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Gasoline Direct Injection: An Efficient Technology

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***Abstract*—In the recent years there has been a tremendous advancement in the automobile sector resulting in Fuel injection system. The effect of stratified and homogeneous mode on the performance parameter along with combustion system (wall guided/ spray guided and air guided), its extend feasibility and complexity in the individual and combine mode of operation is reviewed in detail. The review comes up with the need of optimization in mixture formation to reduce in-cylinder wall wetting, increase combustion stability, and extend up to which charge cooling occurs and feasibility of stratified mode operation in GDI engine. Optical diagnostic and CFD are the tools which can help in optimizing this complex system.**

***Index Terms*— GDI; PFI; CFD; BSFC**

I. Introduction

The basic goals of the automotive industry; a high power, low specific fuel consumption, low emissions, low noise and better drive comfort. With increasing the vehicle number, the role of the vehicles in air pollution has been increasing significantly day by day. The environment protection agencies have drawn down the emission limits annually. Furthermore, continuously increasing price of the fuel necessitates improving the engine efficiency. Since the engines with carburetor do not hold the air fuel ratio close to the stoichiometric at different working conditions, catalytic converter cannot be used in these engines. Therefore these engines have high emission values and low efficiency. Electronic controlled Port Fuel Injection (PFI) systems instead of fuel system with carburetor have been used since 1980's. In fuel injection systems, induced air can be metered precisely and the fuel is injected in the manifold to air amount. By using the lambda sensor in exhaust system, air/fuel ratio is held of stable value. Fuel systems without electronic controlled it is impossible to comply with the increasingly emissions legislation. Continuous hike in petroleum products and tighten global emission standards made the engine development towards notable engine technology whose objective to 1) minimize fuel consumption at the inlet, pollutant and noise emissions at exit of engine 2) maximize the fuel energy conversion efficiency and 3) higher specific power output.. The fuel conversion efficiency is the function of mixture formation process i) internal ii) external iii) internal plus external. Gasoline direct injection engine is the new thought of in cylinder mixture formation technology in which gasoline like fuel is directly added into the cylinder and ignited with spark which enables to combine best features of diesel and Gasoline engine.

II. Direct Injection methods

There are two types of direct injection system

a) Direct injection of liquid fuel
b) Direct injection of air fuel pre mixture

A. Direct Injection of Liquid Fuel

It is a high pressure fuel injection system in which liquid fuel is directly injected into the engine cylinder. The fuel injection pressure should be sufficiently higher than cylinder pressure In the range of 4Mpa- 15Mpa which is sufficient to produce well atomize spray.

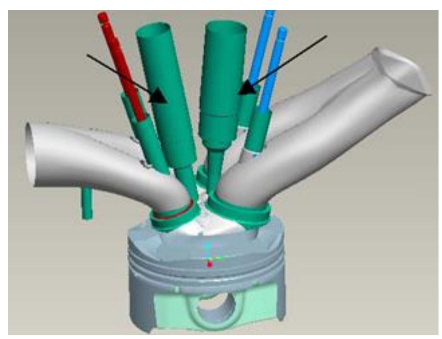

Fig.1. The sketch map of homogeneous combustion system with multi-hole injector

B. Direct Injection of Air Fuel Pre mixture

It is a low pressure injection system in which mixture is formed outside the cylinder by injecting fuel (Pressure range 0 .6 Mpa) in the part of air (Pressure 0.55 MPa). The pre mixture is transformed into combustion chamber by mechanical valve with mechanical control or by solenoid with electronic control. Short duration needed for the complete mixture formation diluting pre mixture in the engine cylinder results complete combustion and less emissions. The Performance and Exhaust Emissions of the Gasoline Direct Injection (GDI) Engine.

1) Performance of the GDI Engine

The parameters that have the greatest influence on engine efficiency are compression ratio and air/fuel ratio. The effect of raising compression ratio is to increase the power output and to

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reduce the fuel consumption. In these engines, the compression ratio is about 9/1-10/1. To prevent the knock, the compression ratio cannot be increased more. For the same
Engine volume, the increasing volumetric efficiency also raises the engine power output.

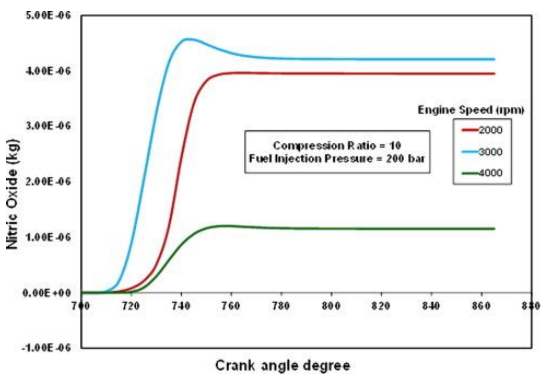

Fig. 2. Crank angel degree

C. *Exhaust Emissions of the GDI Engine*

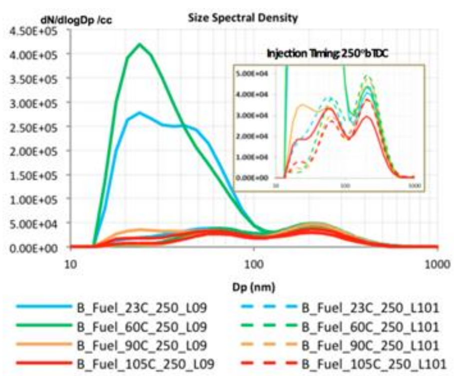

Fig. 3. Size spectral density

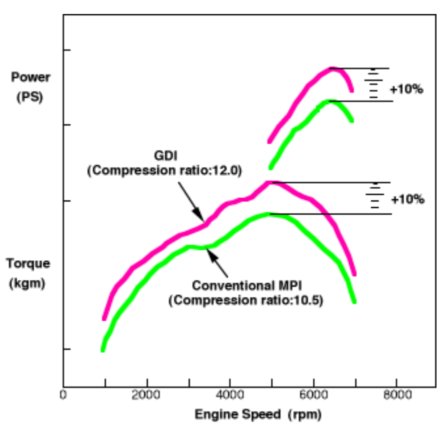

Fig. 4. Graphical representation of engine speed and torque and power

CO emission is very low in GDI engine. CO varies depending on air /fuel ratio. CO is high at rich mixtures. Since GDI engines operate with lean mixture at part loads and stoichiometric mixture at full load, CO is not a problem for these engines. In GDI engine, due to the wetting of the piston and the cylinder walls with liquid fuel, HC emission can increase. Hydrocarbon (HC) emissions are a function of engine temperature and, therefore it can rise during cold start. During cold-start of a GDI engine, homogeneous operation can be employed due to a higher exhaust gas temperature resulting in a shorter time for catalyst light-off, and lower engine out HC emissions. Gasoline engines do not emit soot emission normally. Soot emission can occur at very rich mixtures. However, the GDI engines emit soot at stratified-charge operation, as in–cylinder can be areas with very rich mixtures. In addition, in GDI engine, if mixture formation do not realize at full loads due to rich mixture, the soot emission can increase. NOx emission is maximum at high cylinder temperatures and at λ =1.1. As torque output rises, temperatures rise and, in turn, the engine-out NOx emissions display an increase. NOx emissions increase especially at full load.

D. *The Emission Control in GDI Engine*

Environmental legislation determines the limits for exhaust emissions in the spark ignition engines. It is required the treatment of the exhaust gases to meet these limits. The three-way catalytic converter show high performance for converting the CO, HC and NOx in the engines with operation at λ=1.0. But, NOx cannot be completely converted harmless gases at lean mixture operation. Therefore, engines with lean mixture also require a NOx storage type catalytic converter to convert the NOx. The two catalytic converters are successively used in GDI engine exhaust system. The one is Pre-catalytic converter (Three Way Converter -TWC). This converter has little volume and is connected close to the engine. The other is main catalytic converter which combines a NOx catalyst and a TWC. This converter has higher volume than the pre-catalytic converter and is connected not close to the engine. The Pre-catalytic converter convert the CO, HC and NOx to harmless gases (CO2, H2O and N2) at λ=1.0. However, when engine operates at stratified mode with lean mixture, NOx cannot be converted to nitrogen. In such cases, NOx is sent to main catalytic converter. In the NOx storage type catalytic converter, the components such as Ba and Ca are used for NOx conversion at lean mixtures. These components provide NOx to storage. At λ=1.0, the operation of the NOx converter resembles three way converter. At lean mixtures, NOx conversion is realized in three stages: NOx accumulation, NOx release and conversion. Nitrogen oxides reacts chemically with barium oxide (BaO) and thus barium nitrate (Ba (NO3)2 forms. (NOx storage stage).

III. THE MIXTURE FORMATION AND OPERATION MODES IN THE GDI ENGINE

A. *The Mixture Formation*

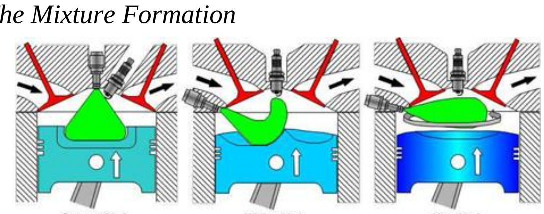

Fig. 5. Types of injection in cylinder

The air-fuel mixture in the gasoline engines is prepared in-cylinder and out-cylinder. While the mixture in the engine with carburetor and port fuel injection is prepared out-cylinder, mixture in the gasoline direct injection engines is prepared in-cylinder. In place of PFI engines where the fuel is injected through the port, in GDI engines, the fuel is injected directly into cylinders at a high pressure. During the induction stroke, only the air flows from the open intake valve and it enters into the cylinder. This ensures better control of the injection process and particularly provides the injection of fuel late during the compression stroke, when the intake valves are closed (Sercey et al., 2005). The acting of the intake system as a pre-vaporizing chamber is an advantage in the PFI engines (Rotondi, 2006). As the lack of time to fuel vaporize in GDI engines, the fuel is injected into the cylinder at a very high pressure to help the atomization and vaporization process. The duration for injection timing is little; advanced injection timing causes piston wetting and retarded injection timing decrease sufficient time for fuel-air mixing (Gandhi et al., 2006). In the PFI engine, a liquid film is formed in the intake valve area of the port, which causes delayed fuel vaporization. Especially during cold start, it is necessary to increase fuel amount for the ideal stoichiometric mixture. This "over fueling" leads to increasing HC emissions during cold start. Alternatively, injecting the fuel directly into the combustion chamber avoids the problems such as increasing HC and giving the excess fuel to engine (Hatchel, 2000). To the GDI engines, it is implemented the two basic charge modes, stratified and homogeneous charge. At the partial load conditions, stratified charge (late injection) is used, that is, fuel is injected during the compression stroke to supply the stratified charge. The engine can be operated at an air-fuel ratio exceeding 100 and fully throttled operation is possible, but the engine is throttled slightly in this zone and the air-fuel ratio is controlled to range from 30 to 40 in order to introduce a large quantity of Exhaust Gas Recirculation (EGR) and to supply the vacuum for the brake system. A homogeneous charge (early injection) is preferred for the higher load conditions, that is, fuel is injected during the intake stroke so as to provide a homogeneous mixture. In most of this mode, the engine is operated under stoichiometric or a slightly rich condition at full load. In the lowest load conditions in this mode, the engine is operated at homogeneous lean conditions with an air-fuel ratio of from 20 to 25 for further improvement of fuel economy (Kume, 1996).

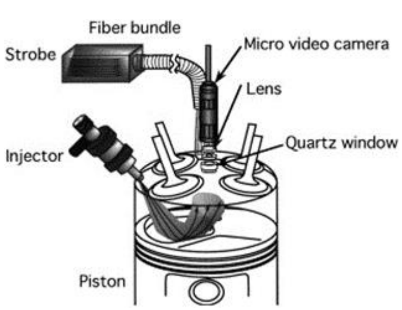

Fig. 6. Mixture formation in GDI engine

During operation with homogeneous charge the adjustment of engine load is done by throttling while during operation with stratified charge the engine runs with throttled conditions and engine load is adjusted by fuel/air-equivalence ratio (Spicher et al., 2000). Fig.3 shows the homogeneous (early injection) and stratified-charge modes (late injection).

IV. Current Trends and Future Challenges

At the present day, in the some gasoline engines are used port fuel injection system. This technique has achieved a high development point. As these engines operate with stoichiometric mixture, fuel economy and emissions of these engines cannot be improved further. However, GDI engines have been popular since these engines have potential for reduction of toxic, CO2 emissions and fuel consumption to comply with stringent Environmental Protection Agency (EPA) standards (Spegar et al., 2009). To attain this potential, it is required that use of the GDI engines with supercharging and/or turbo charging (Stan, 2009). The GDI engines with turbo charger enable the production of smaller displacement engines, higher fuel efficiency, lower emission and higher power (Bandel et al., 2006). The GDI engines also help eliminate the disadvantages conventional turbocharged engines (namely turbo lag, poorer fuel economy and narrowed emissions potential) to provide viable engine solutions.

V. The Experiment System

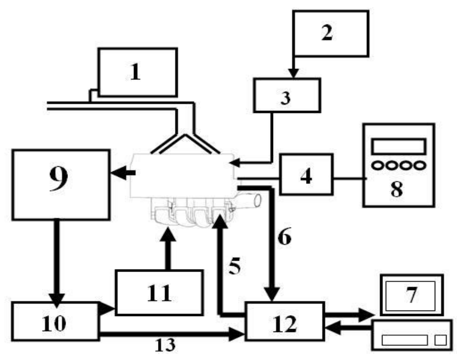

Fig. 7. General layout of the engine experiment system

1. Emission analyzer
2. Fuel Tank
3. Fuel Consumption Meter
4. Dynamometer
5. Low pressure injector control
6. Engine speed signal
7. Data acquisition and control system
8. Control Cabinet
9. Knock signal, throttle position signal, TDC signal , engine speed signal, cooling water signal, MAP signal, pressure signal of the high pressure common rail , signal of the oxygen sensor
10. ECU of the gasoline direct injection engine
11. Injection signal, ignition signal, high-pressure pump signal
12. Control module of the compound fuel injection system
13. Throttle position

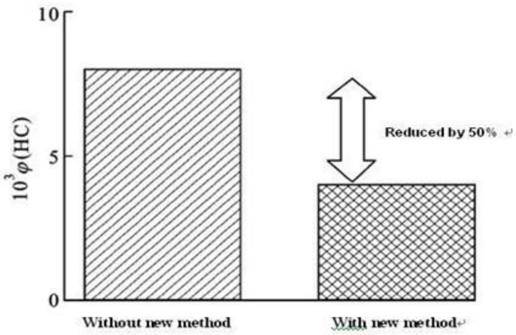

Fig. 7. The comparison result of the HC emissions

Laboratory atmospheric temperature is 280K, air pressure is 101.43kPa. In order to ensure good repeatability of the experiments, the initial temperature of oil and cooling water is controlled to 280K. According to the results of the engine experiment, the new method is able to reduce 50% of the HC emissions during the cold-start conditions of gasoline direct injection engine. The positive experimental results have also effectively proved that the special piston top shape with the compound fuel supply system is a good solution to reduce the HC emissions during the cold-start conditions of gasoline direct injection engine.

VI. Conclusion

The calculated results in this paper indicate that the GDI engine with a special piston top shape is able to optimize cylinder air-flow patterns and distributions at cold-start operating conditions. It also provides the favorable conditions for the mixture formation and flame propagation. The results of engine experiment indicate that the new method is able to reduce 50% HC emissions during the cold-start conditions. So the combination of the special piston top shape with the compound fuel injection system is not only able to guarantee the proper flow in cylinder of the GDI engine but also able to improve the distribution of cylinder air-fuel ratio at cold-start operating conditions and then effectively reduce the HC emissions

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