# An Experimental Assessment of Compression Ratio and Evaluation of Aluminium Cylinder Head in Bi-Fuel(Gasoline+CNG) Engines

**A. Firouzgan***
Master of Science
Irankhodro Powertrain Co. (IPCO)
a.firouzgan@ikco.com

**Corresponding Authors***
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## Abstract

**The first step in dealing with the behavior of an engine on NG mode is the installation of a suitable gas fueling system on the engine. Two generations of gas fueling systems which were studied and installed on research engine were Mixer type and Sequential system type. The results, including performance, emissions and fuel consumption, were recorded and analyzed. The results showed that the sequential gas fueling system is better than the mixer type. The power loss in mixer type is 1.78% higher than that of the other one. On the other hand, injection multi-point sequential gas system makes 1.75% improvement in torque view.**

***Keywords:*** *CNG, Engine, Bi-Fuel, Performance*

## Introduction

Nowadays, the usage of natural gas in internal combustion engines is becoming more and more important. It is essential for a fuel used in an engine to meet specific physical, chemical, and combustion requirements. LPG and CNG are more famous and more popular alternative fuels for engines [1].

The spark power and advance have a strong effect on performance and emissions in SI engines. Experience in CNG application as an alternative vehicle fuel differs significantly around the world. CNG as a vehicular fuel has been popular in the world since the mid–1930 [2]. Bi–fuel vehicles running on both NG (Natural Gas) and gasoline are mandatory in the presence of a low number of NG refueling stations. Having increased the NG refueling stations, there will be a good opportunity to produce dedicated NG vehicles. Consequently, nearly all (OEMs) intend to develop and produce dedicated NGVs, which will be able to run only on NG. Dedicated NGVs are mainly used in public or private fleets such as pick-ups, taxicabs, delivery vans and buses which can use their own NG fueling stations.

In summary, the two driving forces behind NG as a fuel for internal combustion engines are represented as: energy security and environmental requirements [2]. NG as vehicle fuel should be considered in all aspects because of different combustion, chemical, and physical behaviors and characteristics. Choosing the right gas fueling system for gas engines is vital as the gas fueling system is supposed to be installed on gasoline engines to obtain more favorable performance and emissions on the gas mode. After analyzing different gas fueling systems, two types of them were chosen to be installed on the engine, namely MPSFI (Multi Point Sequential Fuel Injection) and traditional mixer type.

All gas fueling systems installed on engines and tested by engine dynamometer. PAYKAN family has two engine types: HC(High compression) and OHV(Over Head aluminum cylinder head Valve). All tests were done at full-load conditions, i.e., engines were set on the maximum load.

Methane ($CH_4$) is a greenhouse gas. It has 62 times the specific potential to heat up the atmosphere more than carbon dioxide ($CO_2$). However, methane exhausted from NG engines represents 0.04% the mass of $CO_2$ while $CO_2$ generated by a CNG engine stands at 20%, which is about 5% less than that of the corresponding gasoline and diesel engines. That is because of the high hydrogen to carbon ratio of $CH_4$. Therefore, the global warming index (GWI = $CO_2$+62$CH_4$) of the NG engine is 22% which is 4-8% lower than that of an engine running on conventional fuels [1].

The authors in previous experimental studies, have worked on LPG and CNG Bi-Fuel engines. Based on the results ,the impacts of spark power and advance have been studied on CNG engine, and some modifications on CNG fueling system and also on the engines have been done [2, 4, 5 and 6].

In this regard, for a more detailed investigation, other improvements have been done on the converted engine, such as changing valve seat material, changing catalyst converter and using MPFI CNG fueling system instead of the MIXER type. The seat material was changed to higher thermal strength in order to tolerate wear and thermal conditions on the gas mode [7]. Due to continuous working, it was decided that the fueling system needed to be improved for gasoline and CNG modes. The steps and approaches to adopt and satisfy these improvements are as following:

• MPSFI gasoline system was installed and underwent several tests on engine dynamometer for full and part-load conditions. Engines in this study were HC type and OHV type.

• All activities related to using mixer fueling system and MPFI were carried out on engines, including catalyst and without catalyst separately. So test results show the effects of mixer CNG fueling systems on both the CNG and gasoline modes with and without catalyst.

## Eng engines specifications

From a general point of view, the natural gas can be very well-mixed with air so that it allows achieving considerable advantages such as:

- Optimum distribution of air/fuel ratio to engine cylinders.

- Optimum control of air/fuel ratio in thermal and dynamic transient operations due to the absence of wall wetting phenomena ( liquid fuel film sitting on intake ducts).

-The Stochiometric air/fuel ratio can be precisely maintained over engine's running conditions. This allows reaching the best compromise among fuel consumption, performance and emissions. On the other hand, the CNG engines and vehicles are faced with the following challenges:

- Higher overall dimensions and costs as well as complexity of the on-board fuel storage system.

- A specific gas network and refueling station distribution.

- A lower engine volumetric efficiency which results in poor performance.

In an engine with a fuel-injection system, the lower volumetric efficiency on the gas mode causes about 10% performance loss compared to a gasoline engine.This is due to the displacement of gas by the combustion air in the suction stroke. The performance loss can be even higher (about 25%) for a conventional carbureted CNG engine because of additional pressure loss resulted from venturi restriction .The venturi section is required for pulling of the gas from regulator and feeding natural gas into the intake manifold.The reduction of air path at venturi throat also will make lead to power loss on gasoline mode.

- Because of the very compact and simple molecular structure of methane( $CH_4$), and slow flame velocity of burning , the knocking resistance of NG is very high (130 for both research and motor octane number – meaning zero sensitivity). it can be said that there is no risk for knocking combustion on the NG engine. This allows achieving a very high compression ratio (11-13) which shows a significant gain in fuel conversion efficiency. The lower laminar flame velocity of methane (33.8 cm/s) compared to that of gasoline (38.0 cm/s) is reflected by the 10% lower burn rate of NG than that of the gasoline inside the engine cylinder at the same turbulence level [1]. The inherent combustion stability of the NG engine can be fully considered at λ equals to 1. The fact is that the lean mixture limits of an NG engine are extended to move extreme values to $\lambda=1.4$. As a result, the fuel consumption is 5-6% lower compared to the stoichiometric one.

The most effective factor in reduction of NOx, i.e. EGR, can affect the combustion stability, especially the EGRs which are close to lean limits.

**Catalyst application**

There is a significant difference between natural-gas and gasoline engines in exhaust gas in terms of after-treatment approach(Fig1). The highly compact molecular structure of methane is a problem for its oxidation in the catalyst. To achieve a conversion efficiency of more than 50%, a temperature of 580 ºC is required while other hydrocarbons, typical of gasoline combustion, show the same conversion efficiency at 280 ºC [2]. In Fig.2, the range and controlling of A/F ratio with and without catalyst application has been illustrated for in engines.

**Gas fueling systems**

Based on gasoline fueling systems, there can be four generations of NG fueling systems installed on engines [3,10]:

**- Generation 1:** This system is known as the traditional NG fueling system. NG flows from a high pressure tank into the regulator and enters the engine through a mixer while the engine makes suction at a point of mixer which has the minimum diameter. The advantages of this system are simplicity, low cost and convenience in diagnosis. On the other hand, the emission level is slightly low and the power loss is so high (about 15-20%) [4, 5].The catalyst needs an accurate stochiometric AFR window based on the closed loop lambda control system. Since this fueling system with mixer can not guarantee and ensure stochiometric AFR ,it is not suitable with the catalyst system. Nowadays generation 1 gas fueling system is preferred not to be used any more due to their high emission and low performance.

**- Generation 2:** NG flows into engine by suction made in the mixer venturi but the amount of NG is under control by a small ECU and λ (Lambda) sensor in closed-circuit system (Fig. 3). This system is called a mixer with lambda control system (Fig. 4). The transient response and overall performance is better than that in generation 1. It is possible to use it in catalytic injection gasoline cars. The NG fueling system is simple, slightly low cost. Moreover, in addition to easy maintenance, it has the potential of achieving a good emission level [3].

**- Generation 3:** Being capable of obtaining more efficient NG fueling systems, meeting emission level standards ( such as EuroII and EuroIII ), being slightly high cost having a good performance, and desirable drivability are the main attributes of this system (Fig. 5). NG comes out from a PPR with the pressure of about 1 to 2 (up to 9) bars above MAP(Manifold Absolute Pressure). Also, using MPFSI reduces the back fire risk significantly at intake manifold [3].

**- Generation 4:** In this system, NG is under control by modern ECU and injectors. Very accurate function, high standard of emission level (EuroIII and EuroIV), good controlling of A/F(air fuel ratio) and spark advance, very smooth and good drivability in gasoline mode, lower power loss (about 10% and even less), more reliability, potentiality of being easily diagnosed and many other characteristics can be attributed to this NG fueling system. NG flows into a joint rail equipped with four Gas Injectors and spreads in each intake manifold runner (Fig. 6).

In the conversion approach, there are two methods of converting a gasoline-based car to a gas-fuelled one: master–slave method and stand alone method[10].

In master–slave system, the whole strategy of fueling is under gasoline ECU control. The Gas ECU merely translates the pulse width of gasoline injection and makes it suitable for gas injectors. On the other hand, due to different fuel characteristics, it is necessary to deal with each fuel according to its own physical characteristics. Hence, in stand–alone systems, NG has its own strategies independent of gasoline ECU. Regarding these systems, the performance, emissions and drivability of second system are better than the other. In table 1, it is possible to find out which NG fueling system is suitable, based on the original gasoline fueling system on the car. This data came from studies and experimental tests on gas engines and are very useful for conversion approach[11].

**Research engine specifications**

In the present experimental studies, both generation 1 and 4 fueling systems were installed on HC and OHV Engines. First, a mixer fueling type system and at the second step , the full sequential system based on stand –alone approach were tested on two HC and OHV engines. Furthermore, all tests were repeated with and without catalyst. Since the A/F ratio has a strong and dominant effect on the engine performance and car drivability [8], all gas systems were tuned and calibrated for best torque and power.

Two types of PAYKAN engine family, HC and OHV, were tested at part and full load modes with and without catalyst. Although the same tests were done in the presence of mixer and full sequential MPFI gas systems. Full sequential injection systems inject the fuel, at each stroke of engine, into each cylinder independently. The detailed engine specifications are shown in table 2.

**Engine setup and test facilities**

The installation of each gas fueling system on engine has been carried out in professional and trained experts. Also, the comprehensive activities of tuning and calibration of fueling and spark systems were fulfilled very precisely according to written software. Injection timing, spark advance and phase of injection were swept and calibrated at the best point in terms of torque and emission with this software and finally saved the best file in ECU. An eddy current SHENK WS 230 dynamometer which has 230 kw power and 400 N.m torque absorption has been used.All the engine tests were carried out and the results were compared based on the same cell test condition.

The emission equipment was PIERBURG HGA 400 and the laboratory had an ISO 17025 standard. The power was corrected according to ISO 1585 standard. The tests were done at constant rotation mode (N=constant) and at each rpm, the torque and power were recorded. The steps of engine rpm were 500 rpm. Sometimes to check the power and torque curves, it was decided to repeat all the tests in every 500 steps in reverse direction of rpm. Throughout the tests, especially while the engine was under checking, the gap of valves and spark plug were being checked carefully.

**Research method**

The main goal of this research is to convert the Paykan engine family to bi-fuel engine. In addition, The study was aimed at making a comparison between two in order to select the best one for gas application.

On the other hand, the engine was equipped with CNG kit (gas fueling system) and all points on power curve were repeated. All the tests related to engine were carried out on dynamometer. During the engine test at full load, power, torque, excess air coefficient (lambda) and spark advance were recorded. In summary, to conduct the research, the following steps were taken:

1-baseline tests were done in the absence of mixer

2-baseline tests were done in the presence of mixer

3-gas fueling system on engine was calibrated and tuned

4-all the tests were done with engine equipped with mixer kit

5-all the tests were done with engine equipped with injection MPFI kit

6-bi-fuel engines were evaluated and analyzed

**Results and discussion**

Fig. 7 shows the engine on dynamometer equipped with MPFI gas fueling system and Fig. 8 illustrates a schematic layout design of the gas stand alone with full sequence system. In table 3, the values of power and torque with power loss on both gasoline and CNG modes have been recorded. Based on the results, the power loss on maximum power (which occurs at 4750 rpm) is 16.1% and on maximum torque is 15.6%.

Figures.9 and 10 Show that the engine power on gas mode for HC engines approximately equals to that of Paykan carburetor LC (low compression ratio) engine. Gasoline with octane number 95 was used to avoid knocking. Results on gas show that the power and torque are so similar to LC retrofit gasoline Paykan car (Fig. 10). On the other hand, the driver cannot recognize any significant difference in these two engines.High compression ratio makes an improvement in thermal efficiency .So the power and tourque will be increased in HC engine.

In table 4, all the data obtained for OHV engine have been recorded.The results show Installing catalyst causes 1-8% power loss at each revolution and 4% on average (table 3). The mixer-type system makes 11-17% power loss but the power loss in MPSI system is 12.68-15.22%. Regarding power loss in the base petrol engine using mixer and also the drivability of the car, it can be said that the second gas fueling system is far better than the mixer type. The specific fuel consumption is lower than the traditional mixer type. Application of catalyst makes back pressure in exhaust path and restricts the gas flow. Since the volumetric efficiency comes down, the engine power will decrease .

For the HC engine, some activities have been carried out on gas mode in CRF (the engine research center of FIAT in Italy). As a result of different types of gas fuels, different wobe indexes [9] and different geography of Tehran, it was decided to repeat all the activities in new circumstances. Hence, engine tuning and fuel calibration were repeated in IRAN. Table 4 shows the different power and torque for engines calibrated according to the CRF and Tehran conditions. The engine delivers lower power and torque compared to Tehran's conditions, due to using lean mixture (Fig. 11). This effect confirms the necessity of recalibration and retuning for new local conditions. Furthermore, the vehicle after calibration for drivability shows lean mixture dominates. As a result, it can be seen that lower power and torque are obtained compared to the time when the engine is calibrated in Tehran's conditions. Also, emission is very low compared to other calibration files of the ECU for the vehicle (Fig. 12). So retuning and recalibration of engine on the gas mode was suggested for better performance and emission.

Effective controlling of A/F and spark advance on engine could be achieved with a good computed calibration software. So it is easier to achieve lower emission and more desirable performance with sweeping and spending time to find the best and optimum point for torque and emission. Figs. 13 to 18 show the detailed results of this experimental research. Fig. 19 shows the negative effects of mixer gas fueling system on base gasoline engine. The mixer restricts the air flow into the engine and can cause 2-4% loss in power, and at the same time, increases the fuel consumption. This phenomena is made because of restriction of inlet air by MIXER. Reduction of inlet air makes lower volumetric efficiency and power. This disadvantage is not present in MPFI gas systems. The car which used these engines has been shown in Fig. 20.

**Conclusion**

Figs. 17 & 18 show the results of OHV engine with 4 different kinds of engine states have been converted to use gas in this research. The 4 methods which have been tested on engine are ,i.e., mixer type, injection type, with-catalyst and without-catalyst .

Briefly, the conducted research leads to the following conclusions:

1-The maximum power for HC engine is 66.1 hp and 54.8 hp on gasoline and gas modes, respectively at 4500 rpm.It shows 17% power loss.

2-The maximum torque for HC engine is 110.25 N.m. and 93 N.m. on gasoline and gas modes, respectively at 2750 rpm.So it shows 15.6% torque loss.

3-The maximum power for OHV engine is 69.55 hp and 59.47 hp on gasoline and gas modes, respectively at 4500rpm.It shows 14.4% loss in power.

4-Obtained torque for OHV is 116.61N.m on gasoline mode and 98.85N.m on gas mode, at 3000 rpm.So it shows 15.2% loss in torque for OHV engine. It means OHV engine is slightly better in torque loss view .

5-The OHV engine has a 4.67hp and 5.5 N.m increase in power and torque, respectively compared to HC engine on gas mode.So the research shows OHV engine has 6.7% and 4.7% improvement on power and torque respectively.

6-Using injection system makes an improvement of 1.75% in torque & 1.78% in power.

7-Lower fuel consumption, higher reliability, better drivability and lower emissions are other advantages of MPSI for fueling system.

8-Applying mixer for gas mode causes power loss in gasoline mode and increases fuel consumption.

9-Regarding absolute low power, using these engines for bi-fuel applications is not recommended at all.

10-Since there is high power loss, it is highly recommended not to convert these engines to gas application with traditional and mechanical gas fueling system. The customer will sense the decreasing of power very clearly and will be very unsatisfied.

11-Application of 4th generation gas fuel with catalyst on aluminum cylinder head and high compression(CR=8.83) will give the best and optimum performance and emission in gas mode .So it will be the best selection of PAYKAN LC and HC conversion engine to use gas as a bi-fuel approach.

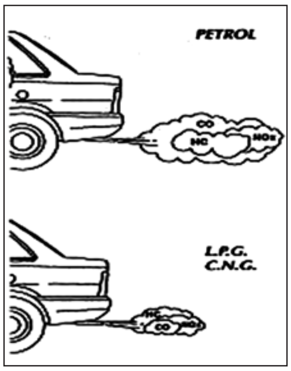


**Fig 1.** Comparing of pollutant for gas and petrol.

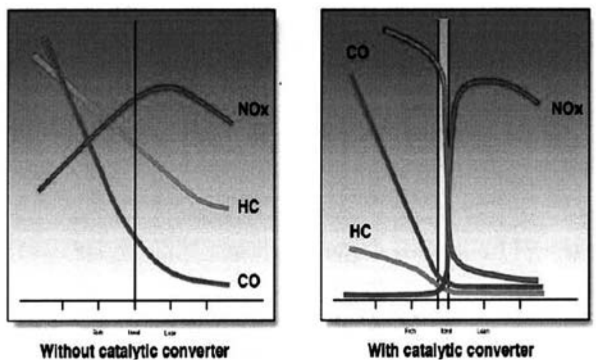


**Fig 2.** A/F ratio with and without catalyst.The horizontal axis is AFR. The middle vertical lines show stochiometric AFR.

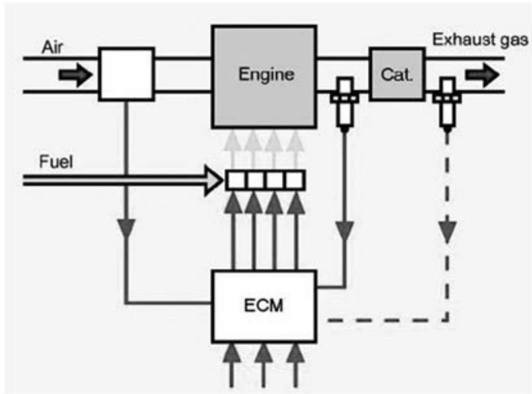


**Fig 3.** Closed loop system

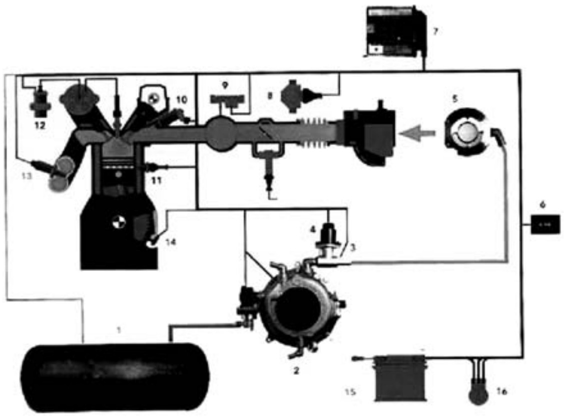

**Fig 4.** Second gas fueling generation. This system has MIXER and lambda control.

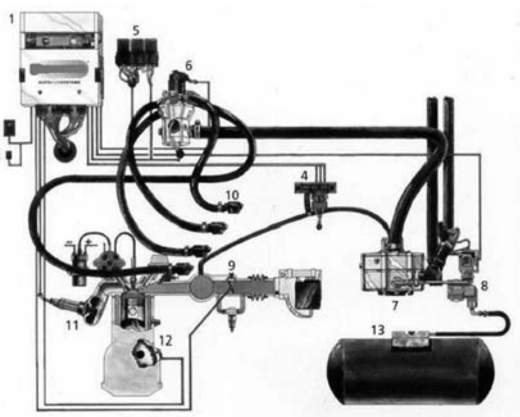

**Fig 5.** Third gas fueling system

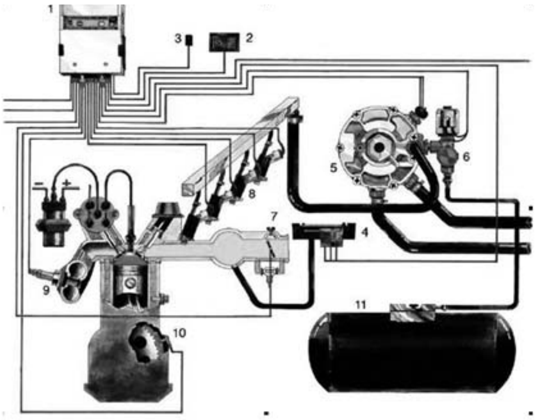

**Fig 6.** Forth gas fueling system

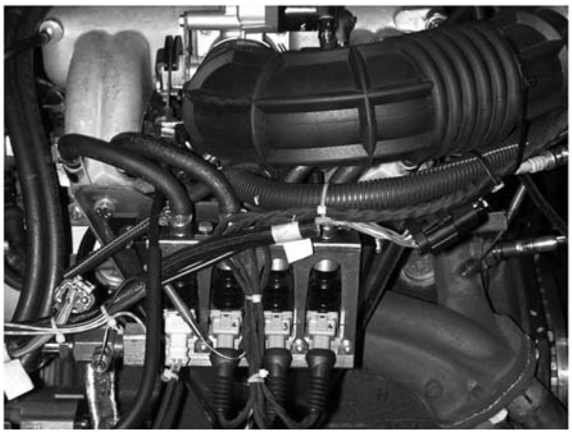

**Fig 7.** Engine on dynamometer

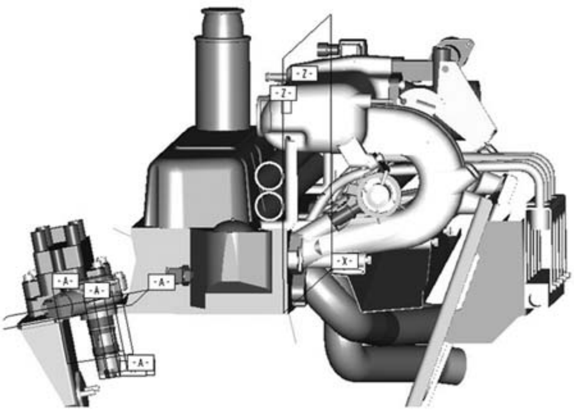

**Fig 8.** CNG Injectors layout design

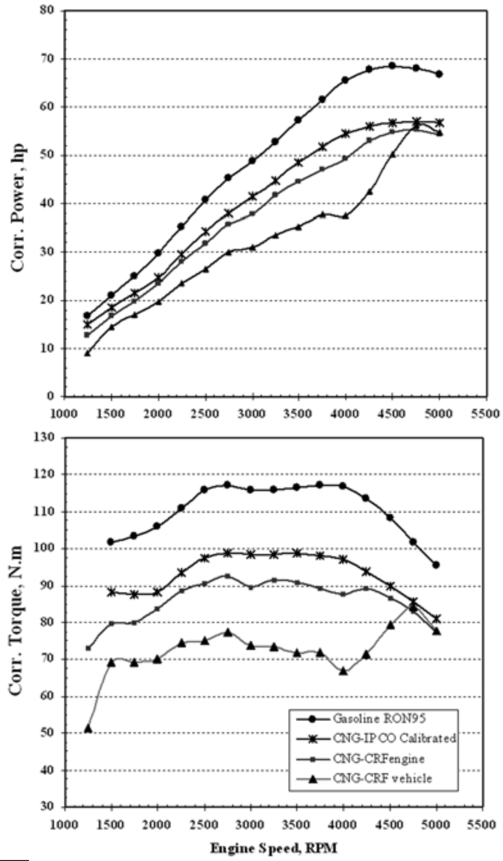


**Fig 9.** HC engine in different condition

**Table 1.** Gas fueling generation vs. car fueling system technology

| Gas fueling engine technology | Gen.1 | Gen.2 | Gen.3 | Gen.4 |
|---|---|---|---|---|
| **Traditional sys.** | ++ | +/- | - | - |
| **TBI sys.** | +/- | ++ | - | - |
| **MPFI (EURO I,II)** | - | +/- | ++ | + |
| **MPFI (EURO III,IV)** | - | - | +/- | ++ |

**Table 2.** Engine specification

| Parameter / Engine | HC | OHV |
|---|---|---|
| **C.R.** | 8.5 | 8.83 |
| **Cylinder Head** | Cast iron | Aluminum |
| **Camshaft** | Same as original | Improved |
| **Position of spark plug** | Same | Close to center |
| **Intake/ exhaust port** | Same | Improved |
| **Fueling sys.** | Semi_sequential SAGEM | “ |
| **Combustion chamber** | Same | Improved |

**Table 3.** Results for OHV engine

| speed rpm | *Gasoline without catalyst* | | *Gasoline with catalyst* | | | *CNG with mixer system* | | | *CNG with injection system* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Power hp* | *Torque N.m* | *Power hp* | *Torque N.m* | *Lost Rate%* | *Power hp* | *Torque N.m* | *Lost Rate %* | *Power hp* | *Torque N.m* | *Lost Rate %* |
| 1500 | 22.22 | 104.13 | 21.91 | 102.66 | 1.4 | 18.35 | 88 | 16.24 | 19.13 | 89.63 | 12.68 |
| 2000 | 30.94 | 108.71 | 30.42 | 106.89 | 1.68 | 26.53 | 93.24 | 12.78 | 26.49 | 93.10 | 12.9 |
| 2500 | 42.54 | 119.58 | 39.45 | 110.89 | 7.26 | 23.58 | 94.39 | 14.87 | 33.13 | 93.12 | 16 |
| 3000 | 52.13 | 122.12 | 49.78 | 116.61 | 4.5 | 41.33 | 96.81 | 16.97 | 42.20 | 98.85 | 15.22 |
| 3500 | 59.96 | 120.40 | 57.91 | 116.27 | 3.41 | 47.87 | 96.12 | 17.33 | 49.23 | 98.85 | 14.98 |
| 4000 | 69.05 | 121.32 | 66.37 | 116.61 | 3.88 | 55.37 | 97.27 | 16.5 | 55.94 | 98.27 | 15.7 |
| 4500 | 71.96 | 112.37 | 69.55 | 108.61 | 3.35 | 58.23 | 90.94 | 16.27 | 59.47 | 92.87 | 14.49 |
| 5000 | 71.63 | 100.68 | 65.89 | 92.60 | 8.01 | 58.19 | 81.79 | 11.68 | 56.02 | 78.73 | 14.97 |

**Table 4.** Results for HC engine

| ***speed RPM*** | ***Gaso line (Octane 95)*** | | ***Calibrated Natural Gas*** | | |
|---|---|---|---|---|---|
| | ***Power hp*** | ***Lost Rate%*** | ***Power hp*** | ***Torque N.m*** | ***Lost Rate%*** |
| 1250 | 16.76 | 95.5 | 15.01 | 85.54 | 10.4 |
| 1500 | 20.91 | 101.63 | 18.6 | 88.26 | 11.05 |
| 1750 | 24.9 | 103.45 | 21.5 | 87.63 | 13.7 |
| 2000 | 29.71 | 105.88 | 24.8 | 88.26 | 16.5 |
| 2250 | 35.2 | 110.95 | 29.5 | 93.45 | 16.2 |
| 2500 | 40.65 | 115.96 | 34.1 | 97.33 | 16.1 |
| 2750 | 45.17 | 117.14 | 38.1 | 98.82 | 15.6 |
| 3000 | 48.7 | 115.8 | 41.4 | 98.34 | 15 |
| 3250 | 52.8 | 115.83 | 44.8 | 98.38 | 15.1 |
| 3500 | 57.2 | 116.67 | 48.5 | 98.72 | 15.2 |
| 3750 | 61.39 | 117.2 | 51.7 | 98.25 | 15.8 |
| 4000 | 67.7 | 113.5 | 55.9 | 93.8 | 17.4 |
| 4250 | 68.4 | 108.38 | 56.7 | 89.78 | 17.1 |
| 4500 | 68.03 | 101.8 | 57.1 | 85.6 | 16.1 |
| 5000 | 66.9 | 95.34 | 56.83 | 80.9 | 15.1 |

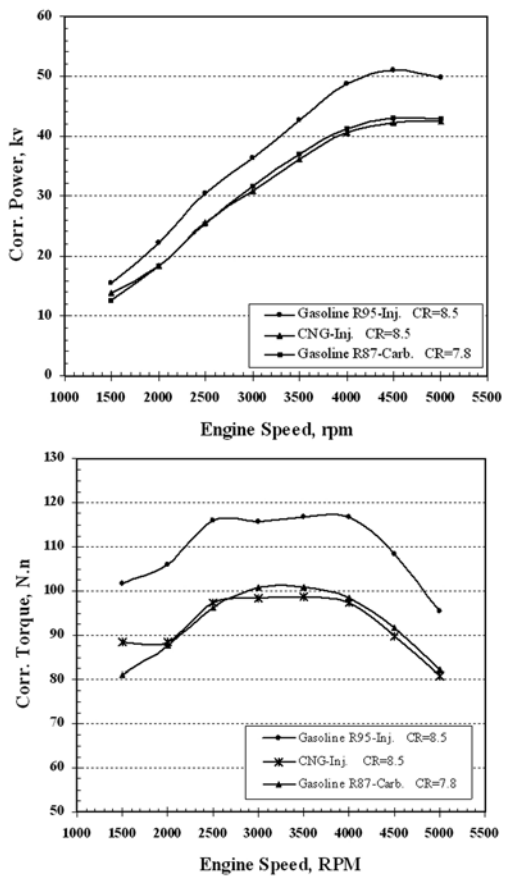


**Fig 10.** Performance of HC vs. LC engine

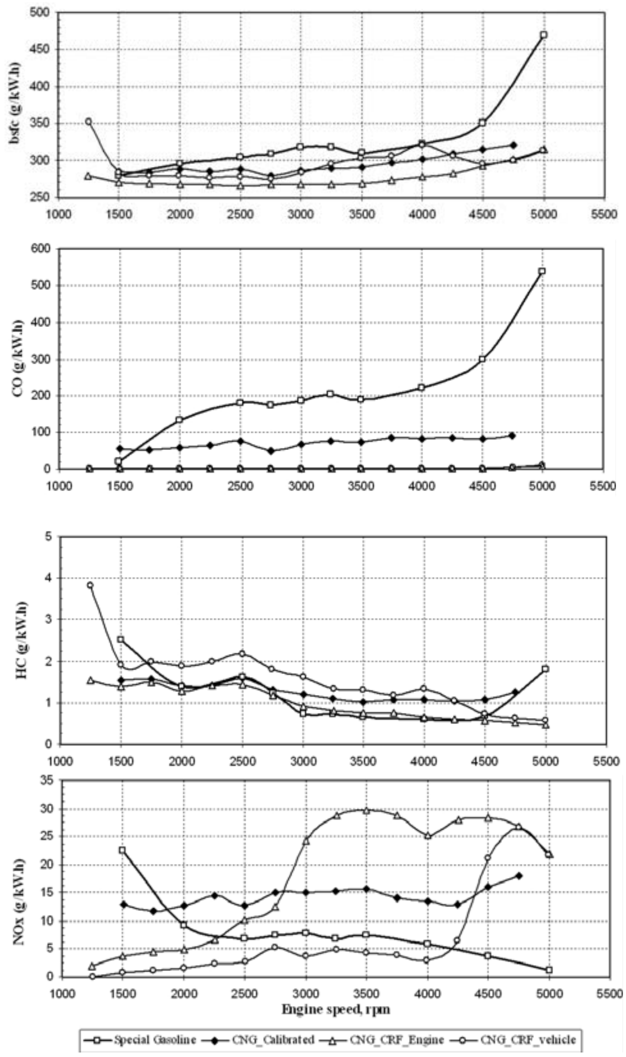


**Fig 11.** HC engine performance result

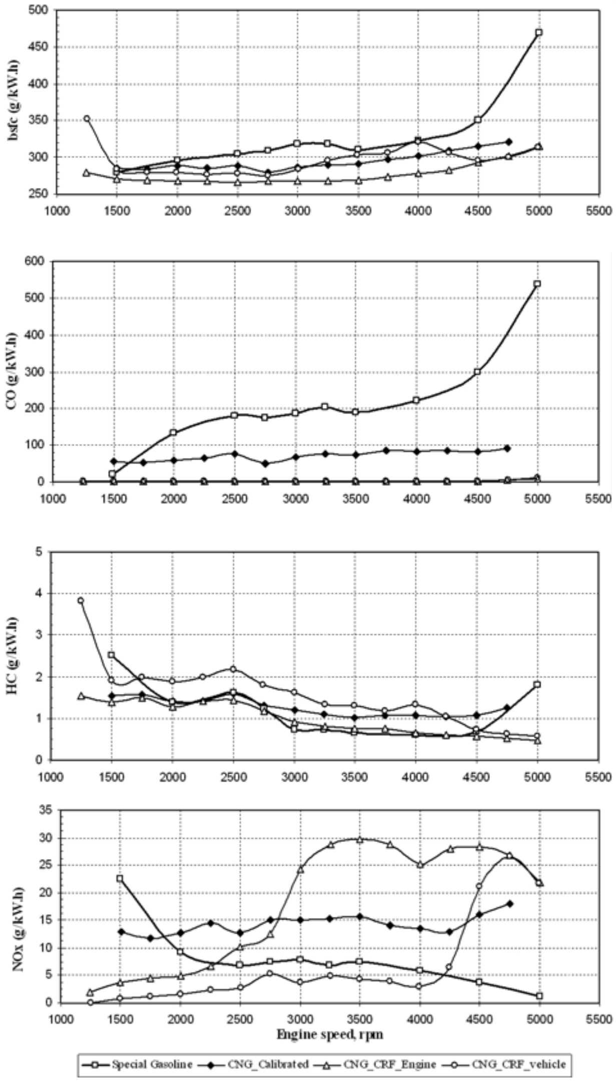


**Fig 12.** HC engine emission result

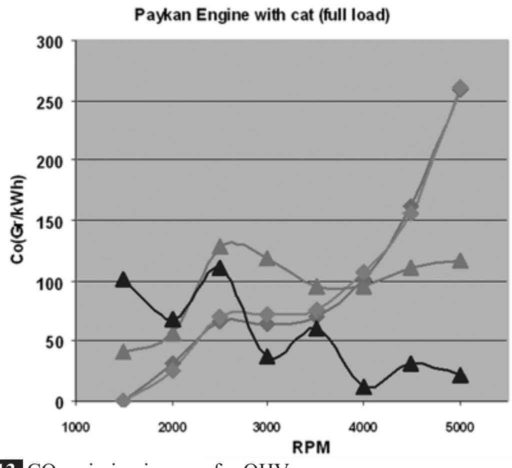


**Fig 13.** CO emission in mass for OHV

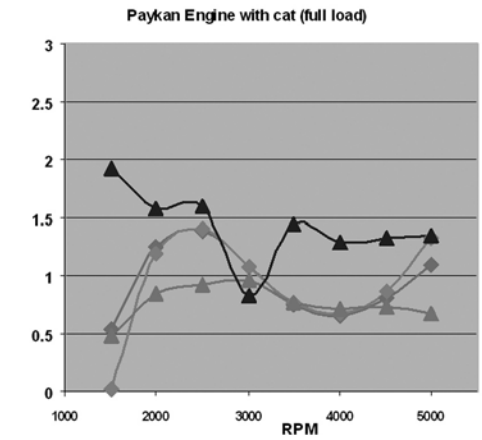


**Fig 14.** HC emission in mass for OHV

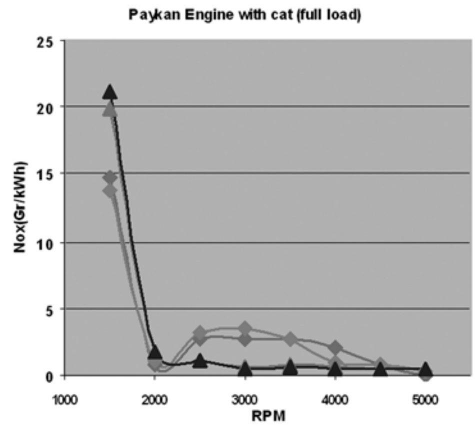


Fig 15. NOx emission in mass for OHV

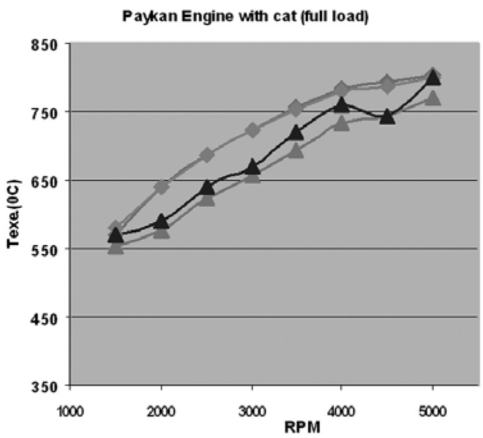


Fig 16. Exhaust temperature for OHV

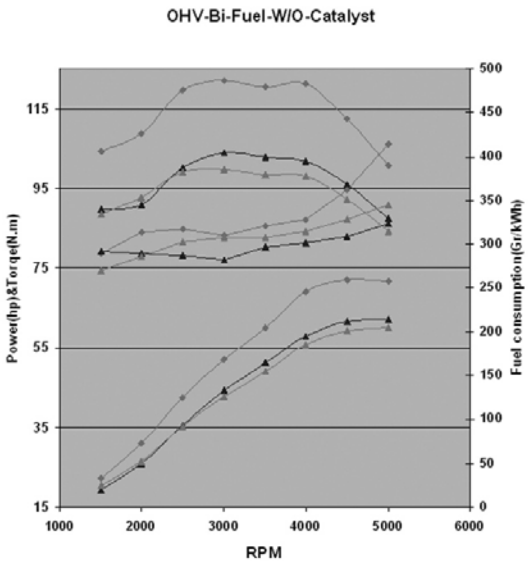


Fig 17. Power and bsfc in OHV w/o cat

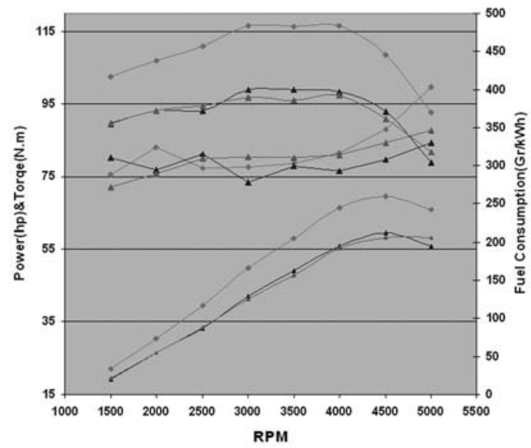


Fig 18. Power and bsfc in OHV with cat

Legends;Red:gasoline baseline,Light green:Mixer fueling gas system,Dark green:Injection gas system.

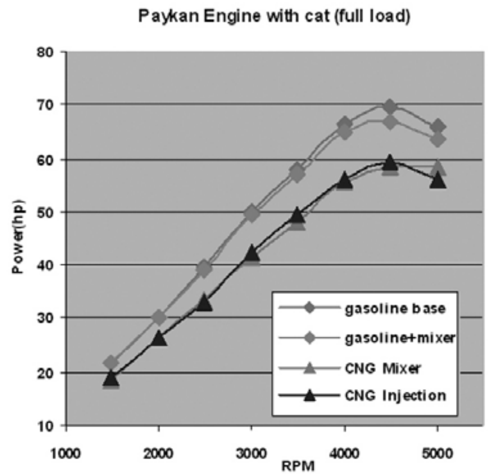


Fig 19. effect of mixer on gasoline mode

*All legend of figures is the same as fig19

Fig 20. Bi-fuel car research

## Nomenclature:

| | |
|---|---|
| NG | Natural gas |
| CNG | Compressed NG |
| LPG | Liquefied Petroleum Gas |
| OEM | Original Equipment Mnufacturerer |
| NGV | NG Vehicle |
| CR | CompressionRatio |
| OHV | OverHeadValve |
| HC | High,Compression(CR=8.5) |
| LC | Low Compression (CR=7.8) |
| MPSFI | Multi Point Sequential Fuel Injection |
| EGR | Exhaust Gas Recirculation |
| PPR | Positive Pressure Regulator |
| ECU | Electric Control Unit |
| AFR | Air Fuel Ratio |
| TBD | Throttle Body Injection |

## References

1-Alireza Firouzgan, Mohammad Reza Rostami, “Experimental Assessment on gaseous engines with effect of spark power and advance on CNG”,3th ICICE ,Tehran, Iran, Irankhodro Power train company (IP-CO), 17th-19th 2004.

2-L. Conti, R. Rinolfi, E. Volpi and G. Cornetti, “CNG engines for vehicle application: a comparative and critical study”, Centro reserche of fiat, 1st ICICE Tehran, Iran, 16TH-17TH February 2000.

3-Alireza Firouzgan, “Passenger gas cars –CNG Retrofit and OEM Conversion”, work shop in 3rd ICICE ,Tehran, Iran, Irankhodro Power train company(IP-CO),17th-19th 2004.

4-Vahab,Pirouzpanah,Alirezafirouzgan, Mohammad Reza Rostami, “Design of mixer for PAYKAN bi-fuel(CNG + gasoline) engine “,The second International Conference On Internal Combustion Engines ,16-17 February 2002.

5-Vahab Pirouzpanah, Alireza Firouzgan, Mohammad Reza Rostami, “Development of gas fuel system in PAYKAN bi-fuel(CNG + gasoline) engine to improve performance and emission “,10th Annual International Conference of Mechanical Engineering”, Khajeh-Nasir University, May 2002.

6-Vahab Pirouzpanah, Mehdi Mousazadeh, Alireza Firouzgan, Mohammad Reza Rostami, “Study and Inspection of performance ,fuel consumption and emission on different kind of natural gas vehicles”, The second International Conference On Internal Combustion Engines ,16-17 February 2002.

7-Mirarash Beheshti Vaziri, Omid Lashgari, Saeed Shabestari, Alireza Firouzgan, “Improvement of Seat material on PAYKAN bi-fuel engine in order to increase life time or durability of gas engine”, The second International Conference On Internal Combustion Engines ,16-17 February 2002.

8-Mehdi Mousazadeh, Alireza Firouzgan, Seid Ali Jazayeri, Mohammad Reza Rostami, Experimental effect of air/fuel ratio on performance , emission and driveability of Bi-Fuel (CNG + gasoline) PAYKAN vehicle”, proceedings of the 11th Annual International Conference of Mechanical Engineering, Vol.5, industrial Papers, Page 377-385,MASHHAD, May 13-15,2003.

9- Vahab Pirouzpanah, Alireza Firouzgan, Mohammad Reza Rostami, Mehdi Mousazadeh, “Natural Gas requirement as vehicle fuel and study on different gas kits”, proceedings of the 11th Annual International Conference of Mechanical Engineering, Vol.5, industrial Papers, Page 326-335,Mashhad, May 13-15,2003.

10-Alireza Firouzgan,”Fundamental of electricity and magnetic in vehicle electrical systems”,chapter 4and 5,first edition ,march 2007,published by KABE DEL.

11- Alireza Firouzgan,”Modern Internal Combustion Engine”,chapter 3and 4,first edition ,march 2008,published by KABE DEL.