial oxidation of ethanol-gasoline blended fuels
- ○ VOC emissions were decreased due to increasing ethanol fractions and the lower proportion of aromatic components in the fuels

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- This study was submitted in FUEL special issue (Dual-fuel and Fuel Additives: Combustion Experimentation and Modeling for Internal Combustion Engines) and now is under review.

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