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Hydrogen Natural gas blends in an I.C. Engine

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***Abstract* - In this review, combustion characteristics of S.I engines fueled with Natural gas and Hydrogen blends along with the changes in EGR rate are studied. Engine efficiency varying with Hydrogen amount, spark timing, compression ratio and equivalence ratio are also studied. CO, HC,CO_2 emissions were studied by incrementing H_2 along with NO_x emissions. By adding Hydrogen into Natural gas, the coefficient of variation of indicated mean effective pressure and effectiveness at high EGR rate is also studied. Combustion characteristics of direct injection S.I engine with natural gas-hydrogen blends are also verified in this paper.**

***Keywords* - NO_x , EGR, Hydrogen blends, Octane number, Combustion.**

I. INTRODUCTION

As concern regarding energy and environment protection increases, research becomes an important aspect in combustion and engine development. Alternative fuels are mainly clean fuels when compared to gasoline and diesel in combustion processes one of which is the natural gas. But natural gas has extremely slow burning velocity and poor lean-burn capability. Hence it needs to be operated at stoichiometric air-fuel ratio with relatively low thermal efficiency. In order to solve the problem, flow intensity in cylinder maybe increased. But due to that heat losses and combustion temperature along with NO_x emissions increases causing environment damage. Method has been developed to use a direct-injection method for increasing the volumetric efficiency and flame propogating speed for overcoming that problem. Another method is of mixing the natural gas with fuel that has fast burning quality which can be used for solving the problem of slow burning speed. Hydrogen in such case could be the best fuel as it has fast burning speed. It is expected to reduce engine emissions along with lean burn characteristics.

Natural gas is the most trusted alternative and also called cleanest fuel in combustion. Anti-knocking capability is due to high octane number of natural gas. Due to this power output and efficiency is improved as it allows to operate even at high compression ratio. Burning velocity is improved as hydrogen is an excellent additive when added to natural gas. The problem of volumetric efficiency decreasing and high power output can be overcomed by Direct injection gas engine [7]. Heat release rate decreases and combustion duration increases when hydrogen fraction is less than 10%. Small amount of hydrogen added to natural gas makes it better in combustion characteristics and reduces exhaust emissions.

Effects of the addition of Hydrogen into methane could not only improve the combustion stability but also the engine could tolerate up to 25% EGR, while maintaining a coefficient of variability of indicated mean effective pressure below 5%. This level of EGR gave a reduction in NO emissions greater than 80% at the stoichiometric air– fuel ratio. However, their study did not reveal the combustion characteristics of engine fueled with natural gas–hydrogen blends combining with EGR.

Investigations regarding the effect of different EGR rates on combustion characteristics of S.I engine are done in this paper. Clarification of combustion behaviours of engine with different amounts of natural gas-hydrogen blends at different EGR rates is expected from this study.

II. REVIEW OF SOME RESEARCHERS

1) **P. Dimopoulos[a] et.al** carried out experiments on four cylinder gasoline engine with a displacement of 1.01 and an output of 37 kw at 5000rpm and 86Nm at 3000rpm.they also studied effects of hydrogen–CNG blends at selected engine loads and speeds First step in Design optimization was to test Engine Dynamometer with specific parameter settings. Also models were built for response factor of the engine. Result shown were:

   i) **Hydrogen-CNG blended effects with EGR which had medium type load:**
   Highest efficiency with spark timing at 323^0 crankangle and moderate EGR (10-12% by mass) were achieved. Due to more EGR, spark timings which were away from TDC reached their associated efficiency maxima and due to less EGR spark timing close to TDC reached engine efficiency maxima. It should be noted that this behaviour was typical when Hydrogen was used as a fuel. While pure methane fuels were used, optimal engine efficiencies were decreased as EGR was increased and were more sensitive to EGR quantity.

   ii) **Combustion anaysis and losses:**
   As hydrogen content was increased in fuel, incomplete combustion losses were decreased. These losses increase when hydrogen addition goes beyond 10vol.% As temperature was high in combustion chamber, hence hydrogen emissions increased. Increase in heat losses were mainly due to two reasons:
   a) High in-cylinder temperatures.
   b) Decrease in presence of hydrogen in fuel.

Combustion chamber design was improved to reduce these losses and to thereby increase the efficiency.

iii) **Hydrogen-CNG blended effects at selected engine loads and speeds:**
As hydrogen in fuel increased, fuel conversion efficiency too increased. Optimization of engine with 10vol.% hydrogen fuel led to an efficiency increase of 2.5% without EGR. Maximal efficiency at higher rpm for same load was lower. On addition of CNG to hydrogen with optimized EGR, efficiency increased additionally by 2%.

iv) **Well-to-wheels assessment:**
In fig.1, comparison of different hydrogen reforming paths was done to produce fuel blends(e.g., refuelling station of CNG transporting pipeline of 4000km). In general CNG reforming and onboard reforming led to reduction of overall GHG emissions by 7%. The more comfortable solution would be of central reforming of CNG (travelling 4000km of pipeline prior to other reforming station) and mixing in CNG refuelled network.such consideration is beyond the scope of article, the interested reader should refer to Ref.[5].

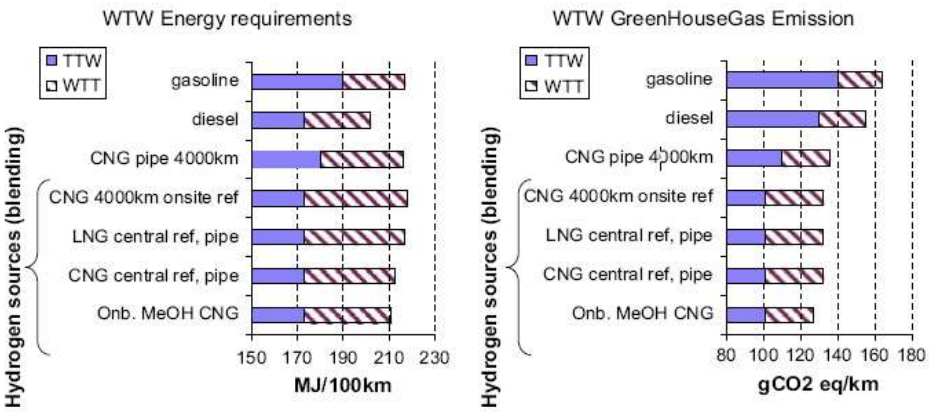

Fig. 17 – Well-to-wheels analysis for different hydrogen reforming production paths.

Fig1. Well-to-wheel analysis for different hydrogen reforming production paths [5].

2) **Nagalingam et.al** carried out experiments with AVL engine, 523.001 type, speed 1200rpm, fueled with 100/0, 80/20, 50/50, 0/100, CNG/H_2 mixtures having a bore of 125 mm, stroke of 130 mm and compression ratio 11.73. Experimental results yield that maximum engine output was 23% due to hydrogen operation and maximum percentage decrement was 12% at speed of 1200rpm. Optimum sparktiming decrement upto 20% BTDC by adding hydrogen results in indicating increased flame speed. Due to higher combustion temperatures, NO_x emissions were increased for pure H_2. The engine performance of Hydrogen added with Natural gas for 0.8-0.9 equivalence ratio lies amidst in natural gas and hydrogen engine performances. Analysis of engine speed or load was ruled out in this experiment.

3) **Swain et.al and Yusuf** carried out experiments by using same mixture, but different engine. Yusuf took a Toyota 2TC type year 1976 1.6 1, 1588cc, maximum HP 88 and maximum speed of 6000rpm having a bore of 85mm, stroke of 70mm and compression ratio of 9:1. Calculations were performed regarding thermal efficiency by varying equivalence ratio on measuring BSHC, BSCO and $BSNO_x$ concentrations. When comparison was done between methane-hydrogen mixture and pure methane operation having same equivalence ratios, methane and hydrogen mixture resulted in increasing BTE and NO_x emissions thereby decreasing best efficiency spark advantage, unburned HCs and CO. On adding hydrogen, equivalence ratios could be reduced by 15% without incrementing duration of combustion and ignition delay.

4) **Larsen and Wallace** carried out research on emissions and efficiency of lean-burn natural-gas and hydrogen mixture fueled engine. A comparison of emissions & efficiency of 85/15 CNG/H_2 mixture fuel by volume, and efficiency of pure natural gas using turbocharged, six cylinders, four stroke, 3.1 1, S.I engine was carried out at different speeds, different loads and different equivalence ratios. Experimental results obtained with respect to matrix and statistical testing showed the potential of methane and hydrogen mixture to decrease the exhaust concentrations of pollutants and thereby result in incrementing the efficiency of a S.I engine.

5) **Bauer and Forest** carried out a study on the effect of hydrogen addition on performance of methane-fueled vehicles. Both of them used single cylinder engine at compression ratio of 8.5:1. Analysis of brake power, ITE, spark degree, BSFC, $BSCO_2$, BSCO, BSHC in 100/0, 60/40, 40/60 CH_4/H_2 percentage were done by them. The conclusion obtained was that on comparison with pure methane, upto 60% volume of hydrogen added from an equivalence ratio 0.58-0.34 was shown to lower the partial burn limit.

6) **Shudo et.al** carried out survey on combustion and emissions regarding methane and hydrogen use. Experimental test was performed with four stroke engine having bore X stroke of 85X88mm and compression ratio 13. There was an increment in thermal efficiency and unburned hydrocarbons were reduced. With hydrogen premixing, NO_x emissions increased. Lean operation improved the thermal efficiency and reduced HC and NO_x emissions simultaneously.

7) **Karim** investigated hydrogen as S.I. engine fuel. His experimentation revealed excellent conditions for achieving satisfactory S.I engine operation having hydrogen as a fuel. Experimental results showed that hydrogen adding to methane decreases the HC, CO, CO_2 emissions whereas NO_x emissions have tendency to increase. Greenhouse gases and atmospheric pollutants are reduced and also combustion characteristics of engine were enhanced. Higher hydrogen contents lessens the effectiveness of knock resistance.

8) **Erjiang Hu et. al** performed experiment on test engines which were modified from an HH368Q gasoline engine. It had a step motor for adjusting amount of CNG/H_2 blends entering cylinder. Flame propogation was expected to rise on addition of hydrogen in natural gas. Mixture concentration was measured by Horiba MEXA-700λ instrument which had an accuracy of 5%. Kistler piezoelectric transducer recorded cylinder pressure which had a resolution of 10Pa and monitor was used for determining the top-dead-center (TDC).

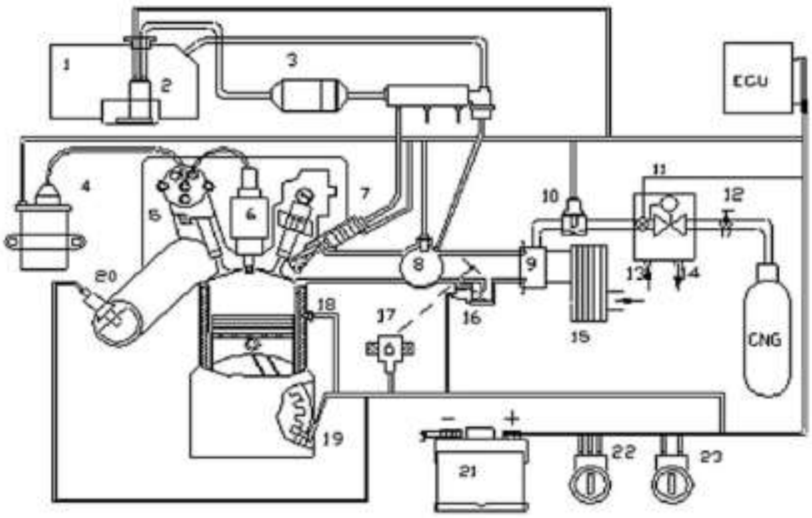

Fig. 1 – Schematic diagram of experimental setup. 1-fuel tank, 2-fuel pump, 3-fuel filter, 4-ignition coil, 5-distributor, 6-spark plug, 7-fuel injector, 8-manifold pressure sensor, 9-gas mixer, 10-CNG-H2 control step motor, 11-CNG-H2 regulator, 12-CNG-H2 valve, 13-coolant in, 14-coolant out, 15-air filter, 16-idling control step motor, 17-throttle position sensor, 18-coolant water temperature sensor, 19-crankshaft position sensor, 20-oxygen sensor, 21-battery, 22-ignition switch, 23-gasoline/CNG selection switch.

Fig2. Schematic diagram of EGR control system.[4]

Experimental results revealed the optimum ignition timings vs EGR rate for different hydrogen amounts in fuels. Maximum brake torque was obtained by the engine due to optimum ignition timing. Due to decrement in flame propogation speed, optimum ignition timing was advanced with increment in EGR rate. Hydrogen addition decrease ignition delay and there was an increment in the flame propogation mixture speed.

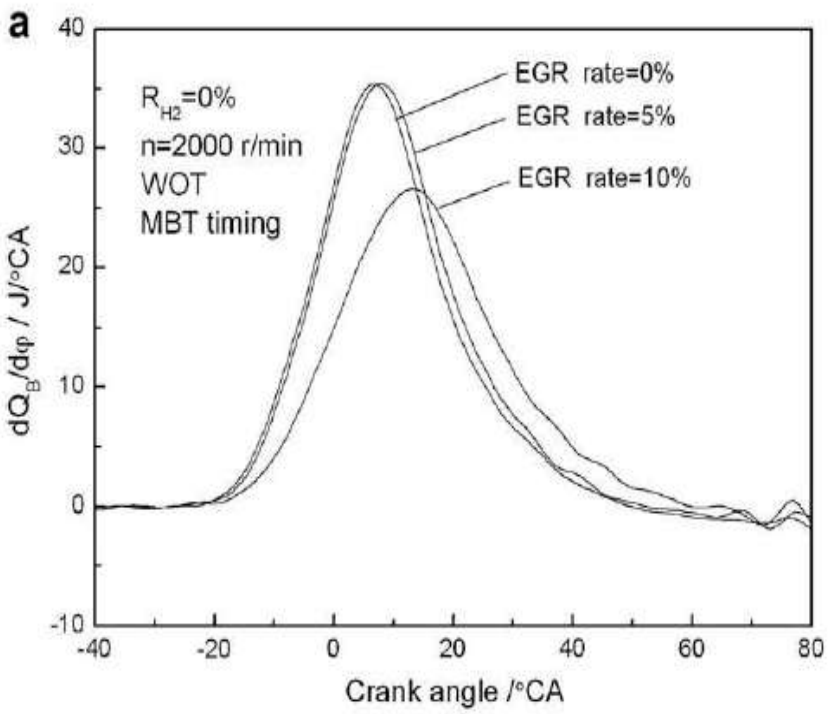

Fig3. Graph shows heat release rate with crankangle deflections.[4]

In this graph shown in fig.3, EGR rate was approximately 0% at a crankangle of 10^0. If we increased the crankangle, EGR rate of 5% was achieved. EGR rate of 10% was achieved at a crankangle of 20^0 approximately. As crankangle increased, EGR rate also increased. Also it was observed that as crankangle increased, heat release rate with crankangle was decreased.

9) **Zuohua Huang et. al.** modified a single cylinder engine into natural gas ignition engine. Engine specifications were as shown in the table 1 below. Modified version of direct gasoline injection engine was used for increasing the flow rate of natural gas. Natural gas injected into the cylinder at 8 Mpa. More time taken for fuel injection corresponds to more amount of fuel injected. Combined volumetric flow rate of natural gas-hydrogen blends were assumed to be unchangeable and it was a function of direct injection in this study. Different modes represent different combinations of injection advance angles and fuel injection duration. Five modes were for engine having speed of 1200 rpm and remaining five were for engine of speed 1800 rpm.

Table 1. Engine Specifications:

bore (mm)	100
stroke (mm)	115
displacement (cm^3)	903
compression ratio	8
combustion chamber	bowl-in-shape
injection pressure (mpa)	8
ignition source spark plug	spark plug

Experimental results obtained showed excess air versus hydrogen fractions in natural gas-hydrogen blends. Due to same speed, the amount of fresh air into the cylinder was same for same mode.

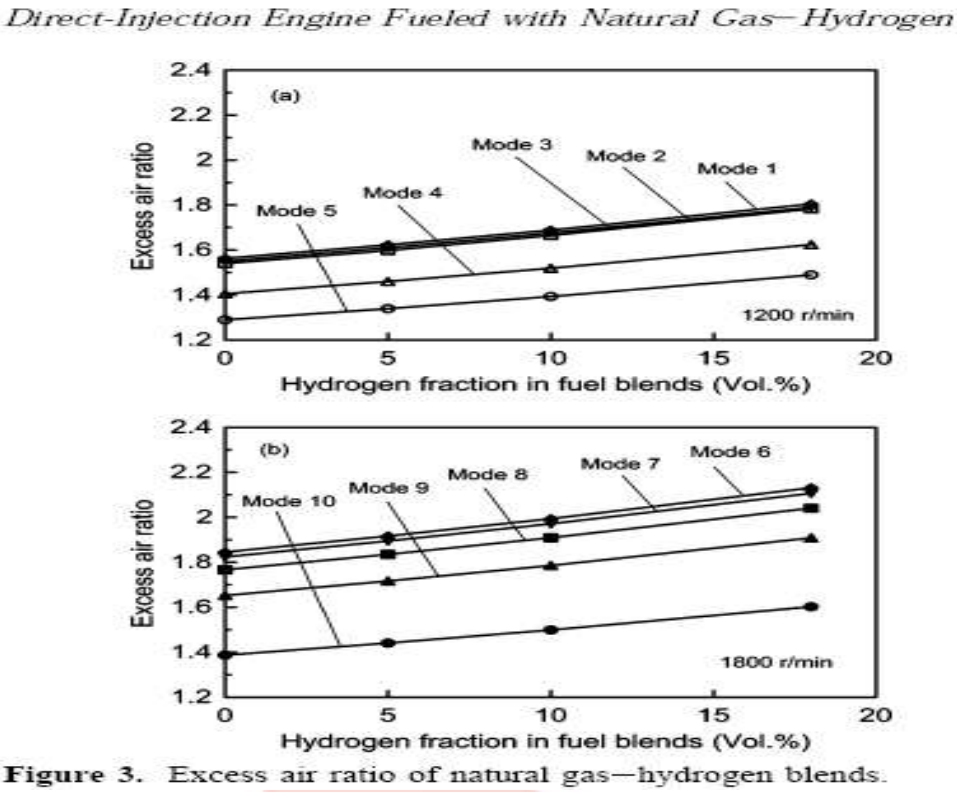

Fig4. Excess air ratio of natural gas-hydrogen blends.[7]

For hydrogen fractions of 5,10,18% in fuel blends, excess air ratio increased by 4,8,15% respectively. Decrement in excess air ratio was observed with an increment in fuel injection duration for specific hydrogen fraction. For a particular engine operation mode, excess air ratio increased linearly due to increment of hydrogen fraction in fuel mixtures.

III. CONCLUSION

It can be summarized that:

Increasing H_2 proportion not only accelerates combustion but also increases wall heat losses. 2-4% efficiency increases on addition of hydrogen in fuel which depends on engine load and EGR too increases by 1-2%. Due to increase in EGR rate, coefficient of variation of indicated mean effective pressure increases. Also we came to know that as hydrogen content is increased, NO_x emissions also increases. Due to perfect knock characteristics, Natural gas did not vary with small addition of hydrogen. High values of peak cylinder pressure is obtained by natural gas combustion for same excess air ratio and proper spark timing. Due to addition of hydrogen into natural gas, ignition delay is decreased. Maximum cylinder pressure, maximum mean gas temperature, maximum rate of pressure rise, maximum heat release decreased with addition of hydrogen fraction when this fraction is less than volumetric fraction, whereas it increased when it was over volumetric fraction.

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