CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The high fuel efficiency of diesel engines has led to their use in many fields including transportation, electrical power generation and agricultural machinery. However, the rapid depletion of fossil fuel with increased environmental concern has increased interest and efforts to produce an alternative to PBDF. Use of biodiesel as an alternative fuel can contribute significantly towards the twin problem of fuel crises and environmental pollution. Researchers (Ramadhas et al 2004, Goering et al 1982) have shown that biodiesel fuel exhibits physico-chemical properties which are similar or some even better than to those of PBDF and hence can be used in diesel engines. However, certain properties of biodiesel such as viscosity, calorific value, density and volatility differ from PBDF.

The high viscosity of biodiesel affects injection characteristics. Poor atomization, insufficient in-cylinder air motion and low volatility of biodiesel lead to difficulty in the air-fuel mixing. Inadequate air-biodiesel mixing and sluggish evaporation process significantly affect the combustion process (Desantes et al 1999) leading to poor performance of biodiesel fuelled diesel engine. Further, increases in NO\textsubscript{x} emission with biodiesel operation is attributed to an inadvertent advance of fuel injection timing due to the higher bulk modulus of compressibility of the biodiesel fuel (Varde 1984, Boehman
et al 2004). The higher bulk density and viscosity transfer the pressure wave through fuel pipe lines faster and an earlier needle lift will lead to advanced injection (Monyem et al 2001, Tat et al 2004).

In DI diesel engine, the combustion chamber has been designed for combustion of PBDF, including improvement of mixing between injected fuel and in-cylinder air but not for biodiesel. Apart from injection parameters, the shape of the combustion chamber can also help to form better mixtures. The shape of the combustion chamber and the fluid dynamics inside the chamber are of great importance in combustion. As the piston moves upward, the gas is pushed into the piston bowl. The geometry of the piston bowl can be designed to produce a squish and swirling action which can improve the biodiesel/air mixture before ignition takes place. The main goals desired from the design of combustion chamber geometry are to optimize the mixing of the biodiesel and air before and during ignition, and to improve the flow of the exhaust products once combustion is complete. Hence to obtain higher performance and lower emissions from biodiesel fuelled diesel engine certain modifications to engine design and injection parameters are required. The available energy in biodiesel should be utilized very efficiently and economically. Inefficient methods of utilizing the available energy should be curbed.

Keeping all this in mind an attempt has been made here to review the previous experimental investigations to look into the effect of biodiesel on the engine from the viewpoint of performance, combustion and emissions and the methods to overcome the practical difficulties to improve the engine performance and to reduce the harmful pollutants by various researchers on biodiesel fed engines.
2.2 BIODIESEL FUELLED DIESEL ENGINE

2.2.1 Performance, Emission and Combustion Characteristics

Bhupendra et al (2012) carried out an experimental investigation to compare performance and emission characteristics of biodiesel derived from Jatropha oil in a dual fuel diesel engine with baseline results of diesel fuel. The performance and emission parameters evaluated were: BTE, BSFC, power output, CO, CO$_2$, HC, NO$_x$ and smoke opacity with the different fuels were also measured and compared with baseline results. The BTE of Jatropha methyl ester and its blends with diesel were lower than diesel and BSFC was found to be higher. However, HC, CO, CO$_2$ and smoke were found to be lower with Jatropha biodiesel fuel. NO$_x$ emissions on Jatropha biodiesel and its blend were higher than diesel.

Oguzhan et al (2012) evaluated the effect of tire-derived fuel (TDF) on performance and exhaust emissions in a diesel engine. Six test fuels, TDF10 (contains 10% tire derived fuel and 90% diesel), TDF30, TDF50, TDF70, TDF90 and diesel, were prepared to test in a diesel engine. The experimental test results showed that the DI diesel engine can run with the TDF fuel blends up to TDF90. The smoke opacity, HC, and CO emissions reduced while NO$_x$ emissions increased with the increasing TDF content in the fuel blends. In addition, TDF fuel content in the fuel blends did not have a significant impact on the engine torque, engine power, BSFC and BTE with respect to those of the reference diesel fuel.

Song et al (2012) explored the effects of differences in the fuel properties on Nitric Oxide (NO) emissions and smoke concentrations from a diesel engine fuelled with biodiesel and its 20% volume blend with petroleum diesel. The biodiesel fuels tend to emit higher NO emissions. More
consistently, smoke concentrations of this study were lower with the biodiesel fuels than with petroleum diesel.

Yuan et al (2012) investigated the emissions of polycyclic aromatic hydrocarbons (PAHs), regulated matters, and BSFC from a diesel engine for five test fuels: ultra-low sulphur diesel (ULSD), WCOB5 (5 vol% waste cooking oil + 95 vol% ULSD), WCOB10, WCOB20, and WCOB30. Results indicated that using ULSD/WCOB blends decreased PAHs by 7.53%–37.5%, PM by 5.29%–8.32%, total HC by 10.5%–36.0%, and CO by 3.33%–13.1% as compared to using ULSD.

Bakeas et al (2011) conducted an experimental investigation to evaluate the fuel impact on emissions using a soy-based biodiesel, a palm-based biodiesel, and biodiesel obtained from used frying oils were blended with an ULSD at proportions of 30%, 50% and 80% by volume. Fuel consumption exhibited increases with biodiesel which ranged up to 5%. NO\textsubscript{x} emissions were increased with biodiesel between 5% and 10% except for the blends prepared with the palm-based methyl ester. The emissions of PM, HC, and CO decreased with the addition of biodiesel reaching maximum reductions in the order of 10%, 30% and 20% respectively.

Gokalp et al (2011) evaluated the effects of biodiesel, soybean methyl ester (SME) and its blend with marine diesel fuel (MF) from 5%, 20% and 50% blends by volume. The results indicated that the use of biodiesel produces lower smoke opacity (up to 74%), but higher BSFC (up to 12%) compared to MF. The measured CO emissions of B5 and B100 fuels were found to be 3% and 52% lower than that of the MF respectively.

Kalam et al (2011) carried out an experimental study to evaluate emission and performance characteristics of a multi-cylinder diesel engine
operating on waste cooking oil such as 5% Palm oil with 95% diesel (P5) and 5% Coconut oil with 95% diesel (C5). The results showed that there were reductions in brake power of 1.2% and 0.7% for P5 and C5 respectively compared with B0. In addition, reduction of exhaust emissions such as HC, smoke, CO, and NO\textsubscript{x} were offered by the blended fuels.

Leevijit et al (2011) performed the performance and emissions tests on indirect injection (IDI) turbo diesel engine operated with diesel and blends of palm oil in diesel at portions of 20, 30, and 40 vol. %. The results showed that, a higher blending results in a higher BSFC (+4.3% to +7.6%), lower BTE (–3.0% to –5.2%), lower exhaust gas temperature (EGT), and a significantly lower black smoke (–30% to –45%). The CO from the 20 vol blend was significantly lower (–70%), and NO\textsubscript{x} from all blends are higher.

Muralidharan et al (2011) carried out experiments on a four stroke variable compression ratio multi fuel engine fuelled with waste cooking oil methyl ester and its blends with standard diesel. Tests were conducted using the fuel blends of 20%, 40%, 60% and 80% biodiesel with diesel, at an engine speed of 1500 rpm, fixed compression ratio 21. The blends when used as fuel resulted in the reduction of HC, CO and CO\textsubscript{2} at the expense of NO\textsubscript{x} emissions. It was found that the combustion characteristics of biodiesel and its blends closely followed those of diesel.

Ozsezen and Canakci (2011) studied the performance characteristics of a DI diesel engine fuelled with canola oil methyl ester (COME) and waste palm oil methyl ester (WPOME). The results indicated that when the test engine was fuelled with WPOME or COME instead of PBDF, the brake power reduced by 4–5%, while the BSFC increased by 9–10%. On the other hand, methyl esters caused reductions in CO by 59–67%, HC by 17–26%, CO\textsubscript{2} by 5–8%, and smoke opacity by 56–63%. However,
both methyl esters produced more NO\textsubscript{x} emissions by 11–22% compared with those of the PBDF.

Rodriguez et al (2011) carried out engine tests using biodiesels obtained from palm oil and rapeseed oil and with diesel fuel as a reference. The analysis focused on the determination of the ignition delay (ID). The test results showed that, no significant difference in in-cylinder pressures at injection timing for each fuel. With biodiesel slightly lower peak cylinder pressures were observed. Palm oil and rapeseed oil biodiesel gave shorter ID than diesel fuel due to the higher cetane number for the biodiesels.

Shehata et al (2011) carried out an experimental investigation to investigate performance, emissions, cylinder pressure and EGT for DI diesel engine. Tests were conducted using sunflower oil (S100) and 20% jojoba oil + 80% pure diesel fuel (B20) in comparison to diesel at different engine speeds. Also, a series of tests were conducted at same previous conditions with different percentage of exhaust gas recirculation (EGR) from 0% to 12% of inlet mass of air fresh charge. Results indicate that S100 or B20 gave lower BTE, BP, Brake Mean Effective Pressure (BMEP), and higher BSFC due to lower heating value compared to diesel. S100 or B20 gives lower NO\textsubscript{x} concentration due to lower gas temperature.

Ali et al (2010) studied the performance of tall oil as alternative diesel fuel. The tests were carried out in an unmodified DI diesel engine on full load conditions. The results showed that the BSFC with the blend fuels did not show a significant change. CO emission and smoke level decreased up to 23.91% and 19.40%, respectively. In general, NO\textsubscript{x} emissions showed an increasing trend with the blend fuels (up to 25.42%).
Barabas et al (2010) performed experimental studies on performance and pollution of a diesel engine fuelled with diesel–biodiesel–ethanol blends and compared with diesel. An increase of the BSFC, especially at lower engine loads and reduction in engine BTE were observed. CO emissions were decreased. NO\textsubscript{x} emissions were slightly increased meanwhile HC and smoke emissions were decreased at all engine loads.

Ekrem Buyukkaya (2010) carried out an experimental investigation on performance, emission and combustion of a diesel engine using neat rapeseed oil and its blends of 5%, 20% and 70% and diesel. The results indicate that the use of biodiesel produced lower smoke opacity (up to 60%), and higher BSFC (up to 11%) compared to diesel. The CO emissions of B5 and B100 fuels were found to be 9% and 32% lower than that of the diesel. The BSFC of biodiesel were found to be 8.5% and 8% higher than that of the diesel fuel respectively. From the combustion analysis, it was found that ID was shorter for neat rapeseed oil and its blends tested compared to that of diesel.

Saravanan N et al (2010) studied the performance of Mahua ester on a single cylinder, four stroke CI engine. Engine performance tests showed that the power loss was around 13% combined with a 20% increase in fuel consumption at full load. Emissions such as CO, HC were lesser for Mahua ester compared to diesel by 26% and 20% respectively. NO\textsubscript{x} were lesser by 4% for the ester compared to diesel.

Saravanan S et al (2010) conducted an experimental study to analyze the combustion characteristics of crude rice bran oil methyl ester (CRBME) blend as a fuel in a DI diesel engine. When operating with CRBME blend the cylinder pressure was comparable to that of diesel. It was observed that the delay period and the maximum rate of pressure rise for
CRBME blend were lower than diesel. The occurrence of maximum heat release rate (HRR) advanced for CRBME blend with lesser magnitude when compared to diesel. The BSFC of CRBME blend was found to be only marginally different from that of the diesel. CRBME blend had lower smoke intensity and higher NOx emission than those of diesel.

Devan et al (2009) carried out engine tests on a diesel engine running on methyl ester of paradise oil (MEPS) and its diesel blends. From the emission analysis it was found that there was a reduction in smoke and HC emissions by 33% and 22% respectively for MEPS50 blend and 40% and 27% reductions for MEPS100. However, there was an increase of 5% and 8% NOx emission for MEPS50 and MEPS100 respectively. BTE of MEPS and its diesel blends were lower than that of diesel.

Ozsezen et al (2009) studied the performance and combustion characteristics of a DI diesel engine fuelled with waste (frying) palm oil methyl ester (WPOME) and canola oil methyl ester (COME). The experiments were conducted in the constant engine speed mode (1500 rpm) under the full load condition. The results indicated that when the test engine was fuelled with WPOME or COME, the engine performance slightly weakened, the combustion characteristics slightly changed when compared to PBDF. The biodiesels caused reductions in CO, HC emissions and smoke opacity, but they caused to increase in NOx emissions.

Sahoo et al (2009) conducted an experimental investigation to access the practical applications of biodiesel in a single cylinder diesel engine. Diesel, neat biodiesel from Jatropha, Karanja and Polanga and their blends (20 and 50 by v%) were used as fuels. The engine combustion parameters such as peak pressure, heat release rate and ID were computed. Combustion analysis revealed that neat Polanga biodiesel that results in maximum peak
cylinder pressure. The IDs were consistently shorter for all neat Jatropha, Karanja and Polanga biodiesel.

Murillo et al (2007) conducted an experimental study to compare the engine performance and emission results of biodiesel derived from used cooking oil. Results revealed that the use of biodiesel resulted in lower emissions of CO (up to 12%) with an increase in emissions of NO$_x$ (up to 20%). Biodiesel also presented a slight increase in SFC (up to 11.4%).

### 2.2.2 Influences of Injection Parameters

Gumus et al (2012) studied the effects of fuel injection pressure on the emissions and BSFC of a DI diesel engine. The engine was fuelled with biodiesel–diesel blends. The engine was run at four different fuel injection pressures (18, 20, 22, and 24 MPa) and four different engine loads. The results revealed that the BSFC, CO$_2$ and NO$_x$ emission increased, smoke, HC and CO emissions decreased due to the combustion characteristics of biodiesel. On the other hand, the increased injection pressure caused to decrease in BSFC of high percentage biodiesel blends, smoke opacity, CO, HC and increased the emissions of CO$_2$ and NO$_x$.

Donghui et al (2011) studied the effect of injection timing and EGR rate on the combustion and emissions of DI diesel engine by using neat biodiesel produced from soybean oil. The results showed that, with the increasing EGR rate, the BSFC and soot emission were slightly increased, and NO$_x$ emission was evidently decreased. Under higher EGR rate, the peak pressure was slightly lower, and the peak heat release rate kept almost identical at lower engine load, and was higher at higher engine load. With the injection timing retarded, BSFC was slightly increased, NO$_x$ emission was evidently decreased.
Ganapathy et al (2011) studied the effect of injection timing on the performance, combustion and emission characteristics of Jatropha biodiesel engine. It was observed that advanced injection timing from factory settings caused a reduction in BSFC, CO, HC and smoke levels and increase in BTE, $P_{\text{max}}$, $HRR_{\text{max}}$ and NO emission with Jatropha biodiesel. However, retarded injection timing caused effects, in the other way.

Maheshwari et al (2011) carried out an experimental investigation to optimize the performance of an IC engine fuelled with a Karanja biodiesel blends, in terms of optimum biodiesel blend and injection timings. Experiments were conducted on a single cylinder, DI diesel engine under variable load conditions and injection timings for diesel and Karanja biodiesel blends (5%, 10%, 15%, 20%, 50% and 100%). Retarding the injection timing for neat Karanja biodiesel resulted in an improved efficiency and lower HC emissions. A tradeoff relationship between the NO$_x$ and smoke emissions was observed. The overall optimum was found to be 13% biodiesel-diesel blend with an injection timing of 24°bTDC.

Mancaruso et al (2011) analysed the spray behaviour of first and second generation biodiesel common rail diesel engine. GTL, SME and RME fuels were used in blends with diesel as reference fuel. The injection process was studied, and the influence of the combustion process on the spray behaviour had been taken into account. Typical jets parameters such as penetration and cone angles were detected. First generation biodiesels, pure and blends, show longer penetration with respect to the reference fuel at both the engine speed analysed. Moreover, they penetrate for a longer time in the combustion chamber. On the other hand, the second generation biodiesels penetrate less than reference one, due to its lower density.
Sayin and Gumus (2011) investigated the influence of compression ratio (CR), injection timing (IT) and injection pressure (IP) on the performance and emissions of a DI diesel engine using biodiesel (%5, 20%, 50%, and 100%) blended-diesel fuel. Tests were carried out using three different CRs (17, 18, and 19:1), ITs (15°, 20°, and 25° CA bTDC) and IPs (18, 20 and 22 MPa) at 20 N-m engine load and 2200 rpm. The results showed that BSFC, BSEC, and NO$_x$ emissions increased while BTE, smoke opacity, CO and HC decreased with the increase in the amount of biodiesel in the fuel. The best results for BSFC, BSEC and BTE were observed at increased CR, IP, and original IT. For all tested fuels, an increase in IP, IT and CR led to decrease in the smoke, CO and HC emissions while NO$_x$ emissions increase.

Celikten et al (2010) carried out tests with a four-cylinder diesel engine for three different injection pressures such as 250, 300 and 350 bar, using rapeseed oil methyl ester and the soybean oil methyl ester. The performance and emission values of rapeseed oil and soybean oil methyl esters were found to be nearly the same with those of diesel fuels when injection pressure was increased to 300 bar.

Gumus (2010) carried out an experimental investigation using hazelnut kernel oil. A comprehensive analysis of combustion (cylinder gas pressure, rate of pressure rise, ID) parameters of a DI diesel engine running with biodiesel and its blends with diesel was carried out. Results showed that, the modifications such as increasing of IT, CR, and IP provided significant improvement in combustion and heat release characteristics.

Jindal et al (2010) carried out research using Jatropha Methyl Ester (JME) to determine the effects of the engine design parameters viz. compression ratio (CR) and fuel injection pressure (IP) jointly on the
performance. It was found that the combined increase of CR and IP increased the BTE and reduced BSFC while having lower emissions. For small DI constant speed engines used for agricultural applications (3.5 kW), the optimum combination was found as CR of 18 with IP of 250 bar.

Xiangang et al (2010) studied experimentally and analytically the Spray characteristics of biodiesels (from palm and cooked oil) and diesel under high injection pressures up to 300 MPa. Injection delay, spray penetration, spray angle, spray projected area and spray volume were measured in a spray vessel using a high speed video camera. Air entrainment and atomization characteristics were analyzed. The study showed that biodiesels give longer injection delay and spray tip penetration. Spray angle, projected area and volume of biodiesels were smaller than those of diesel. The estimation on the spray droplet size showed that biodiesels generate larger Sauter Mean Diameter (SMD) due to higher viscosity and surface tension.

Rosca et al (2009) carried out research to determine the effects of biodiesel on the fuel injection system of a DI diesel engine. The results indicated that the injection characteristics were affected when a blend containing 50% methyl ester and 50% diesel was used as fuel (injection duration, pressure wave propagation time, average injection rate). As a result, the engine characteristics were also affected, the use of biodiesel blend leading to lower power output and torque. The lower ID and pressure wave propagation time led to changes of the cylinder pressure, heat release traces and lower peak combustion pressures.

Su et al (2009) investigated the spray atomization characteristics of SME in a diesel engine and compared with diesel. The experimental results were compared with numerical results predicted by the KIVA-3V code. It was found that the peak injection rate increased and advanced when the injection
pressure increased due to the increase in the initial injection momentum. The injection rate of the SME, which has a higher density than diesel, was higher than that of diesel despite its low injection velocity. The high pressure induced the shortening of spray tip penetration of the SME. The SMD of the SME decreased along the axial distance.

Sukumar et al (2009) investigated the effect of injection pressures on performance, emissions and combustion characteristics of a DI diesel engine using linseed oil methyl ester with varied fuel injection pressures (200, 220 and 240 bar). The results showed that the optimum fuel injection pressure was 240 bar. At this optimum pressure the BTE was similar to diesel and a reduction in CO, HC and smoke emissions with an increase in NO₉ was noticed compared to diesel. The ID was lower at higher injection pressures compared to diesel and the peak pressure was also higher.

Tiegang et al (2009) employed an optically accessible single-cylinder high speed direct injection (HSDI) diesel engine to investigate the spray and combustion processes for biodiesel blends under different injection strategies. The experimental results indicated that the HRR peak became smaller with IT retardation. The ignition and HRR peak occurred later with increasing biodiesel content. For all the ITs, lower soot luminosity was seen for biodiesel blends than diesel. Furthermore, NO₉ emissions were reduced for premixed combustion with retarded ITs.

Breda Kegl (2006) performed a numerical and experimental analysis of injection process using biodiesel-diesel blends with the aim to reduce engine harmful emissions. The considered fuels were neat biodiesel from rapeseed oil and its blends with diesel. The results revealed that, while keeping engine performance within acceptable limits, harmful emissions can
be reduced by adjusting appropriately pump injection timing. This prediction was also confirmed experimentally.

2.3 EFFECTS OF COMBUSTION CHAMBER GEOMETRY ON DI DIESEL ENGINE PERFORMANCE

Takashi Kaminaga and Jin Kusaka (2006) presented a combined experimental and numerical study on combustion and exhaust emissions in a diesel engine by optimizing the combustion chamber design. Two re-entrant bowls and a toroidal combustion chamber were considered. The KIVA-3V code was used for numerical simulation. They found that the modified re-entrant (re-entrant ratio of 1.13 from 1.3) bowl cavity showed a favorable performance in fuel distribution and mixing. They also observed that the modified reentrant bowl cavity showed low soot and better combustion due to the high combustion temperature, while other two combustion chamber cavities did not fare well in soot re-burn.

Fontanesi et al (2005) carried out both experimental and numerical investigations on mixture formation in a heavy duty DI diesel engine. Tests were carried out at 50%, and 100% loads. Two combustion chamber geometries were considered for the study. The CFD code STAR CD was used for numerical analysis. The results showed that, the modified combustion chamber increased the swirl intensity and turbulence level, improved air usage and better air fuel mixing and improved the BSFC by around 10%, soot by 16% and slight increase in NO\textsubscript{x} (3%) emission.

Payri et al (2004) carried out in-cylinder flow analysis during the intake and compression strokes of a DI diesel engine equipped with five different combustion chambers, namely piston coded ‘A’ is a toroidal chamber; piston ‘B’ is the original geometry; piston ‘C’ is weak re-entrant
chamber; piston ‘D’ is similar to piston ‘A’ and piston ‘E’ is strong re-entrant geometry. The resulting flow was analyzed and compared for different combustion chambers by using CFD. The maximum swirl level was maintained during the second part of the intake stroke. During the first phase of compression stroke, the piston had negligible effect on the flow characteristics. The re-entrant bowl had the turbulence level slightly higher and conserved even during the early part of expansion stroke.

Rahman et al (2001) conducted an experimental investigation to study the effects of cavity entrance shapes (round lip and sharp lip) and position of impingement on mixture formation, mixture distribution, combustion, and emissions. Their results showed that, a re-entrant cavity with a round lip and spray impingement just on the lip corner produced larger spray volumes, improved the mixture formation, and spray distribution inside and outside the cavity compared with a simple cylindrical cavity. As a result, the HC and smoke emissions decreased.

Lin et al (2000) carried out numerical analysis of air motion in three different shapes of combustion chambers viz. central projection, shallow W, and pataloid type. It was found out that optimizing combustion chamber geometry, aimed at reinforcing the diffuse combustion at the later combustion period and to get the trade-off of fuel consumption, NO\textsubscript{x} and smoke emissions. The results showed that engine with central projection chamber provide a high swirl ratio (4.7) than other two chambers. Central projection chamber with retarded injection timing (10° bTDC) reduced NO\textsubscript{x} but slightly increased fuel consumption and smoke emission.

Lisbona et al (2000) presented a combined experimental and analytical work on optimization of the combustion chamber of a DI diesel engine aiming to reduce emissions. It was proved that the effect of the swirl
velocity level in the combustion bowl was more important for soot oxidation in the late combustion phase rather than for soot production during its early phases. It was also shown that heat transfer to the piston bowl walls was notably affected by the local gas temperature distribution.

Rahman et al (2000) conducted an experimental investigation to study the effects of combustion chamber geometry on fuel spray behavior in an optically accessed DI diesel engine. Bowl lip shape, wall distance and bowl bottom corner radius were taken for their study. Their results showed that a re-entrant cavity with round lip produced larger spray volumes, wider spray, and better balance of fuel inside and outside the cavity than the simple cylindrical cavity. The large radius of the bottom corner reduces the amount of air near the side wall and the air distribution in the chamber changes and results in poor balance between air and fuel.

Auriemma et al (1998) investigated the flow field behaviour in a diesel engine equipped with a re-entrant bowl in piston. The tests were carried out at 1000, 1500 and 2000 rpm. Tangential and radial components of the air velocity were obtained at different crank angles. The results of the investigation showed that, the tangential velocity (swirl) increased during the compression stroke as the piston approached the TDC and radial inward motion could be observed during the last part of compression.

Long Zhang et al (1998) conducted an experimental investigation to study the effect of combustion chamber geometries on flame behaviour in the DI diesel engine. The experiment was carried out on a single cylinder diesel engine with an operating speed of 1000 rpm. The flame velocity and smoke were analyzed for three different chamber geometries (dish chamber, reentrant, reentrant with a pronounced center cone) and different nozzle protrusion (1.4, 2.4 and 5.1mm). The results showed that, the chamber
geometry has significant effects on flame velocity inside the bowl, the reentrant chamber with a pronounced center cone showed a larger flame velocity (15m/s) than dish chamber during the expansion period. The flame distribution inside and outside the chamber was considerably affected by the chamber geometry, the re-entrant chamber prevents the flame from spreading over the squish region.

Zolver et al (1997) used KIVA code for analyzing the flow and combustion process in the DI diesel engine with different piston cavity shapes. The velocity field at the intake valve closer was used as an initial condition for different geometries. They concluded that, the bowl played an important role on flow near TDC and thus combustion.

2.4 SUMMARY OF LITERATURE REVIEW

A comprehensive review of the previous work available in the literature on the use of biodiesel as an alternative fuel for diesel engines was carried out. From the above review of literature the following important conclusions were made. Many of the experimental works concentrated mainly on biodiesel and its blending with diesel in different proportions to optimize the biodiesel and diesel blend, tested in unmodified engines. These investigations have reported that:

- The use of biodiesel blends and neat biodiesel in diesel engine decreased the brake power output of the engine.
- An increase in BSFC (upto 15%) was found when using biodiesel in most of the reviewed studies.
- Most of the authors reported decreased BTE (upto 9%) for biodiesel operated engine.
Most of the studies reported increase in NO\textsubscript{x} emissions when using biodiesel fuels. Some authors attributed this to the advancement of the injection process with biodiesel. Some authors proposed retarding the injection timing or EGR as a mean to decrease NO\textsubscript{x} emissions.

Other regulated emissions such as those of HC and CO were found significantly lower with biodiesel. Most of the authors attributed this to more complete combustion caused by the increased oxygen content in the flame coming from the biodiesel.

The majority of studies found a sharp reduction in particulate emissions with biodiesel as compared to diesel fuel. This reduction was caused by reduced soot formation and enhanced soot oxidation. The oxygen content and the absence of aromatic content in biodiesel were pointed out as the main reasons.