Conversion development of used diesel vehicle on NGV to meet 2 002 Korean emission regulation and 80,000km durability requirement

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Abstract

The air pollution of Seoul city is the worst place among the 30 OECD countries; average concentration of small particulate (PM10) of one year is 71μg/m³ and NOx is 37 ppb which exceed the WHO recommended level of 40 μg/m³ on PM10 and 22 μg/m³ on NOx.

To improve above air pollution of Seoul city area, the Ministry of Environment of Korea government enacted the “Special law for air conservation of Central city area” from 2006. It enforces the old diesel vehicle which over the certification period of emission by OEM car maker to change into low emission vehicle as installation of Diesel Oxidation Catalyst or Diesel Particulate Filter or engine conversion to LPG or CNG under subsidies of the equipment cost by Korean central and local government.

In this paper, we describe the used vehicle conversion development of CNG from diesel which vehicle was over 150,000Km driving mileage, 6.6ton GVW and 3.5 ton cargo weight. The specification of the diesel engine is Hyundai Motors’ D4AE/D4AL engine model, 3,298 cc swept volume, direct injection type diesel combustion chamber, turbo charged intake system. We machined cylinder head to install spark plug and piston to adjust the compression ratio of 11.5 and combustion chamber to get best fuel economy and least emission under required power condition. Also we installed sensors (cam phase sensor, crank angle sensor, MAP sensor, oxygen sensor), fuel injection system, ignition system and fuel supplying system and inter cooler of intake air.

By the development of combustion system as lean burn and intake charging air cooling system, we restricted the exhaust gas temperature under 750°C in the rated power condition and exhaust emission especially NOx to acceptable level. As a result of this development, it was possible to reach the same level of power with diesel engine, meet the emission regulation of Korean 2002 heavy duty vehicle and

endure engine durability test of 300Hr full load condition with hot water temperature.

The vehicle was driven 50,000Km mileage for vehicle durability test under data acquisition of the engine and vehicle condition and components which influence engine power and emission sealing situation to prohibit component changing over the test period . And finally the engine finished the 50,000km durability test was uninstalled from the vehicle to test exhaust emission and torque with ND13 heavy duty engine test mode to meet Korean 2002 emission regulation and power changing less than 5% comparing to new diesel engine. The developed engine and vehicle meet all requirements of Ministry of Environment of Korean government.

As the result of this all development and certification test procedure, the Korean government certified the above vehicle and engine (D4AE, A4AL) as low emission system to changing the diesel vehicle produced before 2002 model year to CNG under the Korean law of “Special law for air conservation of Central city area”,

1. Preface

The air pollution of Seoul city is the worst place among the 30 OECD countries; average concentration of small particulate (PM10) of one year is 71μg/m³ and NOx is 37 ppb which exceed the WHO recommended level of 40 μg/m³ on PM10 and 22 μg/m³ on NOx.

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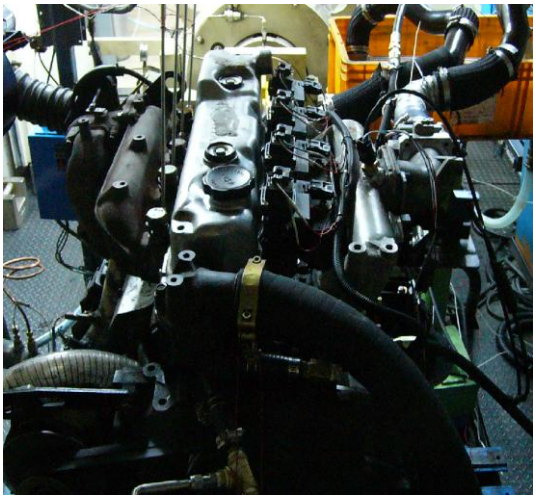
By that reason, the used diesel vehicle which was over 150,000Km driving mileage, 6.6ton GVW and 3.5 ton cargo weight, was converted to meet the requirement of Korean Government and tested the engine performance, vehicle performance and durability test and Korean EPA certification test.

2. Conversion of engine and vehicle

The vehicle to be converted is 3.5 ton cargo truck of Hyundai Motors and the engine is D4AE, D4AL model which was produced 1997 and drove 150,000km

before conversion to NGV. And we developed for this engine and vehicle to dedicated NGV. And the specification is as followed.



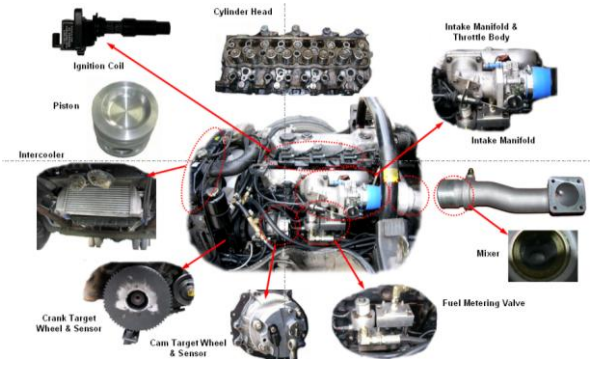
< Fig.1 > vehicle and engine to be converted

Table 1. Specification

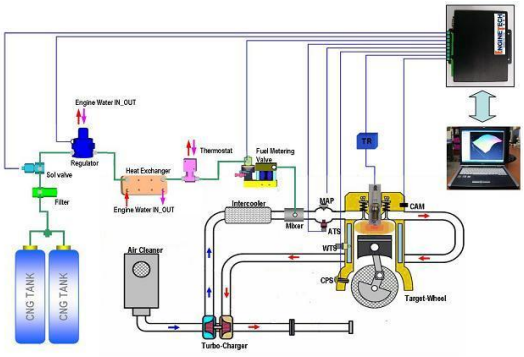
Item	Diesel, D4AE (D4AL)	NGV
Model year	1997	←
Curv weight (kg)	2890	3099
Gross weight (kg)	6585	←
Swept volume (cc)	3298	←
Compression ratio	16.5	11.5
Max. Power(ps/rpm)	118/3400 (120/3400)	112 / 3400
Ignition	Compression ignition	Spark ignition
Intake system	Turbo charge	Inter cooled turbo charge
Fuel system	BOSCH A (PE pump)	Electric control system
Fuel tank volume(ℓ)	60	242 (Water volume)

After uninstall the engine from the vehicle, we machined cylinder head to install spark plug and piston to adjust the compression ratio of 11.5 and combustion chamber to get best fuel economy and least emission under required power condition. Also we installed sensors (cam phase sensor, crank angle sensor, MAP sensor, oxygen sensor), fuel injection system, ignition system and fuel supplying

system and inter cooler of intake air.



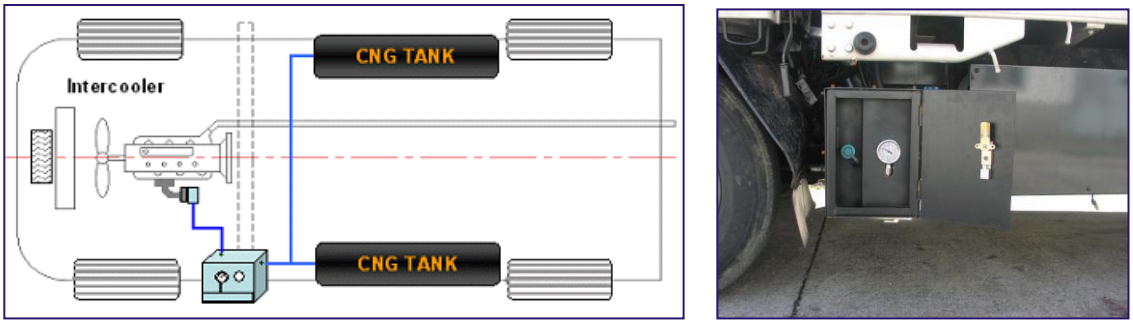
< Fig 2 > Engine conversion



< Fig 3 > NGV engine control system

As the control system of engine, ECU controls fuel injection quantity to meet target air fuel ratio, Ignition timing and dwell time, Idle speed, acc./ deceleration fuel adaptation, boost pressure with optimized control logic on each operating conditions.

Also it has the diagnosis functions to check malfunctions of each systems.



< Fig 4 > Installation of CNG cylinder and fuel module

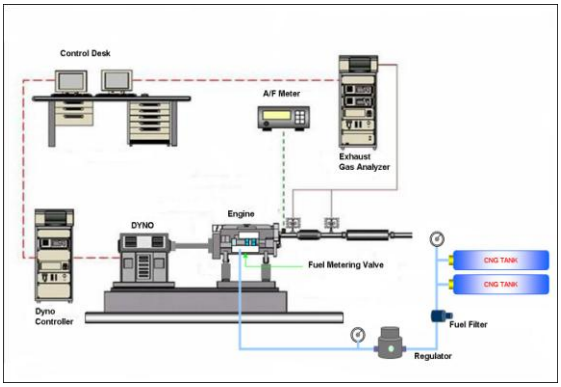
The vehicle was installed with two CNG cylinders of 120L Water volume and can drive 300 Km with one refilling. And the weight of the vehicle after conversion to NGV was increased with 209Kg as the result of engine conversion and CNG cylinder installation.

3. Engine and vehicle development

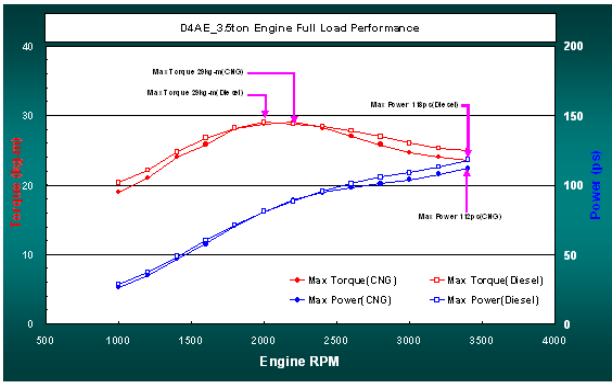
3-1 Engine development

After installation of engine on engine dynamometer for system development, EMS calibration and durability engine test, it was test to get the optimized result on engine power and torque, fuel consumption ratio, engine response and exhaust

emission of engine.



< Fig 5 > Engine test system



< Fig.6 > Comparison of engine power

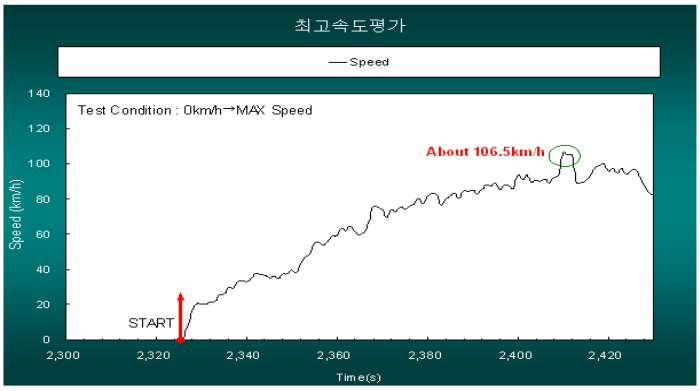
We achieved power 95 % level to new diesel car and 105 % level before conversion, achieved torque as the same level to the new diesel car under the condition of same exhaust temperature level of diesel car. We experienced this kinds of results in almost other car and engines of conversion.

Table 2. The result of engine development

	Torque (kg-m/rpm)	Power (Ps/rpm)	Exhaust gas Temp.(℃)	Notes
Diesel Engine	29/2000	118/3400		New vehicle
	24.5/2000	105/3400	483℃/582℃	Accumulated 150K km
Converted CNG	29/2200	112/3400	519℃/585℃	

3-2 Vehicle development

< Fig. 7 > Data acquisition of vehicle



< Fig.8 > Test of maximum vehicle speed

In the vehicle test, we achieved the maximum vehicle speed as the better level to the before conversion. This 106.5km/h of the maximum speed means same level of the new diesel car. Also these all data were achieved under the condition of same level of exhaust gas temperature with diesel car.

Table 3. Fuel economy of the converted NGV

	Fuel economy (km/ℓ,km/㎥)	Heat value	FC (km/kcal)	Fuel cost	Driving distance	Fuel cost/month
Before Conversion	7.2km/ℓ (field)	9,200 (kcal/ℓ)	0.782	₩1182	300km/day × 25day/month =7500km	₩1,231,250
After conversion	6.15 km/㎥ (field)	10,500 (kcal/㎥)	0.586	₩542		₩660,975

According to the field test data, we evaluated the fuel economy in each NGV and diesel car. The fuel consumption of diesel car before conversion was 7.2Km/L and NGV was 6.15Km/m3. When these car drive the same mileage, the fuel cost might be reduced 47 % at each driving.

3-3 Durability test

3-3-1 Durability test of engine

After installation of test engine to the 250HP eddy current type engine dynamometer of Engine Tech Co. LTD, the engine was tested in the condition of full load and maximum engine speed during 300 hours for the evaluation of durability for all components of engine, fuel systems and control systems.

Table 4. Performance changing between before and after testing of durability

	Test condition	Before test	After test	Notes
Max. Power(PS)	3,400 rpm/WOT	112	111.2	△0.7%
Max. Torque(kg-m)	2,200 rpm/WOT	29	28.3	△2.4%
Oil consumption(g/hr)	3,400 rpm/WOT	38	40	△5.2%

After and in testing evaluation were performed for deterioration of all components,

the changing of engine oil consumption rate and engine performance. And finally we confirmed the properness of development in the view of engine durability in each evaluation items. The result of engine durability test summarized as following table 4.

3-3-2 Durability test of vehicle

We tested the developed vehicle to confirm durability during 50,000Km at the condition of gross vehicle weight with measuring of vehicle speed, engine speed, exhaust gas temperature, engine cooling water temperature, exhaust gas pressure and engine oil pressure as the measuring rate of each seconds. During the all testing period we checked the level of lubrication oil and cooling water at every day, changed the oil filter at every 5,000km and checked the malfunction of every components and systems.

Table 5. The condition of vehicle durability testing

Test weight	Vehicle curb weight + Loading weight 3,500kg
Driving mode	COMBI MODE 50,000km (City +High Way +Mountain)
Data acquisition	DNGV-DAQ System
Testing mileage	Before certification20,000km + During certification 30,000km

After test driving of 50,413km, there were not any changing of engine performance and not any components to show any kinds of deterioration. Fig.9 shows the situation of engine main components after testing.

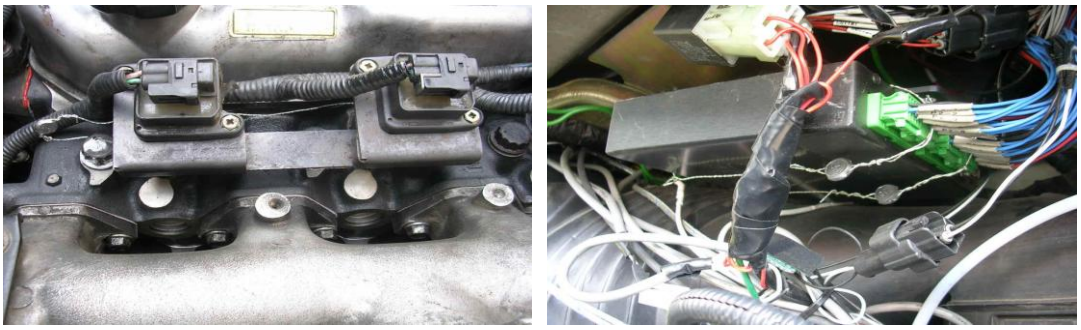
< Fig. 9 > Components verification after vehicle durability test of 50,000Km

4. Vehicle certification of retrofit to NGV

4-1 Certification test of vehicle

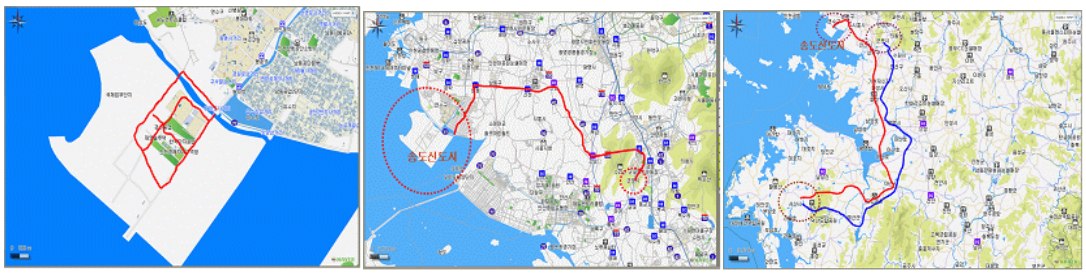
To certify the retrofit program of each kinds of vehicle from the Korean EPA, we need to pass certification procedure for vehicle durability in the view of performance and exhaust engine emission. Also it requests in use appliance for the vehicle exhaust gas emission during 80,000Km or 2 years in advance. So followings describe the certification test to meet Korean 2002 emission regulation as retrofitted vehicle to NGV.

We tested the vehicle under the control of qualified research institute from Korean EPA for retrofit vehicle certification. Before testing all the components to influence vehicle performance and exhaust gas emission were sealed not to permit components changing during certification period. Fig.10 shows the engine cylinder head and ECU to be sealed.



< Fig. 10 > Components to be sealed (Cylinder head / ECU)

During the vehicle test, the vehicle and engine data were saved in every seconds, and supplied to the certification agency. The driving pattern of testing vehicle shares 3 parts with testing time; 30 % of below 30km/hr, 30% of 30~60km/hr and 40 % of over 60km/hr. We defined the driving test road to meet the requested condition as Fig.11 and tested during 3 months.



< Fig. 11 > Test driving road (Rural mode / High way mode / Mixed mode)

4-2 Certification test of emission after vehicle durability testing

After finishing above 50,000Km vehicle durability test, the engine was installed to the engine dynamometer of National Institute of Environment Research to certify the engine power and emission performance. In this test the engine converted to CNG form diesel reached 95% power level to the new diesel car specification 118HP/3,400rpm which value levels within the guideline of ±5% of power variation to new diesel car. And in the view of emission, the engine performed CO reduction 26%, HC increase 17%, NOx reduction 85%, PM reduction 100%. Finally this car meets all the requirements of Korean EPA, and 2002 vehicle emission regulation.

		CO[g/kwh]	HC[g/kwh]	NOx[g/kwh]	PM[g/kwh]	Notes
Diesel (1997 MY)	Regulation	4.9	1.2	11.0	0.9	Test method: D-13 mode
	Used car	4.55	0.87	9.92	35%(SMK)	
NGV (2002 MY)	regulation	33.5	1.3	5.5	-	
	Test result	3.389	1.024	1.475	0	

5. Conclusion

By the development of combustion system as lean burn and intake charging air cooling system, we restricted the exhaust gas temperature under 750°C in the rated power condition and exhaust emission especially NOx to acceptable level. As a result of this development, it was possible to reach the same level of power with diesel engine, meet the emission regulation of Korean 2002 heavy duty vehicle and endure engine durability test of 300Hr full load condition with hot water temperature.

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under the Korean law of “Special law for air conservation of Central city area”,

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  Major : Mechanical Engineering (Master)

Social Experience

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- 1999. 09 ~ CEO of EngineTech Co., LTD
- 2006. 10 ~ CTO of CEV Co., LTD
- 2007. 11 ~ Auditor of Korea Automotive Environment Association

Activities

- 2004. 06 ~ A member of Transportation research society of "Ministry of Commerce, Industry and Energy of Korea"
- 2002. 08 ~ A member of "Committee of New Technology Road Map" of " Ministry of Science & Technology of Korea"
- 2002. 03 ~ A member of "Evaluation Committee of New Technology" of "Korea Institute of Industrial Technology Evaluation and Planning"

Papers

- Research of Stratified Combustion Characteristics of Gasoline Direct Injection Engine, KSAE, 1998
- Development of HFD 2.4L Lean Burn Gasoline Engine, SAE, 1995
- Others