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A TECHNICAL REVIEW OF PERFORMANCE OF CNG DIRECT INJECTION IN SPARK IGNITION ENGINE

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Abstract—*Compressed Natural gas(CNG) is one of the most valuable alternative fuels due to its cleanest burning characteristic and high octane number. Now-a-days, most of the vehicles use Port Injection(PI) system for injecting CNG. This paper presents a new concept of injecting CNG directly into the cylinder which is known as CNG-DI. In SI engine, CNG-DI technology significantly increases the volumetric efficiency and thereby increases the burning efficiency.This CNG-DI technology also permits the use of extremely lean air-fuel mixture in the engine and reduces the fuel use of goods and services.In adopting the CNG-DI technology, the engine requires certain modification. The cylinder head must be modified so that, it can accommodate the gas injector which is specially developed for injecting CNG in the cylinder by making holes near the spark plug in the body. The spark plug and gas injector further connectwith timer device. The suitable gas metering system is too integrated with the CNG storage tank.This paper gives a technical introduction of CNG-DI system over the conventional PI and sequential injection.*

Keywords—*CompressedNaturalGas (CNG); CNG DirectInjection (CNG-DI); Spark Ignition (SI); Port Injection (PI); CNG Bi fuel(CNG-BI)*

I.   INTRODUCTION

The development of a new high performance CNG based engine is now becominga challenging task for automotive engine researcher. The innovative technology is required to achieve higher thermal efficiency and to reduce emissions from the present internal combustion engine as per strict emission norms. Many researchers have put their significant effort to develop a new concept of the fuel supply system for CNG injection. Some of them also present a concept of CNG-DI in SI engine. The investigation of CNG-DI based on the Otto cycle in four cylinder four stroke engine can greatly reduce the fuel consumption and emissions from the existing engine. The noticeable work is also done on a CNG direct injection intoa diesel engine, but in that, the researchers have faced the problem of ignition system due to lack of space in the cylinder head. Many researchers have conducted experimental on CNG Direct injection into SI engine with different modifications in the engine. This report concentrates on the work done by the different researchers and the outcomes obtained in their experimentations. This paper also focuses on the challenging area where the further concentration is required. This is the humble effort to show the effect of various operating parameters on the performance of the CNG Direct injection system with SI engine.It is hopeful that, this investigation related to CNG-DI system in SI engine will be in the reality of engineering dreams and it will cause a drastic alteration in the design of CNG kit for more honest performance in near future.

Note

BTDC   Before Top Dead Centre
SOI   Start of Injection
ECU   Engine Control Unit
BHP   Brake Horse Power
NOx   Nitrogen Oxide
HC   Hydrocarbon
IMEP   Indicated Mean Effective Pressure
CR   Compression Ratio
CNG-BI   CNG Bi fuel

1.1 Various Injection systems for CNG fuel

The CNG fuel can be ignited in the SI engine by supplying it in a various ways. Now-a-days, almost all cars are dual-fuel type in which the CNG kit is fitted to convert petrol combustion into the CNG combustion by applying solenoid valve, Gas vaporizer, emulator and mixer in the path of gas line. This system prepares a mixer of CNG and air in the port or

manifoldwhich is known as CNG Port Injection (PI) by reducing the pressure of CNG before entering into the port through a vaporizer.The car is starting with the petrol fuel and thereafter it will be converted into CNG fuel with the help of emulators. This system is very simple, butthe main drawback of this system is a poor volumetric efficiency due to poor mixing of CNG and air in the port. The combustion efficiency will also reduce and it will reduce the generated power from exiting the engine.Another CNG injection system is a sequential injection in which, the mixer of CNG and air is worked near or just before inserting into the piston chamber.The ECU is controlling the entire blending process and timer device will also aid in the distribution of mixer among the cylinders as per the firing order.The reaction time available for proper merging and forming combustible mixer in this type of injection system is less and therefore again the thermal efficiency will cut.

1.2   Concept of CNG Direct injection Technology

Into CNG direct injection system, the CNG is injected directly into the cylinder at the end of compression stroke just like a diesel injection in the diesel engine. The specially designed gas injector is required to inject the CNG in the piston chamber. The CNG coming from the storage tank is first metered in the metering unit and then it is reached in the distributor unit. The connection of distributor unit is made with the timing device so that it will provide the exact amount of CNG at the right time in the cylinder. The direct injection of CNG in the cylinder will increase the volumetric efficiency and thereby increases the burning efficiency.The BHP of the locomotive is also increased and reduces the emission from the existing engine. The modern engine having direct petrol injection technology has more suitability for converting into the CNG direct injected engine. Minor modifications in this type of engine will earn it a complete CNG direct injection engine.The cylinder head should be altered in such a way that, the provision of holes for placing the injector used for petrol injection is simply straightened out by a suitable size of pickles which can fit a limited size of gas injector.

II.   OBJECTIVES OF THIS STUDY

The primary aims of this type of investigation are:

1   To know about the working of a newly developed CNG direct injection SI engine.

2   To compare the functioning of a CNG-DI engine with existing CNG Port injection and sequential injection engine.

3   To aware readers about the work which is already managed by the various researchers in this area of CNG-DI in SI engine.

III.   SOME IMPORTANT WORK WHICH IS ALREADY DONE ON CNG-DI SYSTEM IN SI ENGINE

Recent developments use Direct Injection (DI) with late injection timings (after the intake valve closes) in order to eliminate CNG fuel mass influence of the intake process. With this concept, **Caley and Cathcart (2006)**were able to increase airflow up to 10% for low speeds and 4% at 5000 RPM in a 450cc engine, with an injection pressure of 22 bar. This presents a particular operational characteristic of late injection regarding mixture preparation at high focal ratios and tons.The late direct injection combined with long pulse duration can negatively affect mixture preparation, increasing cyclic variability in combustion and non-cut fuel emissions.

David Wager (2008) studied the Influence of elliptical nozzle holes on Mixing and Combustion in Direct Injection Natural Gas Engines. Experiments were conducted to compare mixing and combustion of natural gas jets from round and elliptical nozzle holes in an optically accessible combustion bomb. A flame ionization detector was used to measure the concentration fields of the two jet types. Pressure data, combustion imaging, and hydrocarbon measurements of exhaust gas, were employed to compare the ignition delay, heat release, and combustion efficiency of the two beaks.Concentration measurements indicated that, the elliptical nozzle produced jets with smaller rich core regions and lower peak concentrations at all weather. Firing tests indicated that, the two nozzles produced equivalent ignition delays. Peak heat release rates were higher for the round nozzle, while the elliptical nozzle produced smoother transitions from premixed in diffusion burning. Combustion efficiency was slightly higher for the round nose. The result indicates that, the use of elliptical nozzle potentially lowers NOx and particulate emissions.

Semin, Awang Idris & Rosli Abu Bakar (2009) were investigated the effect of port injection CNG engine using injector nozzle multi holes for air-fuel mixing in combustion chamber based on variable intake valve lift using Cosmos Flow simulation. Their aim was to find out the outcome of multi holes of injector nozzle on air-fuel mixing in combustion chamber of sequential port injection.They want to get out the best performance given by the injector nozzle having different numbers of fixes.They have called for different four injector nozzles having different numbers of holes and performed their field with the aid of simulation using Cosmos Flow work software.The simulation of injected gas fuel and intake air mixing in the combustion chamber of new injector nozzle multi hole geometries effect was conveyed in 1.78mm, 3.55millimeter, 5.33millimeter and 7.10 mm intake valve lift and in 1000 RPM engine speed.The first new injector nozzle has 2 holes with 1.5 mm for every diameter holes and 2.5 mm orifice length. The second new injector nozzle has 3 holes with 1.35 mm for every diameter holes and 2.5 mm orifice length. The third new injector nozzle has 4 holes with 1.25 mm for every diameter holes and 2.5 mm orifice length. The fourth new injector nozzle has 5 holes with 1.0 mm for every diameter holes and 2.5 mm orifice length. The primary aim of this pretense was to project the new injector nozzle and analyze the fuel-air mixing at maximum valve lift before compression stroke. For the new injector nozzle holegeometry design, the injector nozzle was replaced with the modified injector nozzle holes in the Solid Work

model of the port injection dedicated CNG engine. Subsequently, they have prepared the models, they had begun to move.

They have watched the simulation effects and they concluded that, the injected gas fuel and intake air mixing of new injector nozzle multi holes are very well and better than the original injection nozzle. In the 1.78 mm valve lift, the 4 holes injector nozzle has the bestair-fuel mixing. In the 3.55 mm valve lift, the 4 holes injector nozzle has the best air-fuel blending. In the 5.33 mm valve lift, the 2 hole injector nozzle has the best air-fuel mixing. In the 7.10 mmvalve lift, the 4 holes injector nozzle has the best air-fuel mixing. In the best results above, the injected gas fuel and intake air has been mixed spread evenly in the combustion chamber for the best trend air-fuel mixing. The mixing has been happening in all the side wall, more turbulence and go to the center of the combustion chamber. The mixed of air-fuel occurs in the center of piston surface.

J.Y.Ha, J.S.Park&J.H.Kang (2009) found the effect of throttle opening ratio and injection timing on the combustion characteristics of a CNG in DI engine. They changed a single DI diesel engine into a CNG-DI engine having compression ratio 13 and the engine was further connected the ignition system, injector, an eddy-current dynamometer and cooling arrangement.They also installed an oxygen sensor in the exhaust tube to measure the absorption of oxygen in the exhaust gases.The Horiba EXSA-1500 exhaust gas analyzer was also practiced to make analysis of the exhaust gases.They have used the ECU to control the timing of the injection of fuel, the duration of injection and the lighting system. The ignition timing was controlled with the maximum brake torque under all the engine conditions.They were used CNG fuel supply arrangement in which two pressure regulators reduced the 22MPa pressure to 6 MPa and then it is supplied to the injector.For safety reasons, two valves were put in between the CNG tanks and the injector: A manual shut-off valve in the high pressure lines and a high-pressure solenoid valve that automatically shuts off fuel when the engine quits.An anti-overflow valve also used which controls when the fuel line is gone.They were investigated, how fuel injection timing either early injection or late injection with throttle opening ratio affects the fuel-air mixing characteristics, combustion characteristics and engine power.

They found that, the combustion characteristic is greatly improved for a complete open throttle ratio with early injection timing and for a partial throttle ratio with late injection timing. They also observed that, as the excess air ratio increases, the optimal fuel injection timing is delayed towards TDC for a late injection at a given throttle opening ratio and engine speed.

M.K Hassan, I.Aris (2009) presents the experimental test results of single cylinder high compression engine fuelled with compressed natural gas. The engine uses central direct injection with a high pressure injector system which is known as Compressed Natural Gas Direct Injection (CNG-DI) engine. This initial experiment on a single cylinder CNG-DI engine was run away to look into the feasibility of the CNG-DI engine with different piston crown shape.The execution of two piston crown shapes for (i) homogeneous (ii) stratified combustion was investigated. The start of injection (SOI) timing for each piston was varied between 120° before top dead center (BTDC) to 220° BTDC to study its combustion response at various engine speeds. SOI laid between 120° BTDC to 180° BTDC, which got a constant force and torque.The experimental results show that, the homogenous crown performance higher than stratified crown.In conditions of engine performance, the homogenous crown has shown higher torque and higher power.The primary advantage of using high-pressure injector is less fuel consumption can be achieved where the fuel is to be injected straight into the combustion chamber after both intake and exhaust valves are shut.

The research work of M.K Hassan, I. Aris, S. Mahmod and R. Sidek (2010) represents an experimental result of engine performance and exhaust gas concentration at various ignition and injection timing for high compression engine fuelled with compressed natural gas (CNG) engine.The aim of this experimentation was to examine the influence of injection and ignition towards brake torque, brake power and discharge at maximum brake torque (MBT) interval. The engine implements central direct injection (DI) method. All injectors are placed within a sure level of spark plug. It is called as CNG-DI engine. The experimental trials were posted out using computer-controlled eddy-current dynamometer, which measures the CNG-DI engine performance. The emission concentration level was recorded with respects to engine speed, ignition timing and injection timing. The suggested power and torque of CNG-DI engine was also supervised during the study. They found that, the advanced ignition timing may result of NOx increment. The NOx concentration has a relatively linear relationship with injection timing. The HC concentration is relatively low at early injection, but high concentration occurs when late injection is given.The ignition timing has no significant effect of the absorption. The low CO concentration occurs at late injection timing and the lowest emission is 0.011% when we applied 30^0 BTDC of ignition at 3600 CA injection timing. The most influential factor for CO development is ignition timing.

Taib Iskandar Mohamad (2010) has designed and tested the SPFI (Spark Plug Fuel Injector) methane direct injection system on a Ricardo E6 engine with gasoline head. The engine was connected and mounted on a common test bed with a direct current electric dynamometer, which operates as a motor or brake. Lubricant circulation was driven by an electric motor and water coolant was circulated by a separately driven centrifugal pump. The engine has one inlet and one exhaust poppet-type valves.

He has found the essence of different start of injection (SOI) timing on indicated power and indicated mean effective pressure. When SOI is earlier than 180°BTDC, both power and MEP are the lowest. The best performance was achieved at SOI of 190°BTDC.He was also found the volumetric efficiencies are in the excess of 80%, which is significantly higher compared to port injection operations. This demonstrated that, the direct fuel injection using SPFI increases

engine's ability to get more air and as a consequence, increases the heating value of the cylinder charge per engine cycle. Again, the highest volumetric efficiency was achieved at 190^oBTDC at SOI timing. The same figure as in power and MEP results is demonstrated with the most efficient outcome was achieved at 190oBTDC.SPFI direct injection operation is really sensitive towards injection timing and for any particular engine speed, a proper calibration of SOI timing must be performed to obtain the optimal public presentation.The solutions are uniform with the findings by Huang et al. (2003) and Zeng et al. (2006).

Asok K. Sen, Jianjun Zheng & Zuohua Huang (2011) were investigated the dynamics of cycle-to-cycle variations (CCV) in a natural gas direct-injection spark ignition engine. The method of continuous wavelet transform was used to analyze the time series of the indicated mean effective pressure (IMEP) and other combustion variables. The dominant oscillatory modes in the CCV were identified, and the engine cycles over which these modes may persist were delineated. Results were obtained for four compression ratios: CR = 8, 10, 12 and 14, at two engine speeds of 1200 and 1800 rpm. The results say that, the CCV exhibit multi-scale dynamics with fluctuations occurring at different time scales. As the engine speed of 1200 RPM, the spectral power of CCV for CR = 12 was found to be significantly trimmed back at the different time scales compared to the CCV at other values of CR.At the higher engine speed of 1800 RPM, this decrease was less marked.In gain, cross wavelet transform was applied to explore the relationships between the CCV of IMEP and those of flame development duration, main combustion duration and total combustion duration.Strong interdependence was found to survive between the IMEP and the main combustion duration as well as total combustion duration, over a broad range of frequencies and engine cycles.

M.A. Kalam & H.H. Masjuki (2011) found experimental results of a new compressed natural gas direct injection (CNG-DI) engine that has been developed from modification of a multi cylinder gasoline port injection (PI) engine. The original gasoline-PI engine was also changed to a CNG bi-fuel scheme.The examination results obtained from CNG fuel using two dissimilar organizations (i.e.bi-fuel and DI) have been investigated and compared with the original gas engine.The aim of this investigation was to compare the test results between CNG-DI, with CNG-BI and gasoline-PI engines with the same displacement volume. It was found that, the CNG-DI engine produces similar brake power at 6000 RPM and wide open throttle (WOT) but produces higher brake power at part load condition as compared to the original gasoline. The CNG-BI engine produces 23% lower brake power than the CNG-DI engine. The average brake specific fuel consumption (BSFC) of the CNG-DI engine was 0.28% and 8% lower than gasoline-PI and CNG-BI engines respectively. The CNG-DI engine reduces 42% NOx emission as compared to the base engine. Nevertheless, the CNG-DI engine produces higher HC and CO emissions as compared to the base engine.

Y. Liu, S.I.Hwang, J.K.Yum& S.S. Chang (2012) has presented the experimental results of the spray and combustion characteristics of CNG-DI system in SI engine. In their work, they have designed a combustion chamber with a visualization scheme.They have followed the spray development and combustion propagation process of CNG-DI system by digital recording with CCD camera and too analyzed.The researchers have focused particularly on (i) Spray development (ii) Spray tip penetrates (iii) Flame propagation and (vi) Ignition probability.In their work, the CNG injection process was separated into two periods.One period referred as the CNG passed through the L-shaped pipe in their experimentation and it was found approximately 1ms. Another period referred as the time for the CNG exited from L-shaped pipe and penetrated further into the combustion chamber. The CNG spray tip penetration is determined as the length from the CNG spray tip to the L-shaped pipe exit.The spray angle is the angle that CNG spray expands in the radical way. It was found that, the CNG spray tip penetration and spray angle increased with time. They were also found that, the injection pressure has a substantial result on the firing probability. The high injection pressure results in a high spray velocity, which reduced the ignition probability significantly.

B. Yadollahi & M. Boroomand (2013) have explained the effect of combustion chamber geometry on injection and mixture preparation in a CNG direct injection system with SI engine. A mathematical model has been evolved by them in AVL FIRE software to convert four cylinder MPFI gasoline engine into a CNG-DI engine.They have considered this phenomenon in two stages.In their first phase, they have developed multi-dimensional mathematical model for transient gas injection.They have also used two different validation cases to verify the accuracy of the mannequin.In their second stage, they have developed the validated model using the moving mesh capability to determine the essence of different piston geometry on the execution of direct methane injection into the piston chamber.Five different types of piston head shape along with two types of injector (single hole and multi hole) have been brought into thoughtfulness.In all the five cases, a common, centrally mounted injector location has been accommodated.Their objective was to find out the result of combustion chamber geometry, injector type, cylinder head shape and injection parameters on the mixture preparation of aviation and fuel.

They have found that, the simulation results are strongly sensitive to the number of grid points across the nozzle diameter, boundary condition, location and limit values.Their reflections are as per followings: (i) Out of five piston head configurations, the narrow bowl configuration showed a better outcome to get stratified charge in the cylinder due to better mixture distribution near ignition timing. (ii) The multi hole injector produces less amount of rich mass fraction and a slightly more amount of flammable mass fraction in comparison to the single hole injector. (iii) The pent roof cylinder head was shown to have more influence on in-cylinder flow field and also drives a non-symmetrical flow field in the cylinder as compared to the flat cylinder head. It was also shown that, using narrow bowl piston head is helpful to

achieve more flammable mixture near the approximate spark plug location. Some modifications are necessary to capture the better quality flow field in the piston chamber.

IV.   CONCLUSION

Based on the above discussion, we may draw some important conclusion as per followings.

(i)   The new CNG-DI system is safer than conventional Port Injection (PI) and Sequential Injection due to its better volumetric efficiency, combustion characteristics and therefore better thermal efficiency.

(ii)   The CNG-DI engine produces around 15-23% higher brake power than the CNG-BI engine using port injection at rated load and velocity.

(iii)   The CNG-DI reduces approximate 30% NOx emissions as compared to the gasoline base engine.

(iv)   The working of the CNG direct injection engine can be built more efficient by making changes in the design of cylinder head, piston geometry and gas injector.

(v)   The CNG direct injection engine gives best output results if certain engine operating variables are checked.E.g Injection pressure, throttle opening ratio, compression ratio, Air-fuel ratio, valve opening with respect to TDC and BDC, suction pressure and temperature and so forth.

REFERENCES

(1) Semin, Rosli Abu Bakar, "A Technical Review of Compressed Natural Gas as an   Alternative Fuel for Internal Combustion Engines" American J. of Engineering and Applied Sciences 1 (4): 302-311, 2008, ISSN 1941-7020

(2) M.A. Kalam, H.H. Masjuki, "An experimental investigation of high performance natural gas engine with direct injection" International journal of Energy, vol.36, April 2011

(3) Taib Iskandar Mohamad,Shahrir Abdullah, Yusoff Ali, "The Combustion and Performance of a Converted Direct Injection Compressed Natural Gas Engine using Spark Plug Fuel Injector" SAE Technical Paper 2010-32-0078/20109078

(4) G.P. McTaggart-Cowan, S.N. Rogak, S.R. Munshi, P.G. Hill, "The influence of fuel composition on a heavy-duty, natural-gas direct-injection engine" Journal of Fuel Vol.89 (2010) 752-759

(6) Yu Liu, Jeongkuk Yeom, Seongsik Chung, "A study of spray development and combustion propagation processes of spark-ignited direct injection (SIDI) compressed natural gas (CNG)" Journal of Mathematical and Computer Modelling, vol.57(2013) 228-244

(7) Asok K. Sen, Jianjun Zheng, Zuohua Huang, "Dynamics of cycle-to-cycle variations in a natural gas direct-injection spark-ignition engine" Journal of Applied Energy, vol.88 (2011) 2324-2334

(8) Taib Iskandar Mohamad, "Compressed natural gas direct injection(spark plug fuel injector)" from www.intechopen.com

(9) David Wager, "The Influence of elliptical nozzle holes on Mixing and Combustion in Direct Injection Natural Gas Engines" Thessis submitted to University of Toronto 2008 for Master of Applied Science.

(10) M.K Hassan, I.Aris, S..Mahmod and R. Sidek, "Influence of Injection and Ignition of CNG Fuelled Direct Injection Engine at Constant Speed" Australian Journal of Basic and Applied Sciences, 4(10): 4870-4879, 2010

(11) Semin, Awang Idris, Rosli Abu Bakar,"Effect of Port Injection CNG Engine Using Injector Nozzle Multi Holes on Air-Fuel Mixing in Combustion Chamber" European Journal of Scientific Research, ISSN 1450-216X Vol.34 No.1 (2009), pp.16-24

(12) J.Y.Ha, J.S.Park&J.H.Kang, "Effects of the Throttle opening ratio and the Injection timing on the combustion characteristics of a DI engine" International Journal of Automotive Technology, Vol. 11, No. 1, pp. 11−17 (2010)

(13) Y.Liu, S.I.Hwang, J.K.Yeom& S.S. Chung, "Experimental Study on the Spray and Combustion characteristics of SIDI CNG" International Journal of Automotive Technology, Vol. 15, No. 3, pp. 353−359 (2014)

(14) B. Yadollahi & M. Boroomand, "The effect of combustion chamber geometry on injection and mixture preparationin a CNG direct injection SI engine" Journal of Fuel Vol.107 (2013) 52-62