# Compressed Natural Gas as Alternative Fuel to Diesel in Transport Sector: The Fuel Consumption and Emission in Light Duty Truck

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**Abstract:** *In 2008's energy crisis, the compressed natural gas (CNG) was promoted as alternative energy in Thailand's transport sector, especially, in trucks and buses. To use CNG as alternative fuel, the engine, compression ignition system, needs to be converted to spark ignition system and makes reduction on compression ratio (CR) that matches the properties of CNG. Consequently, due to conversion, the thermal efficiency and fuel consumption is dropped. In this paper, the light duty truck that equipped with 3.0-liters commonrail diesel engine was converted to natural gas spark ignition engine. In addition, this vehicle was test with driving cycle on the controlled environment chassis dynamometer and the EUDC (European Driving Cycle Test) was selected for fuel consumption and emission study. The results were compared to the standard test made by vehicle's company. The CNG consumption was approximately 5.91 km/kg which 2.5 time compare to standard's vehicle test result using diesel as fuel. On the other hand, the $CO_2$ emission from CNG was relatively less than original diesel engine.*

**Keywords:** CNG, Natural Gas Engine, SI Engine, Driving Cycle, EUDC

## 1. INTRODUCTION

In 2008, the major oil price crisis had principal impact to transportation sector that critically relying on oil. Almost half of it was diesel fuel which consume in truck's compression ignition engine. In case of Thailand, the compressed natural gas (CNG) was promoted as alternative energy source for transport sector [1], because the price was cheaper, and it had relatively less greenhouse gas (GHG) emission. However, the application of CNG as alternative source to diesel fuel needed to be converted the engine from compression ignition (CI) system to spark ignition (SI) system which affected to lower thermal efficiency and higher fuel consumption comparing to diesel fuel.

Since, the conversion of the engine from CI to SI was totally difference in combustion system, especially, the control of engine power. The CI engine limited the power by controlling amount of fuel into combustion chamber, regardless the amount of air or air-fuel mixture ratio (AFR). While, the SI engine limited the load by controlling amount of air-fuel mixture into combustion chamber, at exact stoichiometry AFR, using throttle.

O.A. Kutlar, et. al., [2] revealed the issue in SI engine at part load operation. From actual Otto cycle analysis, the comparison between wide open throttle (WOT) condition and close throttle condition indicated that at part load operation, close throttle condition, had high ratio IMEP (Indicated Mean Effective Pressure) in pumping which accounted for 30%. On the other hand, at full load or WOT condition, IMEP accounted only 2% for pumping energy. The pumping loss affected overall thermal efficiency of SI engine with variation on load. At full load, the thermal efficiency of engine might be 30% – 35% while, at part load during vehicle constant speed with 50-60 KPM, the thermal efficiency with same engine might be lower as 10%-20%.

This factor was a weak point for SI engine in comparison to CI engine. Especially, application of engine in vehicle needed maximum power from the engine to accelerate in a few second but it only needed small amount of power as part-load to maintain cruising-speed almost of travailing.

In this study, the rate of fuel consumption and emission of 1-ton truck that modified from Diesel-CI engine to CNG-SI engine was tested and compared between original and alternative fuels. In addition, the test in this study employed standard driving cycle and factor following TIS standard no. 2155-2546.

## 2. METHODOLOGY

### 2.1 The standard driving cycle

The standard driving cycle is a simulation of vehicle movement that represents the real movement on the road (consists of acceleration, deceleration and stop) that affect to the rate of fuel consumption and emission. In general, there are 3 main standard which are ECE (European), FTP-75 (Untied State) and 10-15 Mode (Japan).[3] In this study, as mention, the TIS standard was employed that equivalent to ECE standard. The driving pattern is shown in Fig. 1 and probably called NEDC (New European Driving Cycle)

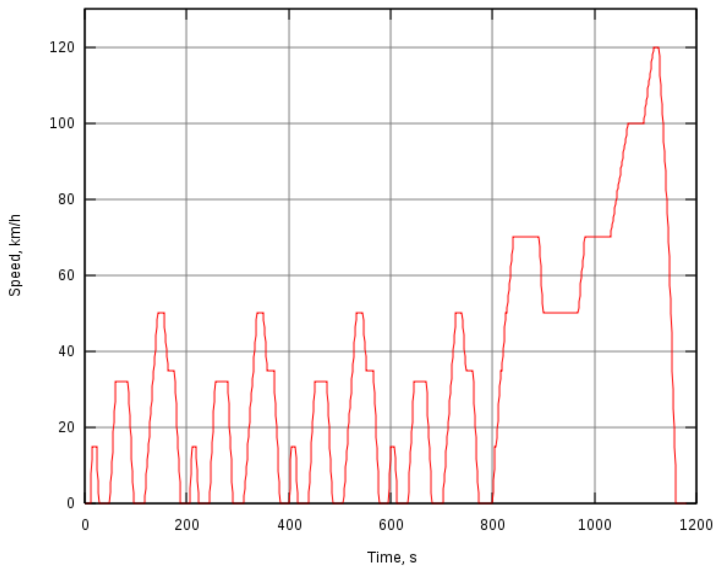


**Fig. 1** NEDC used in this test.

The NEDC driving pattern composes of several sets of accelerate and break under 50 KPM which represents the driving in urban area. Moreover, for speed pattern over 80 KPM, it simulates the driving in extra urban (suburb) area, and the total distance is 11.254 km. The truck that used in this test was origin on diesel's EURO3 emission standard in class less than 1760 kg. The emission standard is shown in table 1.

**Table 1** The emission standard

| g/km | ***CO*** | ***$NO_x$*** | ***$HC+NO_x$*** | ***PM*** |
|---|---|---|---|---|
| EURO3 | 0.95 | 0.78 | 0.86 | 0.1 |

### 2.2 Tested Vehicle

The sample vehicle in this test was 1-ton pick up truck (Toyota Hilux Vigo). Originally, the truck had been diesel commonrail engine (CI engine) and it was modified to CNG-SI engine. The high pressure diesel fuel injector was replaced by spark plug with embedded ignition controller. Moreover, the CNG equipments were installed including throttle at air intake to control the power of the engine. The specifications of equipments were listed in table 2

**Table 2** The technical specifications of tested truck

| item | OEM | converted |
|---|---|---|
| Engine | 1KD-FTV | |
| Displacement | 2982 cc | |
| Compression Ratio | 17.9:1 | 9.7:1 |
| Air-intake | turbocharged | |
| Fuel System | Direct Injection Diesel Commonrail | Mixer-Vaporizer |
| Ignition System | | Spark Plug with NECTEC DIS4 |

After modification, the engine maximum power on CNG was tested with standard facility [5] as results shown in Fig. 2 and table 3. In addition, the modified engine had more maximum power than original diesel engine [6] and revealed that fitness of this modified engine.

**Table 3** The engine performance

| | CI-Diesel | SI-CNG |
|---|---|---|
| Maximum Torque | 343 N.m@1,400-3,200 rpm | 444 N.m@3,200 rpm |
| Maximum Power | 120kW @3,400 rpm | 148kW @3,200 rpm |

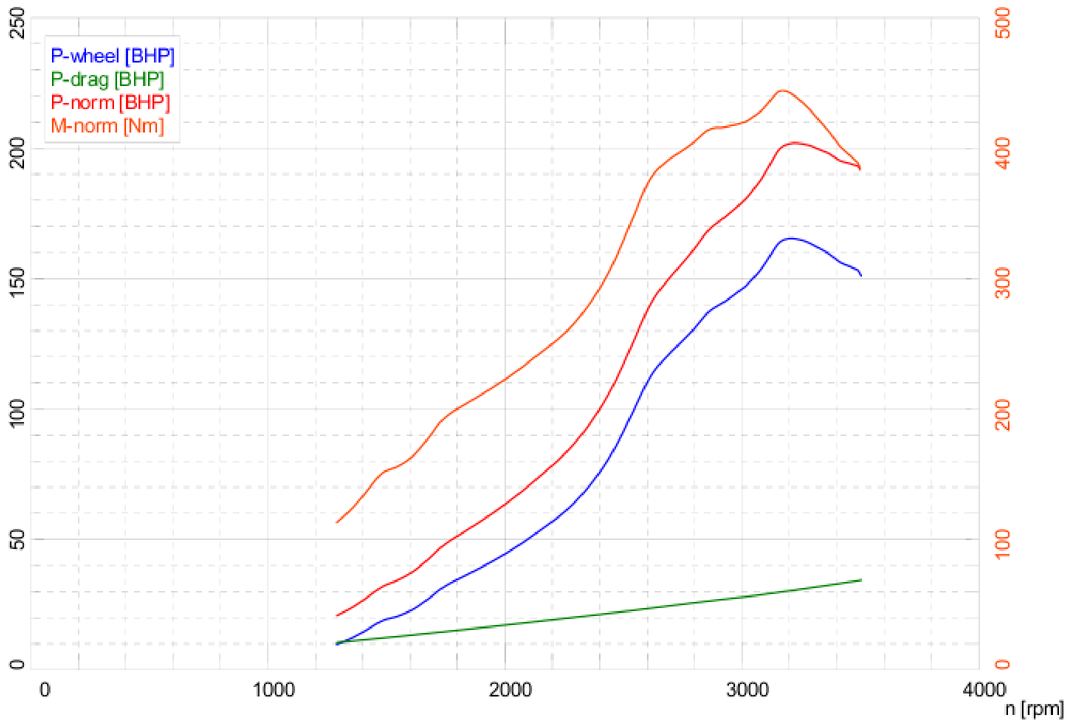


**Fig. 2** The converted engine performance curve

### 2.3 Tested Facility

For the emission and fuel consumption were tested under light duty diesel vehicle test cell, automotive emission laboratory, department of pollution control which simulated the driving cycle on chassis dynamometer as shown in Fig. 3. Moreover, the exhaust emissions were sampling for analyzing both emission ($CO_2$, CO, HC, $NO_x$, PM) and fuel consumption via carbon balance. [7]


**Fig. 3** The standard emission laboratory

## 3. RESULTS AND DISCUSSION

### 3.1 Gas Composition

First of all, the gaseous fuel that used in this experiment was sampling for composition analysis, since CNG in Thailand has noncombustible gases. The samplings were analyzed using Gas Chromatography (CG) method. The composition is shown in Fig. 4 as fraction by volume and Fig. 5 as fraction by mole. The results shown that this fuel contain 73.49%(v/v) of methane or 55.85%(m/m) and this data would be used in carbon balance's fuel consumption analysis.

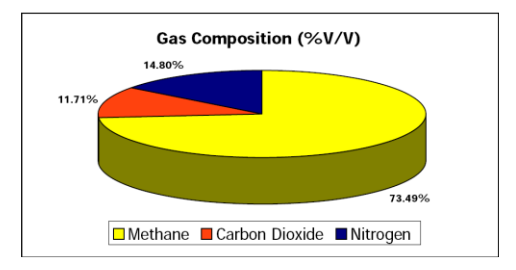


**Fig. 4** CNG composition by volume

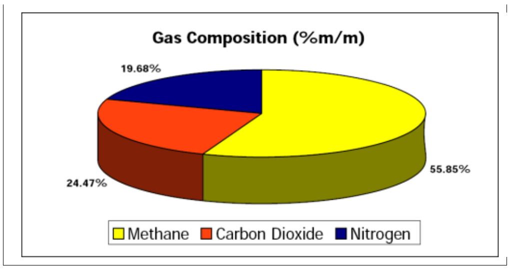


**Fig. 5** CNG composition by mole

### 3.2 Fuel Consumption

The fuel consumption result in km/kg was shown in Fig. 6 which compared the fuel between converted CNG fuel with OEM's diesel fuels. The OEM's results obtained from specification in reference [6] and as CNG generally measures in unit of mass, so the diesel fuel data of fuel consumption were converted into same unit of km/kg with diesel fuel density at 850 kg/m$^3$. The results raveled that CNG consumption in urban mode was 8.11 km/kg and 4.60 km/kg for extra urban (suburb) mode. Consequently, the average NEDC was 5.91 km/kg which briefly twice times more than original diesel commonrail engine as illustrated in Fig. 7. These results indicated that the converted engine had less efficiency at part-load than original engine.

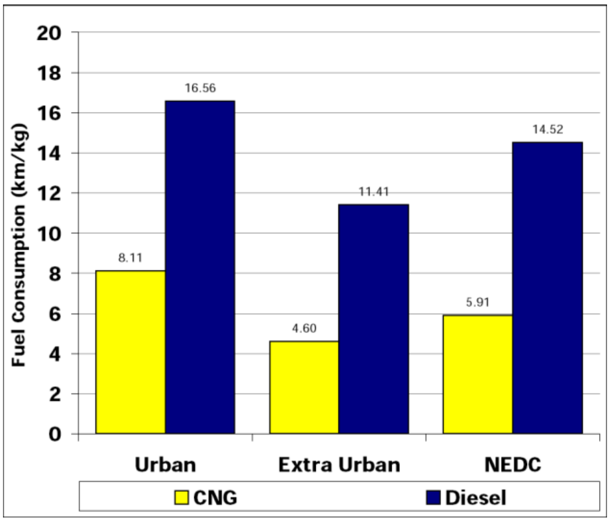


**Fig. 6** Fuel consumptions

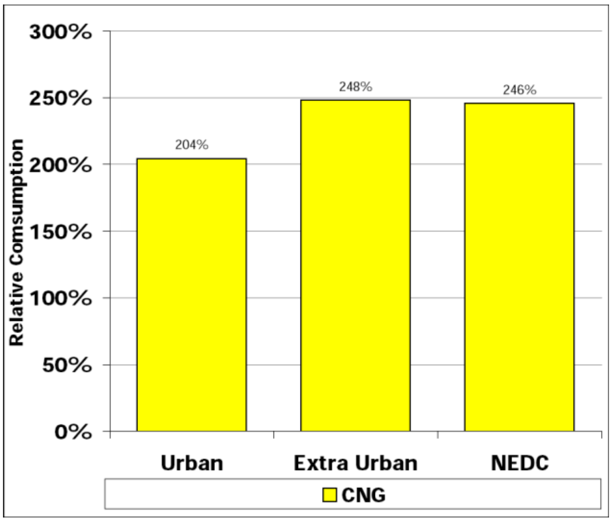


**Fig. 7** Relative fuel consumption between CNG & Diesel

### 3.3 The Fuel Cost per Distance

Although the CNG SI engine had higher rate of fuel consumption, the CNG fuel price was relatively cheaper than diesel which was 8.5 bath/kg[1] that reflected to the cheaper operation cost than diesel fuel. As illustrated in Fig. 8, the cost per distance were 1.05, 1.85 and 1.44 bath/km for urban, extra urban and NEDC mode respectively which, at same operation cost for Diesel CI engine, equivalent to diesel fuel at price 14.76, 17.92 and 17.75 bath/liter for those mode of driving as shown in Fig. 9. In conclusion, this were brake even point for conversion the engine to CNG system, in case that diesel fuel price cheaper than this point, diesel commonrail engine with diesel as fuel would less operation fuel cost than SI-CNG mode

1 On Feb. 3rd, 2009

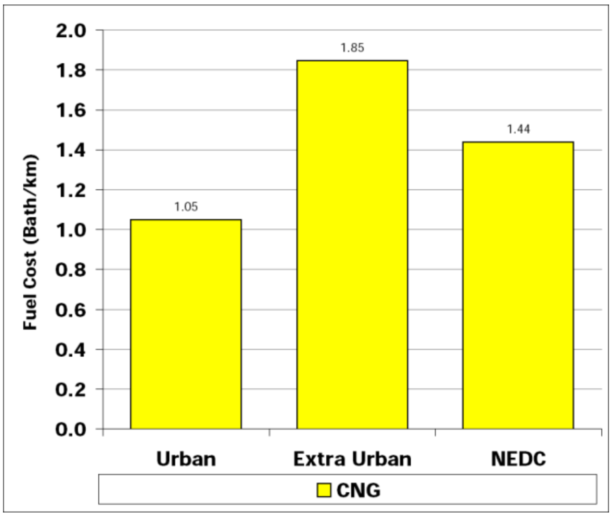


**Fig. 8** SI-CNG mode fuel cost per distance

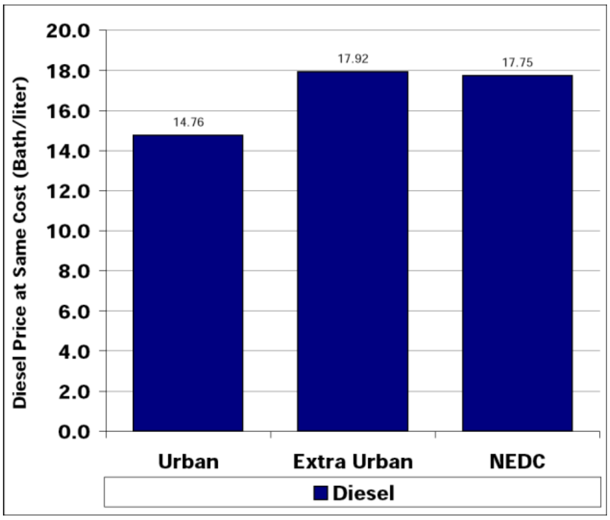


**Fig. 9** Diesel price with CI-diesel mode at same cost

### 3.4 Emission

The emission in were sampling including $CO_2$, CO, HC, $NO_x$, and particulate matter (PM). The carbon dioxide ($CO_2$) that is not cited in EURO3 standard could be compare with OEM specification [6]. As illustrated in Fig. 10, the tested result manifested that CNG SI emitted, at 156 g/km, less $CO_2$ than CI-diesel at 219 g/km. In addition, although, the fuel consumptions on CNG SI were twice time of Diesel CI, the carbon emission of CNG SI stilled less than Diesel CI because it has less carbon molecule in CNG.

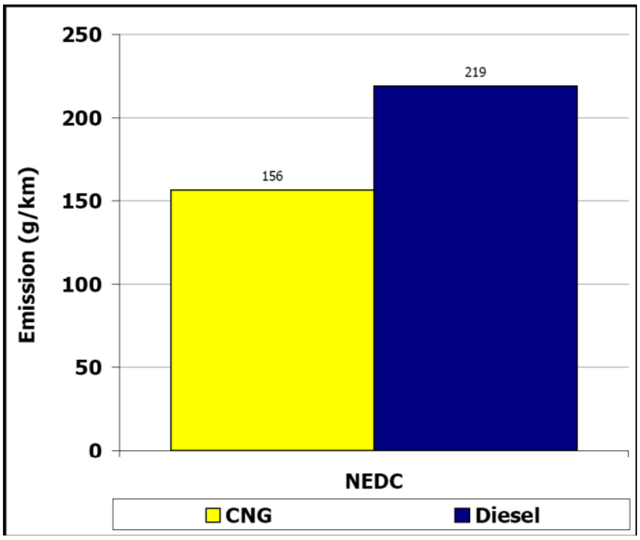


**Fig. 10** $CO_2$ Emission

For the other emission, the test results were compared with EURO3 diesel directive following the original vehicle standard which categorized into 2 groups:

1) Satisfied EURO3 directive, the $NO_x$ and PM were less than limit as illustrated in Fig. 11 and Fig. 12 because the SI engine charactered in low emission for both substances.

2) Unsatisfied EURO3 directive, the CO and HC were over the standard limit as illustrate in Fig. 13 and Fig. 14 due to the incomplete combustion and inadequate fuel calibration.

## 4. CONCLUSION

Natural gas is a clean fuel and inexpensive that has been promoted to be alternative fuel in oil crisis. However, this fuel needs conversion of engine from compression ignition to spark ignition system, so, SI engine has less conversion efficiencies especially at part-load condition. The standard driving cycle test that simulates road condition revealed the information to fuel consumption study. The results show that the modified spark ignition natural gas engine had 2.5 time of fuel consumption more than original diesel engine due to low efficiency at part-load condition but the carbon dioxide emission was relatively lower.

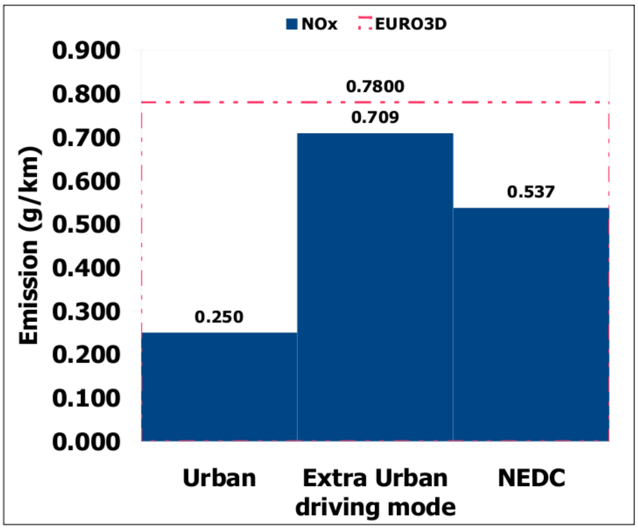


**Fig. 11** $NO_x$ Emission

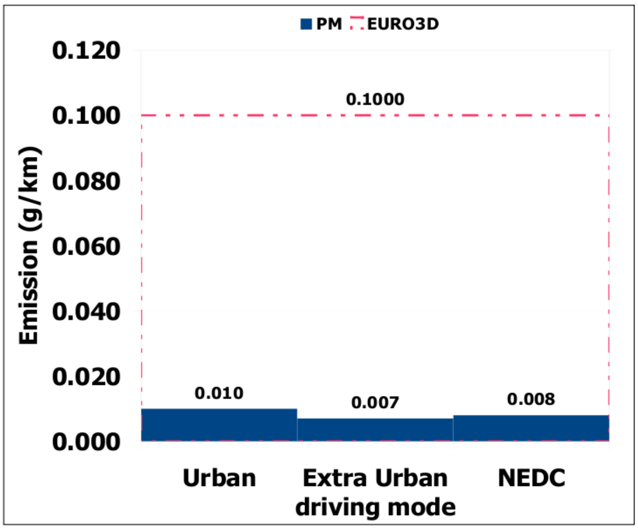


**Fig. 12** PM Emission

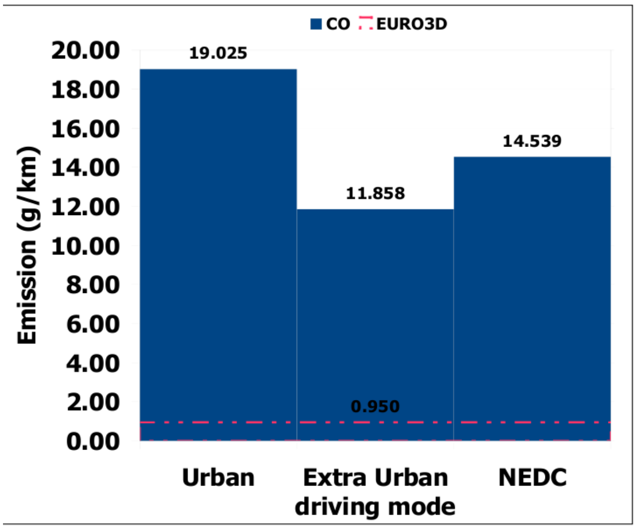


**Fig. 13** CO Emission

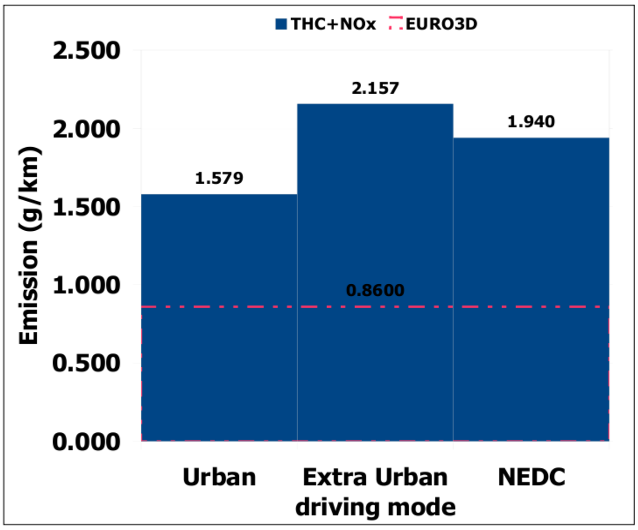


**Fig. 14** THC+NOx Emission

## 5. ACKNOWLEDGMENTS

This study has finance support from NSTDA B4-2 "Intelligent Transportation Systems Program". Also, the authors gratefully thanks Automotive Emission Laboratory, Department of Pollution Control, Thailand for the emission testing cooperative, and the tested vehicle & natural gas conversion from Ninbless, Co., Ltd., Rayong, Thailand.

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