Reflection and Review of Fuel Delivery Systems

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ABSTRACT

In attempting to keep up with emissions and efficiency forces, the fuel method employed in contemporary automobiles has changed a lot over the past few decades. Fuel solution has been in for decades, and electronic fuel injection was applied widely on European automobiles beginning in 1980s. Today, all automobiles in the world have fuel injection schemes in place for emission control. This paper compares the different fuel delivery systems, explains the working and types of fuel delivery systems currently in use in automobiles and discusses some problems present in the current fuel delivery systems.

Keywords: *fuel efficiency, fuel injection, emissions, fuel delivery systems, performance characteristics.*

1. INTRODUCTION

In the present world, efforts for achieving maximum energy conversion efficiency are being attempted. One of the focus areas in this regard is the design of efficient fuel delivery systems. There has been a transition from carburetors to electronic fuel injection systems in all modern vehicles. The major reason for this transition is the reduction in carbon emissions and higher energy conversion efficiency.

2. CONCEPT OF FUEL INJECTION SYSTEMS

It is the introduction of fuel to the combustion chamber by means of an injector. This is a very crucial step as there should be proper mixing of fuel and air so that the combustion proceeds accurately. After this, the normal cycle of the engine continues. A variety of sensors and controllers were used in the development of electronic fuel injection systems. Together, these electronic components can detect changes, and the main system calculates the correct quantity of fuel required to improve engine performance based on a "map" that is stored of the best settings for a particular set of conditions. This characteristic was absent in mechanical fuel injectors, which gave rise to the electronic fuel injection system. Also fuel injectors do a dual job, they supply fuel as well as do fuel metering. [1]

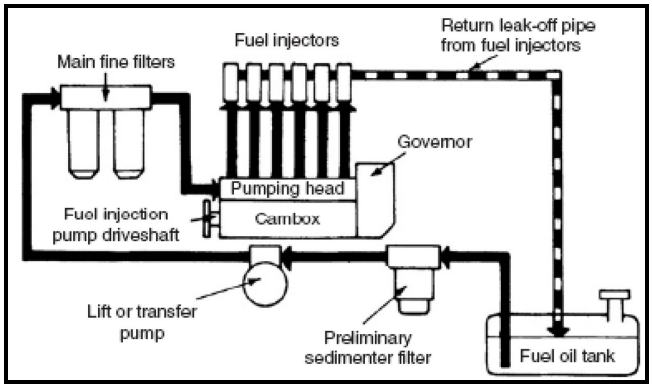

Figure 1: Simple representation of diesel engine fuel injection system

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The construction of a simple fuel injection type fuel delivery system has been given in Fig.1. [2]

3. TYPES OF FUEL INJECTION SYSTEMS

3.1 Mechanical Fuel Injection Systems

3.1.1. Air injection system

Also known as blast injection system, in this type of injection, the fuel is propelled by using compressed air. It needs an additional compression system for the injection system to work. This causes an increase in the overall weight of the engine, making it more inefficient and reducing brake power output. This system is rarely used these days due to engine weight complications. [5]

3.1.2 Solid injection system:

Also known as airless mechanical injection system, unlike in air injection, liquid fuel is directly injected into the cylinder without the use of an additional compression system. This system is further classified into four different types of injection systems.

- Individual pump and nozzle system,
- Unit injector system,
- Common rail system,
- Distributor system. [2]

3.2 Injection in SI Engine

Fuel injection systems are common in CI engines but not so much in SI engines. Presently gasoline injection systems are becoming more mainstream in SI engines due to the following drawbacks of carburetion. [2]

- Non uniform distribution of the air-fuel mixture in combustion chambers of multi-cylinder engines. [2]
- Loss of Volumetric efficiency. [2]

A gasoline injection system eliminates all these complications. The injection of fuel into an SI engine can be done by the following methods.

a. Direct injection of fuel into the cylinder
b. injection of fuel close to the intake valve
c. injection of fuel into the intake manifold. [2]

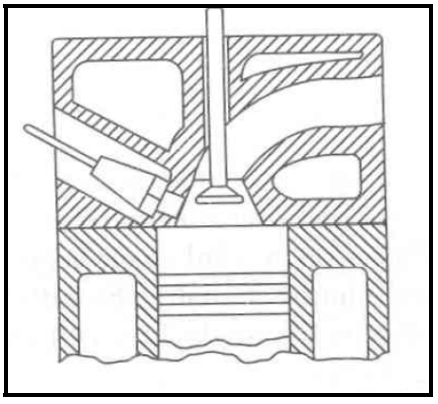

Figure 2(a): Direct injection into the cylinder

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Figs. 2(a), 2(b) and 2(c) represent the cross-sectional view of Direct injection of fuel into the cylinder, injection of fuel close to the intake valve and injection of fuel into the intake manifold respectively. [2]

3.2.1. Continuous injection systems:

This system includes a rotary pump. The system injects the fuel through a nozzle located in the intake manifold immediately down the throttle plate. The timing and duration of the injection of fuel is determined by the ECU of the engine. [2]

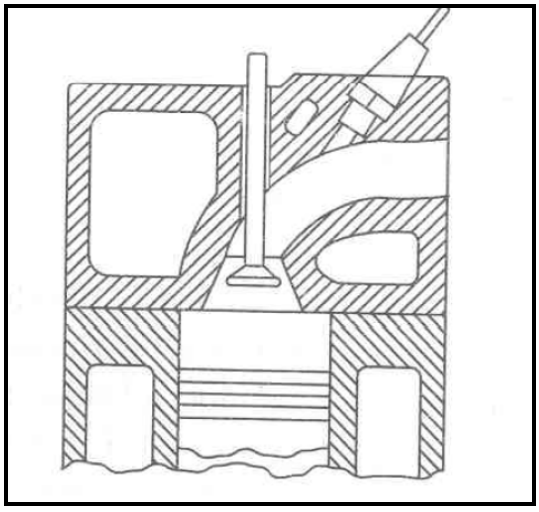

Figure 2(b): Injection of fuel close to the intake valve

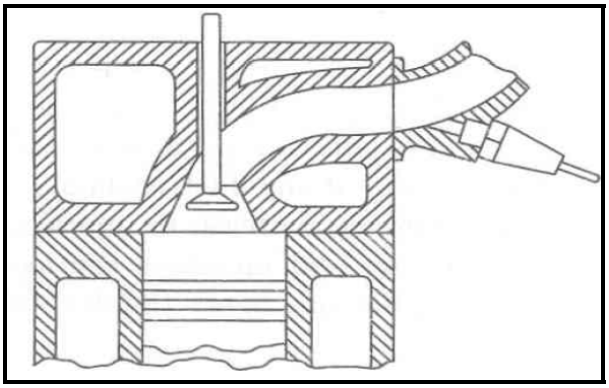

Figure 2(c): Injection of fuel into the intake manifold

3.2.2. Timed injection systems:

This system has a fuel supply pump which sends fuel at a low pressure. An injection pump and a nozzle are the other parts of this injection system. The nozzle injects the fuel into the combustion chamber or the intake manifold at very high pressures. Timed injection systems inject fuel during the early part of the intake stroke. [2]

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3.3. Electronic Fuel Injection Systems

Modern injection systems use a lot of sophisticated electronic systems which include engine sensors, a computer, and solenoid operates fuel injectors to meter and inject the right amount of fuel into the combustion chambers. These systems called electronic fuel injection (EFI) use electrical and electronic devices to monitor and control engine-operation. An electronic control unit (ECU) uses stored data to operate the injectors and other engine related systems. [2]

3.3.1. Advantages of EFI

- It enhances the volumetric efficiency of the engine.
- Wetting of the manifold is eliminated due to direct fuel injection into the cylinder.
- Good atomization of fuel even when starting the engine makes it easier to start the engine.
- Less knocking occurs due to good atomization of the fuel.
- Forming ice on the throttle plate is eliminated.
- Fuels with low volatile nature can also be used as distribution is not dependent on vaporization of the fuel. [7]

3.3.2. Disadvantages of EFI

- The maintenance cost of EFIs is very high.
- It is very difficult to service the components.
- Malfunctioning of electronic equipment is high.[2]

The fig.3 represents a simple block diagram of an electronic fuel injection system.[7]

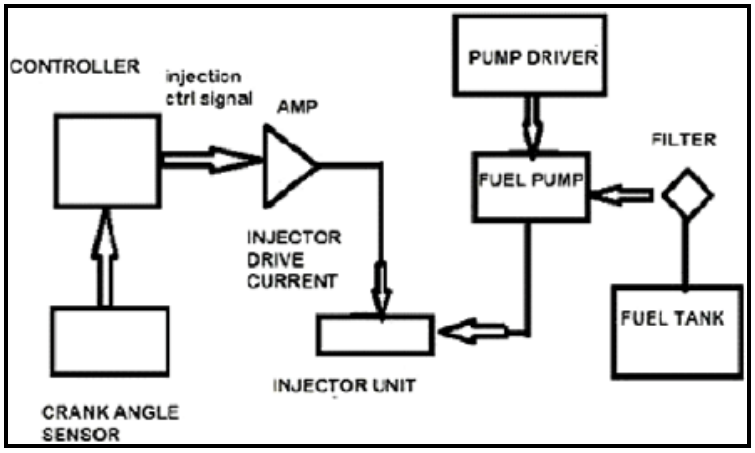

Figure 3: Block diagram of an EFI

3.4. Multi-Point Fuel Injection (MPFI) System

The main purpose of the MPFI system is to supply a proper ratio of the air-fuel mixture of gasoline and air to the combustion chamber. This system works under two basic arrangements, they are.

a. Port injection
b. Throttle body injection [8]

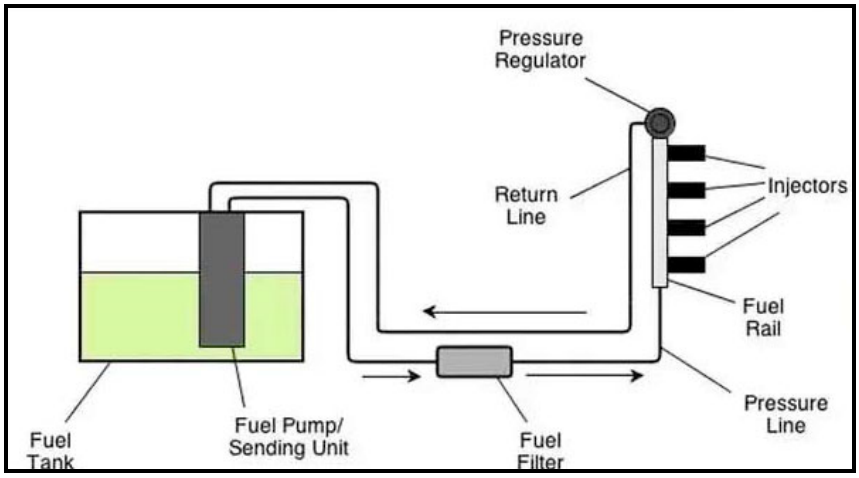

Figure 4: Multi-Point Fuel injection system

Fig. 4 represents the construction of Multi-Point Fuel injection type fuel delivery system.[9]

3.4.1. Central Port Injection System

Instead of using the central throttle body, General Motors created an 'in-between' method called central port fuel injection (CPFI), which uses tubes from a central injector to spray fuel at each intake port. However, all ports are simultaneously continually fed with fuel, which is not ideal. The standard multi-port injection system is very similar to this technology. The injector(s) are centrally located in the intake manifold plenum assembly as opposed to being placed at each intake manifold port. [4]

3.5. Comparision of Different Fuel Delivery Systems

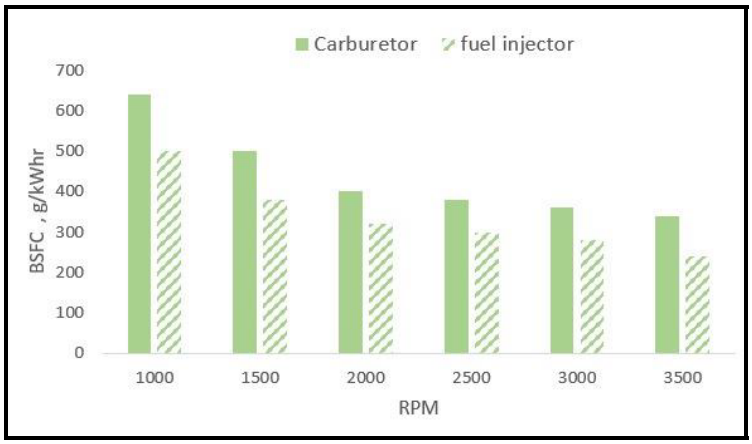

Figure 5: Variation of BSFC with respect to RPM in carburettor and EFI

Fig. 5 compares the BSFC of an engine with respect to the RPM of the engine. [6]
It is observed that the BSFC of the carburetor type of fuel delivery system is around 30-40% higher than that of the fuel injection type fuel delivery system.

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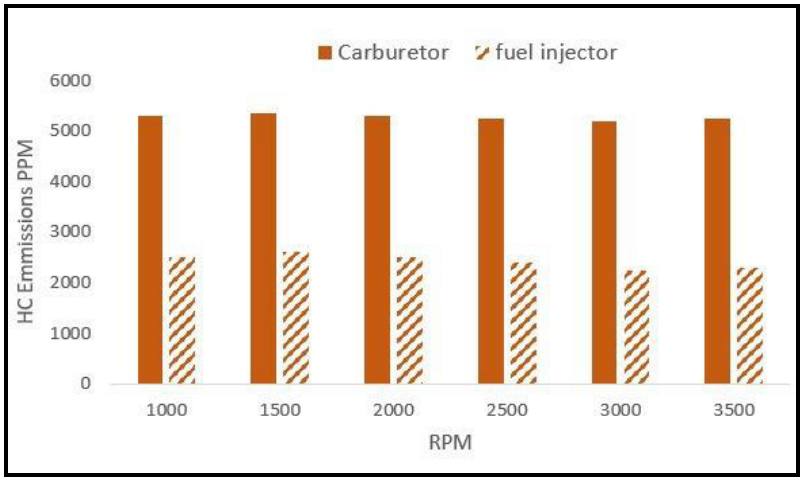

Figure 6: Variation of HC Emission with carburettor and fuel-injector

Fig. 6 compares the HC emission of an engine with respect to the RPM of the engine. [6] It is observed that the HC emissions of the carburettor type of fuel delivery system are 50-60% higher than that of the fuel injection type fuel delivery system.

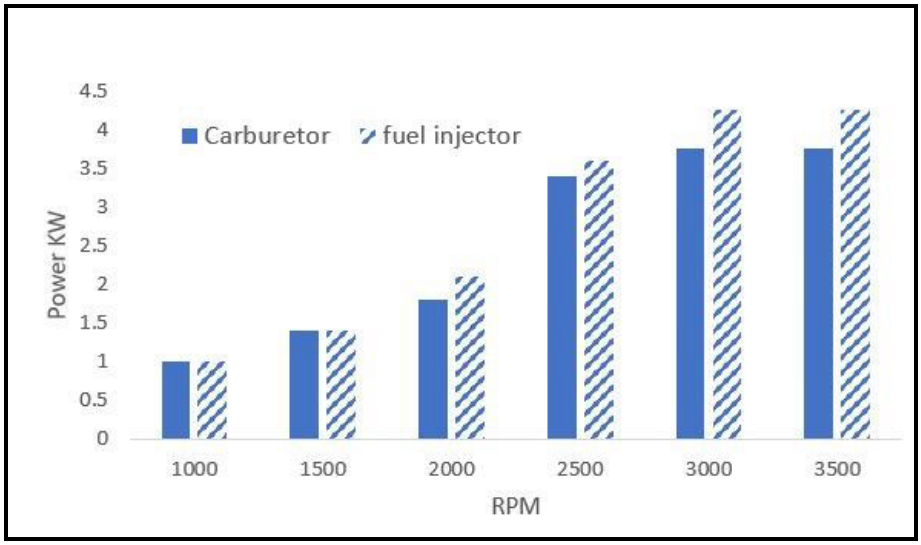

Figure 7: Variation of RPM with respective to power

Fig. 7 compares the output power of an engine with respect to the RPM of the engine. [6] It is observed that the power generated by the carburettor type of fuel delivery system is on average 8-12% lower than that of the fuel injection type fuel delivery system.

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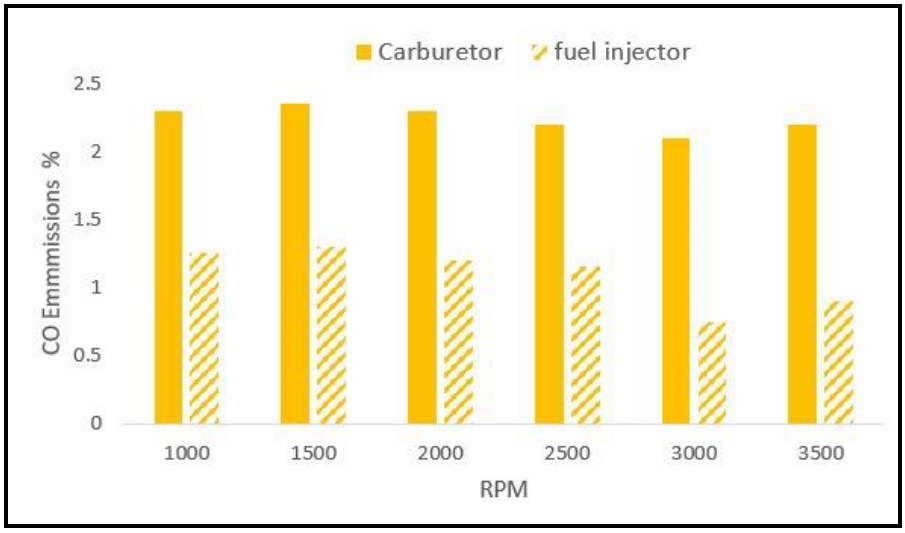

Figure 8: Variation of CO emission with respective to RPM

Fig. 8 compares the CO emissions of an engine with respect to the RPM of the engine. [6] It is observed that the CO emissions of the carburettor type of fuel delivery system are 80-120% higher than that of the fuel injection type fuel delivery system.

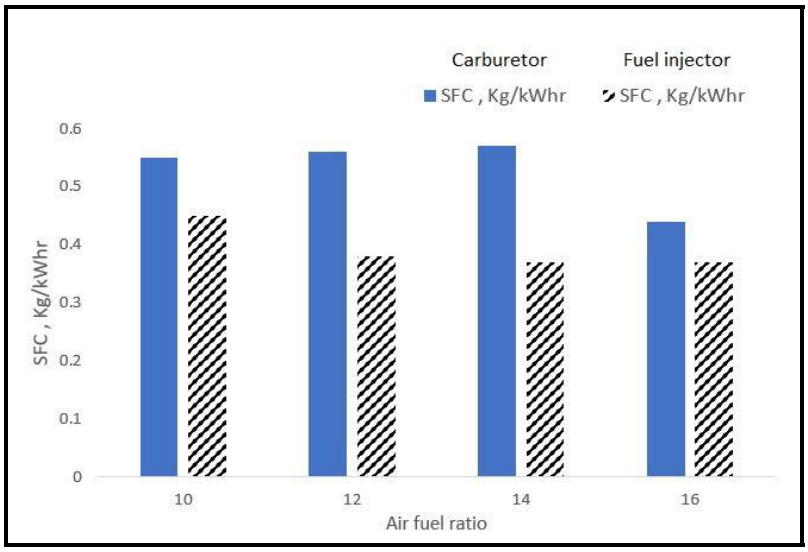

Figure 9: Difference in Specific Fuel Consumption (SFC) with respect to Air-Fuel ratio.

Fig. 9 compares the SFC of an engine with respect to the air fuel ratio input to the engine. [6]. It is observed that the SFC of the carburettor type of fuel delivery system is on average 20-50% higher than that of the fuel injection type fuel delivery system.

- Typically, gasoline engines for two-wheelers use carburettors. Even if we attain optimal performance, it is always difficult to monitor the intake of air-fuel mixture into the cylinder chamber. Due to this, there have been more exhaust emissions and the engine does not last long. Since fuel injection systems accurately determine the intake air-fuel mixture and have lower emission levels while maintaining consistent engine performance, they became more popular and good carburettor alternatives. The difference between direct injection and port injection can be determined depending on

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where the fuel injection is positioned. Direct Injection is more efficient in terms of combustion, improved fuel economy, and reduced emissions.

- Placement of fuel injection can tell the differences between a port injection and direct injection, the latter is more efficient in terms of combustion, increases fuel economy and lowers emissions. The only drawback with Gasoline Direct Injection (GDI) is that it develops a form of a deposit from oil and dirt particles that are blasted from the crankcase ventilation in the opposite direction and deposit on the walls of the inlet valve opening and the inlet valve's backside.
- A single-point injection system is a modified carburettor that optimizes the customer's driving performance while simultaneously reducing exhaust emissions.
- The development of a multi-point injection system allows the air-fuel combination to be precisely injected at a chosen location within the cylinder chamber, increasing fuel efficiency without wasting any and further lowering emissions compared to single-point injection. [6]

3.6. Why EFI are better than MFI

EFI is efficient and offers the control versatility needed for the optimum overall engine performance. EFI offers superior pollution control. The usage of an EFI system enhances atomization, which results in significant increase in the quality of the combustion of fuel. [12]

The two fundamental improvements are:

1. Reduced response time to rapidly changing inputs, e.g., rapid throttle movements.
2. Delivery of an accurate and equal mass of fuel to each cylinder of the engine, dramatically improving the cylinder-to-cylinder distribution of the engine. [12]

3.7. Performance Comparision for Single Point Fuel Injection (SPFI) and Multi Point Fuel Injection (MPFI)

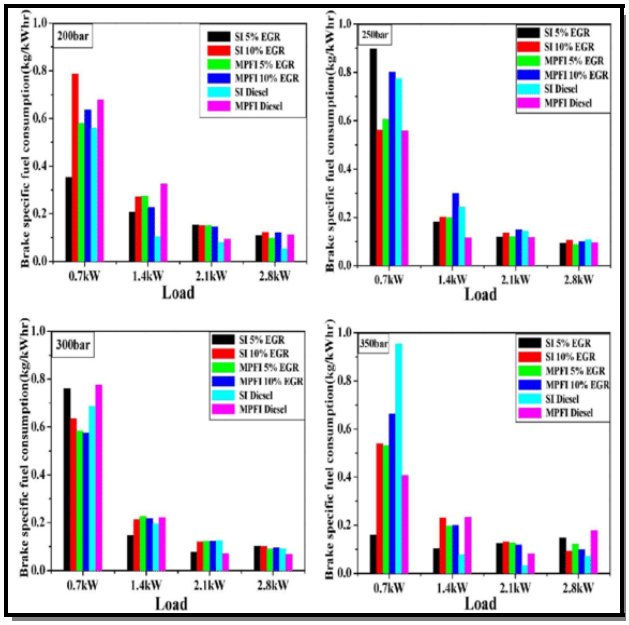

Figure 10: BSFC of SI* (SPFI) and MPFI diesel combustion at varying injection pressures for different EGR conditions.

Fig. 10 compares the BSFC of an engine with the load on the engine at different Injection Pressures. [10]

It is observed that the BSFC of the MPFI System is lower at 250-300 bar Injection Pressure but at lower injection pressure of 200 bar, but SI* (SPFI) at a higher injection pressure of 350 bar at higher power loads with very low BSFC compared to MPFI.

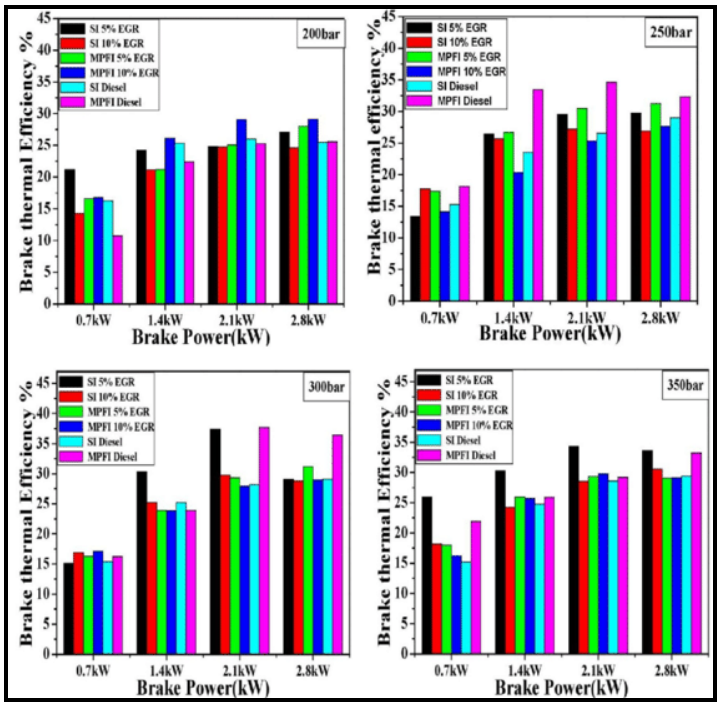

Figure 11: Brake thermal Efficiency of SI* (SPFI) and MPFI diesel combustion at varying injection pressures for different EGR conditions.

Fig. 11 compares the BTE of an engine with the Load on the engine at different Injection Pressures. [10]

It's observed that the BTE of the MPFI System is higher on average when compared to the SI* system.

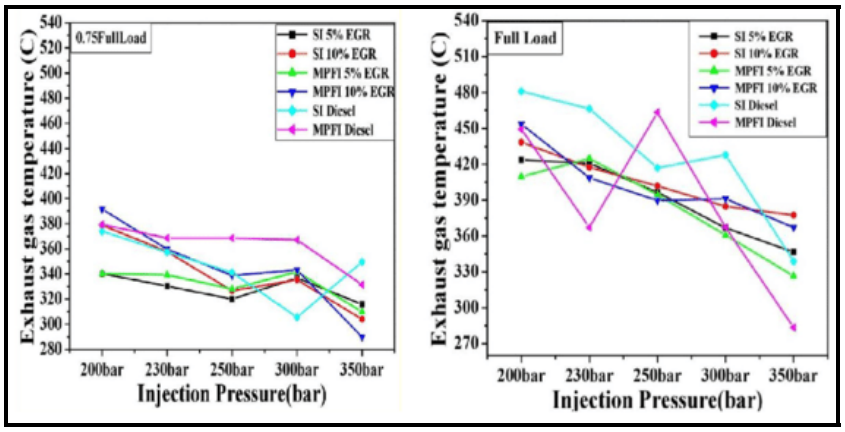

Figure 12: Exhaust gas temperature of SI* and MPFI diesel combustion at varying injection pressures for different EGR conditions.

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Fig. 12 compares the Exhaust Gas Temperature of an engine with the Injection Pressure. It is observed that the Exhaust gas temperature is an anomaly against injection pressure. [10]

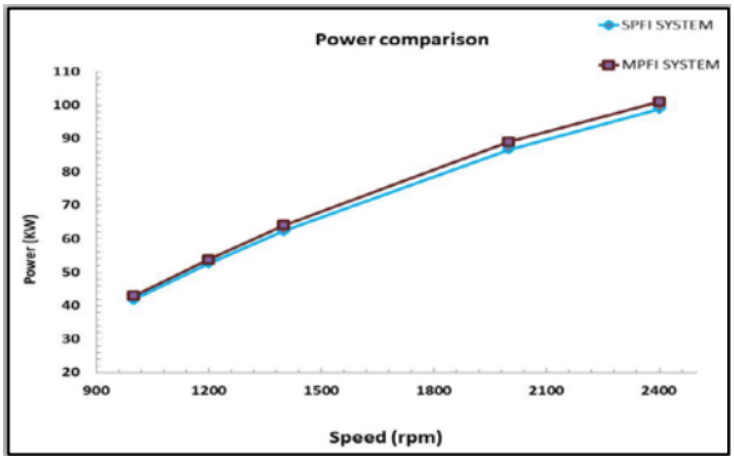

Figure 13: Power Comparison of SPFI and MPFI Systems

Fig. 13 compares the Power of an engine with the RPM of the engine. [10]

It is observed that the MPFI system delivers 3-5% higher power for the same speed compared to that of SPFI system with the same engine characteristics.

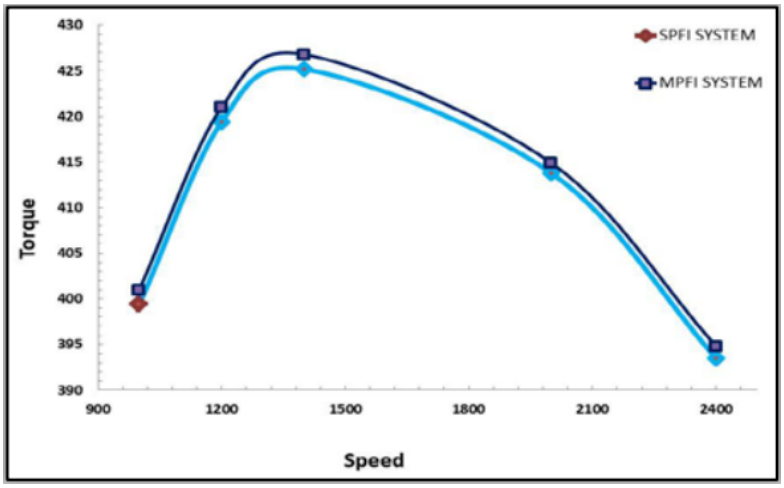

Figure 14: Torque comparison of SPFI and MPFI Systems

Fig. 14 compares the Torque output of an engine with the RPM of the engine. [11]

It is observed that the MPFI system delivers 0.5-0.7% higher torque for the same speed compared to that of SPFI system with the same engine characteristics.

3.8. Problems with Current Fuel Delivery Systems

1. The issue with this system is that because the timing is still mechanically determined by the camshaft and the injection is done into the inlet valve, some fuel does not get into the combustion chamber when the inlet valve opens. This issue affects not only this system but every other system that has been studied in the past. This is since all of them use indirect injection systems.

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2. Other issues with indirect injection include spontaneous ignition, that also affects electronic injection systems using indirect injection commonly. Therefore, the Multipoint Injection System with Direct Injection was designed to tackle these issues.
3. A direct injection engine's downsides are its complexity and price. Because direct injection systems handle fuel at much greater pressures than indirect injection systems, and because the injectors themselves must be able to withstand the heat and pressure of combustion inside the cylinder, direct injection systems are more expensive to build. [14]

4. Results and Discussions

Table 1: Subjective comparison of characteristics of different fuel delivery systems

Fuel Delivery System	Maintenance Cost	Ease of Manufacturing	Fuel Efficiency	Emissions	SFC
Carburettor	Lower	Easy	Lower	Higher	Higher
SPFI	Higher	Complicated	Higher than Carburettor	Lower than Carburettor	Lower than Carburettor
MPFI	Higher	Complicated	Higher than SFI	Lower than SFI	Lower than SFI
EFI	Higher	Complicated	Higher than MPFI	Lower than MPFI	Lower than MPFI

Table 1 compares the maintenance, ease of manufacturing, fuel efficiency and their emissions of different fuel delivery systems. It is observed that though the carburettor has lower fuel efficiency and higher emissions, it is still widely used in two-wheeler vehicles for its ease of manufacturing and low maintenance cost. Fuel Injection type fuel delivery systems are widely used in LCVs and HCVs as they have lower emissions and higher fuel efficiency even though they are complicated to manufacture and have higher maintenance than that of a regular carburettor type fuel delivery system.

5. Conclusions

With the increase in emissions, the quest for more efficient technologies is more prominent. Systems such as common rail systems are highly used for more efficiency. Injection of fuels at high pressure into the combustion chamber is going to be a lot more efficient. These systems are going to increase efficiency a lot and help in the control of emissions and in maintaining emission standards. If the above factors discussed in table 1 are addressed, there can be considerable improvement in fuel delivery systems, energy conversion efficiency and reduction in cost.

6. Acknowledgments

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