Direct Fuel Injection System in Gasoline Engine - A Review

Ajay Kumar Singh, A. M. Lanjewar, A. Rehman

Abstract— This paper deals with the development of spark ignition engines that are designed to inject gasoline directly into the cylinder. Conventional spark ignition engine have defects such as high exhaust emission, low break thermal efficiency due to short circuiting losses and incomplete combustion which occur during idling & at part load operations conditions. The introduction of direct injection to the engine allows proper mixing of fuel & air giving complete control on combustion and emissions and thereby increasing power and efficiency. Another significant advantage of using direct fuel injection is that it is economical too as it provides a correct estimation of the quality of fuel required at proper time & provides control over combustion. Gasoline direct injection is becoming an important option to further optimize internal combustion engine.

Index Terms— Direct fuel injection, gasoline engine, engine performance parameters, emissions.

I. INTRODUCTION

Engines are machines or device that utilize some form of energy and convert it into useful work specifically mechanical work. The engines were introduced in early 18th century in form of Heat Engine that derives heat energy from the combustion of fuel or any other sources and converts this energy into mechanical work. In general energy source comes from burning fuel .Internal Combustion (IC) Engines are those in which product of combustion act as a working medium over the piston head. The heat generated by combustion of fuel increases pressure over the piston head. Due to this pressure it starts moving and so does the crank shaft. The introduction of Internal Combustion (IC) engines has provided a healthy strong and relatively cheaper means of mobility indeed the operating principal of an IC engine has also not changed since their introduction. Gasoline IC engines utilize the four-stroke 'Otto' cycle which was developed around 1867 by Nikolaus Agust Otto. Initially research and development on IC engines concentrated on improving performance and efficiency. However, after a century of their use. IC engine emissions contributed towards global warming and other environmental impact as well as economical effect. Coupled with reducing oil reserves it has became obvious that IC engine research and development is to be shifted towards reducing engine emissions and fuel consumption. World-wide various emission legislation have been put in action in a concerted effort of motivating vehicle manufacturers to produce relatively cleaner and more fuel efficient vehicles.

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Ajay Kumar Singh, Department of Mechanical Engineering, Maulana Azad National Institute of Technology, Bhopal 462051, India.

Dr. A. M. Lanjewar, Department of Mechanical Engineering, Maulana Azad National Institute of Technology, Bhopal 462051, India.

Dr. A. Rehman, Department of Mechanical Engineering, Maulana Azad National Institute of Technology, Bhopal 462051, India.

A. Gasoline Carburetion System

Carburetion is a process of preparing the optimize AFM (Air Fuel Mixture) for SI Engine to get better combustible charge. Carburetors are used to supply a fuel and air mixture to both 4- stroke and 2-stroke small internal combustion engines. In its typical operation the carburetion involves entrainment of fuel in the intake air stream before intake air starts to enter the engine crankcase. The underside of the piston compresses the charged mixture. Continuous presence of combustion products from the previously completed combustion power stroke is forced out from the cylinder by this new air/fuel mixture. Since the engines with carburettor 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. Unfortunately the exhaust stroke also allow 30-40 % fuel to be lost with the exhaust stream also under idle conditions the losses can be as high as 70%. The higher rate of CO emission results from an unstable inefficient combustion that leads to low thermal efficiency and higher emission of green house gases.

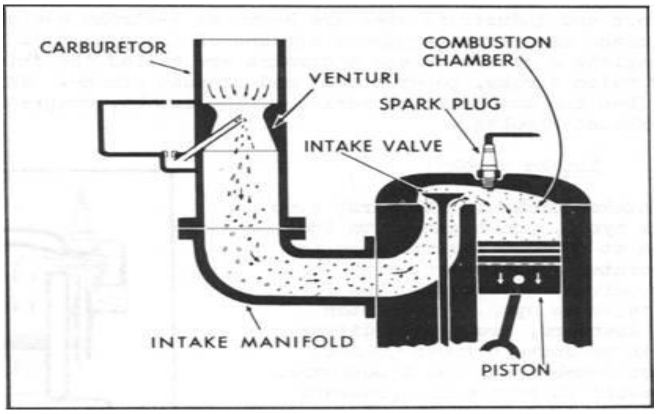

Fig. 1.1 Working of Gasoline Carburetion System

B. Fuel Injection System

In fuel injection systems, induced air can be metered precisely and the fuel is injected in the manifold. The fuel injection system has a charge forming device which supplies a rich fuel and air mixture to a tuned injector tube connected adjacent to one end through a port or valve to the engine cylinder and is adjacent the other end to the engine crankcase. The charge forming device has an injector air inlet and fuel mixing passage to which under engine wide open throttle operating conditions at least a majority of the fuel is supplied by a high speed fuel circuit and preferably a minor portion of the fuel is also supplied by an idle fuel circuit. Due to low cost of small engines it is not preferred to use electronic fuel injection system instead of it there are relatively low cost mechanical

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fuel injections available. Fuel injection system has proven to be an effective and durable strategy for controlling emissions and reducing fuel consumption from gasoline-fuelled engines. Fuel injection system is a promising technology that enhances positively the fuel economy, engine performances and emission reduction as compared to the conventional carburettor system. Currently, motorcycles using carburettor system are widely used as a mean of transportation especially in urban areas. This conventional fuelling system produces more harmful emissions and consumes more fuel compared to the fuel injection system. It is therefore desirable to have a fuel injection system that can easily be retrofitted to the current on-road motorcycles.

C. Direct Injection

Fuel is injected directly into the main combustion area. The engines would have either one main combustion chamber or a divided combustion chamber made up of a primary and secondary chamber. Direct fuel injection reduces hydrocarbon emission with proper design of the injection timing and the positioning of the injector. The overall gas flow in the two-stroke engine has a significant effect on the motion and evaporation of the fuel spraying process. The fuel injection system for conventional spark ignition engines injects the fuel into the engine intake system. The advantages of port fuel injection are increased power and torque through improved volumetric efficiency and more uniform fuel distribution, more rapid engine response to changes in throttle position and more precise control of the equivalence ratio during cold-start and engine warm-up. Fuel injection allow the amount of fuel injected per cycle for each cylinder to be varied in response to input derived from sensors which define actual engine operating conditions. Two basic approaches have been developed but the major difference between the two is the method used to determine the air flow rate. It is reported that parameters such as fluid flow pattern, injector location, injection timings and injection pressure effectively influence the droplet vaporization process and spatial vapour distribution in the cylinder. Fuel droplet after injection have definite amount of kinetic energy based on their mass and velocity which is truly function of pressure difference in the rail and in the cylinder. The air in the chamber during compression process is in tumble motion which produces deflection in the fuel spray. The addition air stream during the injection process can force the fuel stream in the center of combustion area and enhances chances that fuel droplet do not reach the cylinder and piston crown. The development of four-stroke spark-ignition engines that are designed to inject gasoline directly into the combustion chamber is an important worldwide initiative of the automotive industry. The thermodynamic potential of such engines are significantly enhanced fuel economy, transient response and cold-start hydrocarbon emission levels has led to a large number of research and development projects that have the goal of understanding developing and optimizing gasoline direct-injection (GDI) combustion systems.

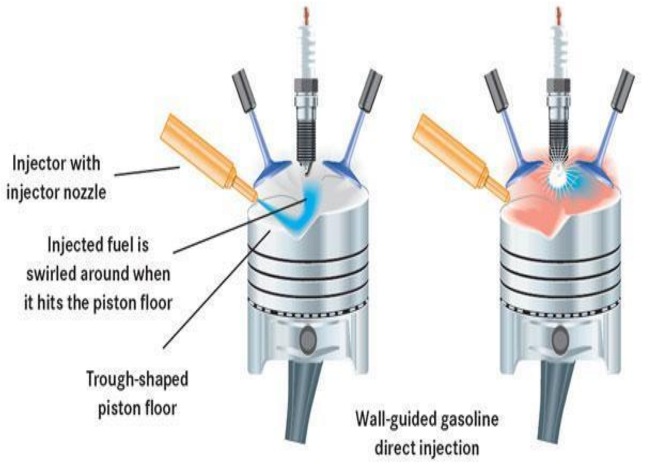
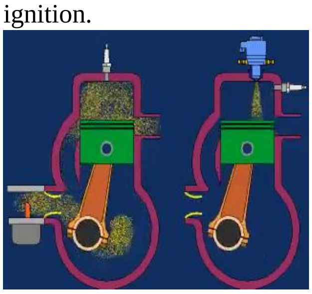


Fig. 1.2 Direct fuel Injection System

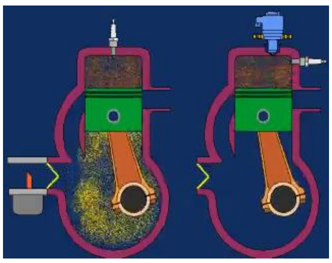
D.Gasoline Direct Injection (GDI)

In internal combustion engines, gasoline direct injection (GDI) sometimes known as Fuel Stratified Injection (FSI) is an increasingly popular type of fuel injection system employed in modern four and two-stroke petrol engines. The petrol/gasoline is highly pressurized and injected by high voltage driven injectors via a common rail fuel line directly into the combustion chamber of each cylinder as opposed to conventional single or multi-point fuel injection that happens in the intake manifold tract or cylinder port. In some applications gasoline direct injection enables stratified fuel charge (ultra lean burn) combustion for improved fuel efficiency and reduced emission levels at low load. The major advantages of a GDI engine are lower emission levels, increased fuel efficiency and higher engine power output. In addition the cooling effect of the injected fuel and the more evenly dispersed combustion mixtures and temperatures allow for improved ignition timing settings which are an equally important system requirement. Emissions levels can be more accurately controlled with the GDI system. The lower levels are achieved by the precise control over the amount of fuel, air and ignition settings which are varied according to the engine load conditions and ambient air temperature. In addition there are no throttling losses in some GDI designed engines as compared to a conventional fuel injected or carbureted engine which greatly improves efficiency and reduces pumping losses in engines without a throttle plate. Engine speed is controlled by the engine management system which regulates fuel injection and ignition timing parameters instead of having a throttle plate which restricts the incoming air supply. Adding this function to the engine management system requires considerable enhancement of its processing and memory as direct injection plus other engine management systems must have very precise mapping for good performance and drivability. The engine management system continually chooses among three combustion cycles: ultra lean burn, stoichiometric, and full power output. Each cycle is characterized by the air-fuel ratio.

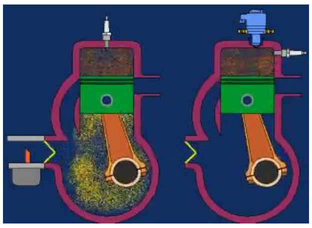
The stoichiometric air-fuel ratio for petrol (gasoline) engines is 14.7:1 by weight, but the ultra lean cycle can involve ratios as high as 35:1 (or even higher in some engines for very limited periods). These mixtures are much leaner than in a conventional fuel injected engine and reduce fuel consumption and certain levels of exhaust emissions considerably. Ultra lean burn cycle is used for light-load running conditions, at constant or reducing road speeds, where no acceleration is required. The fuel is not injected at the intake stroke but rather at the latter stages of the compression stroke so that the small amount of air-fuel mixture is optimally placed near the spark plug. This stratified charge is surrounded mostly by air which keeps the fuel and the flame away from the cylinder walls for low emissions and heat losses. The combustion of the fuel takes place in a radial (donut-shaped) cavity on the piston's surface designed to improve air swirl and delivered by a specially designed injector nozzle. This allows successful ignition without misfire even when the air/fuel mixture is very lean. Stoichiometric cycle is used for moderate load conditions. Fuel is injected during the intake stroke creating a homogenous fuel-air mixture in the cylinder. From the stoichiometric ratio an optimum burn results in a clean exhaust emission further cleaned by the catalytic converter. Full power cycle is used for rapid acceleration and heavy loads (as when climbing a hill). The air-fuel mixture is homogenous and the ratio is slightly richer than stoichiometric which helps prevent knock (pinging). The fuel is injected during the intake stroke. Direct injection is supported by other engine management systems such as variable valve timing (VVT) with variable length intake manifold (VLIM) or acoustic controlled intake system (ACIS). A high performance exhaust gas recirculation valve (EGR) is certainly required to reduce the high nitrogen oxides (NOx) emissions that result from burning ultra lean mixtures. Conventional fuel injection engines could inject fuel throughout the 4 stroke sequence, as the injector injects fuel onto the back of a closed valve. Earlier direct injection engines where the injector injects fuel directly into the cylinder were limited to the induction stroke of the piston. As the RPM increases the time available to inject fuel decreases. Newer GDI systems have sufficient fuel pressure to inject more than once during a single cycle. Fuel injection takes place in two phases. During the intake stroke, some amount of fuel is pre-injected into the combustion chamber which cools the incoming air thus improving volumetric efficiency and ensuring an even fuel/air mixture within the combustion chamber. Main injection takes place as the piston approaches top dead centre on the compression stroke shortly before ignition.



Charge Transfer and Scavenging



Crankcase Compression



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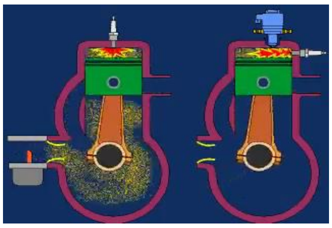
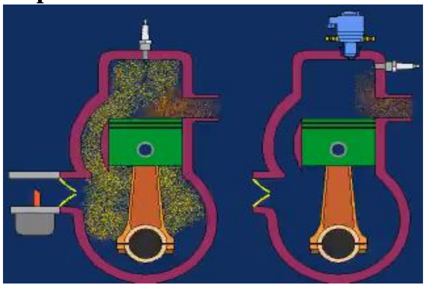


Power



Transfer and Exhaust

Fig. 1.3 Comparison of 2-Stroke Carbureted SI Engine & Gasoline Direct Injection System

II. LITERATURE REVIEW

Hushim et al. [1] presented a review and comparative study using 1-D simulation software - GT-Power on electronic fuel injection (EFI) system between port-fuel injection (PFI) and direct injection (GDI) system for retro fitment purpose of small 125cc 4-stroke gasoline engine. From the study PFI system was selected based on its high brake power, brake torque and brake mean effective pressure with low brake specific fuel consumption. Wislocki et al. [2] the injection duration in gasoline engines is similar (pressure values at present approx. 20 MPa) to the injection duration of diesel fuel. The methodology and results of the tests related to the fuel dose division and injection strategy on the thermodynamic indexes during the combustion process were presented by them. The tests were performed for several ways of fuel dose division at injection pressures of 5, 10 and 20 MPa (modifying also the time of the injection).They reported that the rate of pressure increment after the ignition is higher if there are more fuel injected before the ignition of the main injection it also grows along the growth of the pressure of the injected fuel. The rate of heat release is proportional to the cylinder pressure increment and depends on the same relations. Sellnau et al. [3] developed a gasoline compression-ignition combustion system for full-time operation over the speed-load map. Low-temperature combustion was achieved using multiple late injection (MLI), intake boost, and moderate EGR for high efficiency, low NOx, and low particulate emissions. The relatively long ignition delay and high volatility of RON 91 pump gasoline combined with an advanced injection system and variable valve actuation provided controlled mixture stratification for low combustion noise. Tests were conducted on a single cylinder research engine. Design of experiments and response surface models were used to evaluate injection strategies, injector designs and various valve lift profiles across the speed-load operating range. At light loads an exhaust rebreathing strategy was used to promote auto ignition and maintain exhaust temperatures. At medium loads a triple injection strategy produced the best results with high thermal efficiency. Detailed heat release analysis indicated that heat losses were significantly reduced. At higher loads a late-intake-valve-closing strategy was used to reduce the effective compression ratio. For all tests intake air temperature was 50 ^{0}C. They reported that with multiple late injections and low-to-moderate fuel pressure spray penetration was low, mixing was fast, and wall wetting was avoided. Burke et al. [4] reported that gasoline direct injection provides reduced engine emissions, increased power and increased fuel economy as compared to port fuel injection (PFI). Reduced emissions are largely due to starting the engine using high fuel pressure (up to 150 bar) and injecting into the compression stroke. During a cold start fuel pressure must be increased from lift pump pressure (typically 4 to 6 bar) to desired injection pressure (typically 25 bar minimum). This study investigated the temperature and pressure effects during engine soak which allow vapor and air to form in the fuel system. Vapor and/or air in the system caused a slower fuel pressure build and increased start times. They concluded that by preventing air and vapor formation in the fuel system start times were reduced and consistent. Gajbhiye et al. [5] developed an in-cylinder gasoline direct injection (GDI) engine incorporating novel combustion technologies which consists of the upright straight ports to generate tumble motion, the electromagnetic swirl injector to realize optimized spray dispersion and atomization and the compact piston cavity to maintain charge stratification. Zhao et al. [6] analyzed the processes of fuel injection, spray atomization and vaporization, charge cooling, mixture preparation and the control of in-cylinder air motion. The new technologies such as high-pressure, common-rail, gasoline injection systems and swirl-atomizing gasoline fuel injectors were also discussed by them. They concluded that technologies, along with computer control capabilities have enabled the current new examination of an old objective that is the direct-injection, stratified-charge (DISC), gasoline engine. Ayaz et al. [7] used the concept of making hole in transfer port by direct injection of air stream in two stroke single cylinder SI engine for eliminating the drawbacks of poor scavenging and relatively high emissions. The variation of BSFC, NOx, smoke and particulate emission with brake power were studied for both scavenging and without scavenging and results of work showed an improvement in the performance and emissions characteristics of engine with scavenging. This was reported as comparative analysis of experimental investigations carried out on a single cylinder, 2 strokes S.I. Engine with carburetor and with and without scavenging. Loganathan et al. [8] developed and tested an electronically fuel injection system on a 2 stroke SI engine at Indian institute of Technology, Madras. The system was fitted on the intake manifold of a single cylinder; air cooled 2 stroke scooter engines. Tests were conducted at 3000 rpm and 4000 rpm at different throttle position. The optimum injector pulse widths for thermal efficiency, lowest HC emissions and highest power were all different. The maximum brake thermal efficiency value were 22.6% and 23% at 3000 and 4000 rpm respectively. At a power output of 3kW and 1000 rpm the brake thermal efficiency was about 21% for the carbureted engine. It increased to 23% with the fuel injection system. HC emissions were considerably lower than the carbureted version at all operating condition and speeds. The engine could work with leaner mixtures with the injection system in general as compared to the carburetor. The maximum power increased with the injection system. The developed system could be used for mapping the engine for the development of software for injection system control. Govindasamy et al. [9] investigated the performance and emissions of a 2 stroke SI engine fitted with a fuel injection system. The use of strong magnetic charge from the magnet put into the fuel line gave a complete and clean burn so that power was increased with reduced operating expenses. The magnetic flux on the fuel line dramatically reduced harmful exhaust emissions while increasing mileage thereby saving money and improving engine performance. It increased combustion efficiency and provided higher-octane performance. The experimental results show that the magnetic flux on fuel reduces the carbon monoxide emission up to 13% for base engine, 23% in copper coated (inside the cylinder head) engine and 29% in zirconia coated (inside the cylinder head) engine. Non supercharged SI engine using LPG with mixture formed by evaporated LPG has lower power output by about 8% as compared to original petrol engine. This disadvantage was eliminated by Mares et al. [10] by using mixture formed by injection of liquid LPG. The thermodynamic analysis of the indicator diagram showed that the characteristic parameters of the cycle (including parameters of the combustion course) stood practically identical for operation on petrol and on LPG. The experimental results showed that favorable operating economy for car drive and positive ecological effects for environment. Kumarappa et al. [11] developed an electronic compressed natural gas (CNG) direct injection system to eliminate the short circuiting losses in two stroke spark ignition engines to eliminate high exhaust emissions and improve brake thermal efficiency during idling and at part load operating conditions. The fuel and time maps were generated for the various operating conditions of the engine. For the mapping the visualization tool was used to estimate the fuel injection time and fuel quantity for required running conditions of the engine. Experiments were carried out at the constant speed of 3500 rpm with a compression ratio of 12:1. The performance and emission characteristics of direct CNG injection system and carburetted engine were described. The above studies indicate the improvement in brake thermal efficiency from 15.2% to 24.3%. This was mainly due to significant reduction in short circuit loss of fresh charge and precise control of air fuel ratio. The pollution levels of HC and CO were reduced by 79.3% and 94.5% respectively compared to a conventional carburetted engine. Anand et al. [12] characterized PFI injectors which are suitable for small engines to study the effect of pressure on various spray parameters. Two plate-type PFI injectors were studied: one with two orifices and the other with four orifices. The nozzle orifice sizes were determined by microscopy. The fuel quantity injected at pressures of 200 kPa, 500 kPa and 800 kPa were measured by collecting the fuel for injection pulses of different durations.

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The spray structure of the PFI sprays was determined by shadowgraphy. A single pulsed Nd:YAG laser in conjunction with fluorescent diffuser optics was used as the light source for shadowgraphy. Backlit images of the spray were obtained at various times after the start of injection using a CCD camera. This was done for sprays at different pressures and different pulse durations. The spray angle and spray tip penetration were determined from the processed shadowgraphy images. The backlit images also showed insights into the development of the spray. It was observed that coalescence occurs with liquid from the orifices merging early on to form a single core. Tan et al. [13] investigated LPG direct injection from the transfer port of a loop-scavenged two stroke engine. The injector nozzle was placed in an area where it could inject through the transfer port window directly into combustion chamber with minimal fuel spillage into the port and minimal loss of fuel to the exhaust port. Several portions and orientations were simulated to determine the best injector nozzle location and orientation. The simulation results indicated that high fuel trapping efficiency was possible with the proper location of the injector and injection timing. Experimental results showed an 80% reduction in exhaust emissions with the transfer port mounted injector nozzle compared to the baseline carbureted engine. Marouf et al. [14] performed the experimental investigations on a single cylinder two stroke spark ignition engine in the carburetor and gasoline direct injection (GDI) modes. The experiments were conducted on the engine in the carburetor mode up to 80% throttle opening and for different combinations of speed and load. The engine was modified and fitted with an in-cylinder injector in the head. Fuel was supplied through injector with the help of a high pressure DC pump. Experiments for varying speed and load were conducted under in-cylinder injection mode up to 80% throttle opening. They reported that there is a significant reduction in BSFC, unburnt HC and CO emissions. Also the power output of the engine had shown an improvement. Hiltner [15] determined the impact of fuel injection timing in-cylinder fuel distribution. Equivalence ratio maps were acquired by Planar Laser Induced Fluorescence in an optical engine with a production cylinder head. Experimental results were used to determine the injection timing which produced the most uniform fuel distribution for the given engine. Cornel [16] presented a concept based on the ram tuned injection. The engine results showed that the engine torque remains in all of the speed range at least at the same level as for the base engines equipped with carburetors while the bsfc decreased generally by 35-45%. But the most important result was the reduction of pollution with 80-94% for the HC emissions and 90% for the CO emissions respectively. Johnson[17] described the development and demonstration of an electronic direct fuel injection (EDFI) solution which was applicable to low cost and high production volume engines in several industries. The system was based on the accumulator fuel injection operating principle which involved pressurizing fuel within an injection nozzle and subsequently releasing the pressurized fuel into the combustion chamber on command. This concept provided very short injection duration throughout the dynamic operating range of the engine as well as high injection frequency capability. Obodeh et al. [18] described the basic exhaust tuning mechanisms with respect to a two-stroke single-cylinder engine. Tuned adjustable exhaust pipe for use on two-stroke motorcycle was designed and tested. The dynamometer used incorporated a flywheel of appropriate moment of inertia to simulate the mass of the motorcycle and rider. The test procedure involved measurement of the flywheel speed during an acceleration phase resulting from opening the throttle. Calculation of the instantaneous flywheel acceleration gave a measure of the torque and power characteristics. The airflow based values of delivery ratio, trapping efficiency and charging efficiency were evaluated from the fuel flow values and the Spindt computation of the exhaust gas analysis. Experimental test results were presented for power output, specific fuel consumption and engine-out emissions. The tuned exhaust system was found to improve fuel economy of the engine by 12%. The major engine-out emissions HC and CO were reduced by a minimum of 27.8% and 10.7% respectively. An improved power output of 15.8% increase was achieved also exhaust noise was reduced. Fathi et al. [19] studied the effect of the initial charge temperature on the second law terms under the various injection timings in a direct injection spark ignition hydrogen fuelled engine during compression, combustion and expansion processes of the engine cycle. The first law analysis was done by using the results of a three dimensional CFD code. The results showed a good agreement with the experimental data. Also for the second law analysis a developed in- house computational code was applied. The results revealed that the indicated work availability is more affected by varying hydrogen injection timing in comparison with other second law terms. Also increasing the initial charge temperature caused the heat loss availability and exhaust gas availability to be increased and indicated work availability, combustion irreversibility and entropy generation were found to be decreased. Salah [20] conducted the experiments to determine the effect of fuel-injection timings on engine characteristics and emissions of a DI engine fueled with NG-hydrogen blends (0%, 3%, 5% and 8%) at various engine speeds. Three injection timings namely 120°, 180° and 300° CA BTDC with a wide open throttle at relative air–fuel ratio as 1.0 were selected. The ignition advance angle was fixed at 30° CA BTDC while the injection pressure was fixed at 1.4 MPa for all the cases. The tests were firstly performed at low engine speed of 2000 rpm to determine the engine characteristics and emissions. The results showed that the engine performance (Brake Torque, Brake Power and BMEP), the cylinder pressure and the heat release have the highest values at the injection timing of 180° CA BTDC, followed by the 300° CA BTDC and the 120° CA BTDC. The NO*x* emission was found to be highest at the injection timing of 180° CA BTDC. The THC and CO emissions were found to decrease while the CO_2 emission increased with the advancement in the injection timing. The addition of a small amount of hydrogen to the natural gas was found to increase the engine performance enhance combustion and reduce emissions for any selected injection timings. Secondly the tests were carried out at variable engine speeds (i.e. 2000 rpm–4000 rpm) in order to further investigate the engine performance. The injection timings of 180° and 300° CA BTDC with CNG–H_2 blends were only selected for comparisons. The injection timing of the 300° CA BTDC was reported to yield better engine performance as compared to the 180° CA BTDC injection timing after a cutoff engine speed of approximately 2500 rpm. Alimin et al [21] developed a retrofit fuel injection kit to address such challenges of meeting power requirement as a small cubic capacity prime mover and also in complying with the emissions regulations currently put in place. The experimental works on the proposed fuel injection retrofit kit was initiated by preparing a dedicated engine test rig equipped with the necessary instrumentation which allowed analysis on the engine operating performance. Among the parameters investigated were engine torque, brake power, specific fuel consumption and engine thermal efficiency. Throughout the work, other key operating parameters that were monitored the emissions levels of the exhaust gas and operating consistency and durability. They concluded that the developed prototype is able to work effectively in providing efficient fuel supply to power the small gasoline fuelled engine. Karthikeyan et al. [22] designed and developed a electronic fuel injection kit for a small capacity engine to run it at various speeds (in the range of 1000 to 5000 rpm) and at no load. They reported on design, development and fabrication of a new and compact port fuel injection (PFI) system that could replace an in-used carburetor easily with minimum modifications. Mitianiec et al. [23] presented a modified air-assisted direct fuel injection in a two-stroke engine, which changes propagation of fuel jet in the combustion chamber. The main problem of mixture formation is short time for fuel evaporation after injection which should begin after closing of the exhaust port. The study showed interaction between the scavenged air, additional air stream and fuel jet from the injector located in the cylinder head can induce the small size of fuel droplets and fast evaporation. The computational results of fuel mixture formation and combustion process in direct fuel injection two-stroke engine Robin EC-12 with capacity 115 cm^3 were also presented. Sanjaikumar et al. [24] designed a prototype kit for use in retrofitting existing carbureted two-stroke engines to direct injection. The kit was designed for use on a TVS 50 a motorcycle from the INDIA that is commonly used as a transportation. The conventional fuel injection system kit incorporates the Orbital air blast direct injection system. This injectionsystem was implemented in TVS 50. The design involved replacing the existing cylinder head with onedesigned to incorporate the direct injection valves as well as a modified combustion chamber. An external compressor was added to supply compressed air to the system. The carburetor was refined with a throttle body. They reported that 88% reduction in hydrocarbon emissions and a 72% reduction in carbon monoxide emissions versus the baseline engine, while at the same time virtually eliminating visible smoke. The central fuel injection(CFI) system also showed a 32% increase in fuel economy, and had similar to better performance than the carbureted engine. The central fuel injection (CFI) system also showed improved cranking and idling characteristics over the carbureted engine. Junpei et al. [25] tested newly developed reverse- uniflow type 2-stroke direct injection gasoline engine that was designed by numerical simulations. They reported that in comparison with the base engine, HC emission was decreased by up to 80%, and BSFC was reduced by around 40%.Power and BSFC were superior to that of a latest 4-stroke engine. Also the effects of the start of injection timing and the fuel spray amount on the diffusion of fuel were examined by performance tests and numerical simulations and the process was found important to improve the engine performance. Ghadikolaei [26] investigate the effect of cylinder air pressure and fuel injection pressure on combustion characteristics of direct injection (DI) diesel engine. The combustion characteristics in this experimental study were measured in terms of ignition delay, combustion duration and injection duration at varying cylinder air pressure (10-15-20 and 25 bar) and fuel injection pressure (100-200 and 300 bar) based on diesel and gasoline. The tests were performed in a constant combustion chamber with single-hole pintle nozzle which the conditions were similar to real DI engine conditions. The results showed that with increase in cylinder air pressure from 10 to 25 the ignition delay and Combustion duration decrease for diesel and gasoline. And the duration of injection gradually decreases for diesel and gasoline irrespective injection pressure of 100 bar for gasoline with increase in cylinder air pressure. Also minimum values of ignition delay, burn duration and injection duration were observed at the fuel injection pressure of 300 bar for both fuel at varying cylinder air pressure. It was also found that the combustion duration increases with increase in ignition delay for both fuels, due to more time to mix the fuel and air. And combustion duration increases with increase in duration of injection for diesel. But that increases until approximately 61 ms of injection duration and then decreases for gasoline. Archer et al. [27] developed air-assisted Synerject Direct Injection (aSDI) for 2-stroke engines and the other Synerject electronic Port Injection (SePI) for 4-stroke engines. Both systems are intended for application on small vehicles fitted with small 1 – 2 cylinder gasoline engines of displacement 50 – 250 cm3 per cylinder. Typical examples of such small vehicles are ATV's (All Terrain Vehicles), auto-rickshaws, motorcycles, motor scooters and mopeds. They reported that significant reduction in small vehicle fuel consumption & emission are available, through application of the recently introduced air-assisted synerject direct injection system to 2-stroke engine & synerject electronic port injection system to 4-stroke engines. Hunicz et al. [28] used direct injection contolled auto-ignition (CAI) single-cylinder research engine for gasoline combustion. CAI operation was achieved with use of the negative valve overlap (NAV) technique and internal exhaust gas re-circulation (EGR). Experiments were performed at single injection and split injection, where some amount of fuel was injected close to top dead centre (TDC) during NVO interval, and the second injection was applied with variable timing. Application of split injection showed benefits as regard to single injection. Use of different fuel mass split ratio and variable second injection timing resulted in optimization of mixture formation. At equal share of the fuel mass injected in the first injection during negative valve overlap (NVO) and in the second injection in the beginning of compression the lowest emission level and cycle variability improvement were observed.

III. CONCLUSION

The following conclusions are drawn from the present review:

- The development in electronic fuel injection system has made it possible to overcome the level of pollution and improve the performance of engine in term of parameters like fuel consumption. It has eliminated the short circuiting losses completely.
- The fuel consumption and emission in two stroke SI engine can be reduced by optimizing the parameters like air-fuel ratio, bore-stroke ratio, delivery ratio and processes like combustion and scavenging energy in combustion chamber.
- The optimization of injection timing greatly reduces the specific fuel consumption and exhaust emission due to better control over the air fuel ratio.
- The use of injector, fuel pump, crank angle encoder and ECU with various series can replace the carburettor and its various disadvantages.
- The use of DI system can improve atomization which leads to proper burning of fuel and have less pollution and better efficiency.

IV. FUTURE SCOPE

The development of direct injection system in petrol engine is beneficial in numerous fields like agricultural, heavy duty works and applications where the operating conditions vary with load. The scarcity of fossil fuels has urged the use of alternative fuels which are less costly and less harmful to the environment. As biofuels are eco-friendly their use in direct injection engines can lead to additional advantages in the time of high price of petroleum based fuels. The biofuels like ethanol, methanol, butanol and their blends with petrol can be successfully used in direct injection engines. With the use of biofuels in direct injection engines the pollution can be reduced and efficiency can be increased. The existing two stroke engines in market can be redesigned with direct fuel injection system instead of existing carburetor system. This is going to replace the carburetor with combination of injector, fuel pump, crank angle encoder and electronic control unit beside with various sensors.

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