Term Paper
ME514 - Internal Combustion Engine

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Macroscopic spray parameters studies using a constant volume combustion chamber

➢ Abstract

The ambition of this term paper is the observation of macroscopic spray parameters studies using a constant volume spray combustion chamber. Microscopic spray parameters and Macroscopic spray parameters are the two categories for investigation of spray characteristics. Spray droplet velocity, droplet size distribution and spray tip penetration, spray area and spray cone angle , respectively are the characteristics for microscopic and Macroscopic analysis. Inherent physical and chemical features of the fuel are the governing attributes for spray behavior. Fuel injection and fuel- air mixture are the cruel factors for the combustion inside the chamber. Spray parameters are affected highly by fuel injection process,fuel temperature, ambient temperature and pressure, fuel combustion inside the chamber, geometry of spray nozzle , chemical and physical features of fuel. For experimental setup , A high speed photography system and constant volume spray combustion chamber is required. Bio-diesel, diesel and mixed biodiesel with diesel is used for study of spray tip penetration, spray area spray cone angle.. Diesel , bio-diesel, mixture of bio-diesel with diesel with various BD's of the fuel are accustomed to investigate the behavior of the fuel. Ambient pressures are substituted with an increment of 0.2 MPa to examine the spray behavior from 0.1 to 0.9 MPa and injection pressure is also used with an increment of 10 ranging from 60 to 100 Mpa. Small diameter spray (0.3mm) and at 700 microseconds fuel injection

system is required in a constant volume chamber. Physical properties of diesel and Bio-diesel ,condition for experiment and physical measurements , quantities of fuel in various injection pressures are notified and used for the observation to fulfil the objective of this term paper. There is a decrease in the spray tip penetration when the chamber pressure is increased.

Introduction:

Observed Spray parameters are differentiated into two basic categories. Microscopic spray parameters and Macroscopic spray parameters. Microscopic spray parameters are spray droplet velocity and spray droplet size distribution.Macroscopic spray parameters are spray tip penetration, spray cone angle and spray area. These parameters influence the cylinder of fuel and also the process of the internal combustion engine.

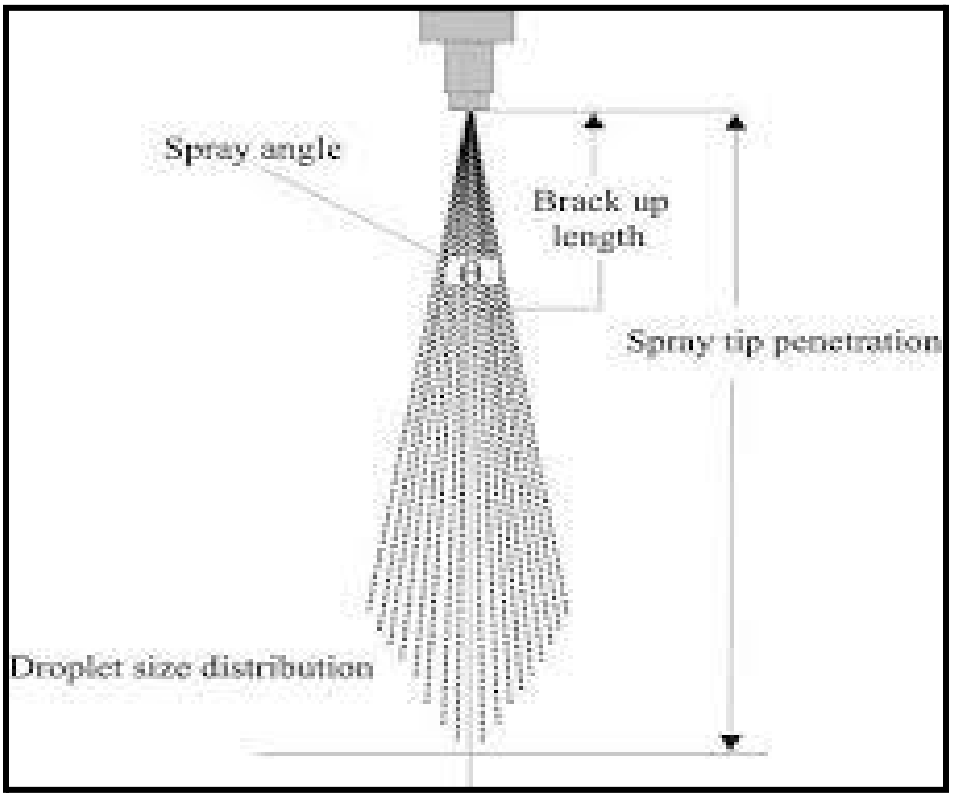


Fig1. Diagram for Spray tip penetration and Spray Cone Angle

Automatic macroscopic characterization of spray

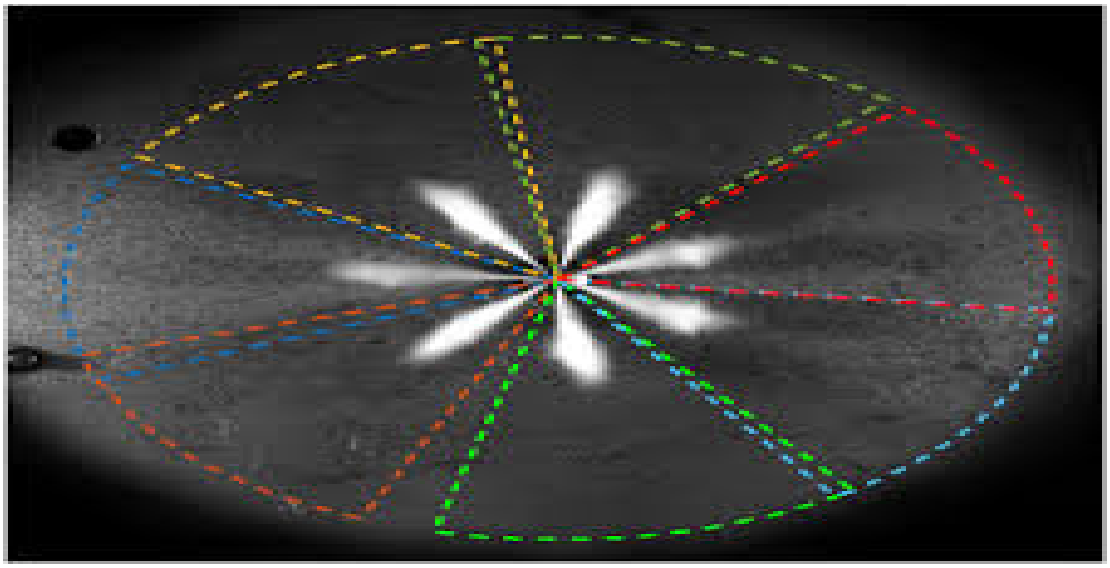


Fig2. Fuel injection in CI engine.

According to most of the researchers , it was found that physical properties of fuel(gasoline, diesel, biodiesel) were the inherent factors governing the spray parameters or spray characteristics. The objective of this term paper is to observe the macroscopic spray parameters that are spray tip penetration, spray cone angle. Researchers observed that in favor of achieving more methodical combustion, efficient spray cone angle and extended penetration length are advised in absence of spray wall contact. Spray tip penetration is defined as the length between origination of the spray nozzle tip and distance that spray can maximize along its axis. Spray cone angle is the straight line on the both sides of the droplet from the tip of the spray nozzle.

The combustion which took place in the chamber is mostly affected by the fuel injection method and mixing of fuel and air. It is significantly needed to understand the formation of fuel spray and its characteristics for better fuel-air mixing and fuel injection. Spray parameters are mainly affected due to fuel injection process, ambient temperature and pressure, fuel temperature, fuel combustion inside the chamber, chemical and physical properties of fuel and geometry of spray nozzle. In general, diesel spray nozzles are Smaller in diameter and usually

concerned with ultra high injection pressures. It is observed that in biodiesel the spray tip penetration is greater at ultra high injection pressures.

Fuels like diesel, gasoline, biodiesel, emulsified bio-diesel and emulsified diesel were examined and studied in order to determine the properties of spray behavior. Study shows that flow velocity of biodiesel at the outlet of nozzle is lower than the diesel due to the higher viscosity of biodiesel than the diesel which results in lower mass flow rate of biodiesel. Because of the above mentioned phenomenon biodiesel has lower spray atomization and results in longer spray tip penetration. However in diesel the velocity at the outlet of the nozzle is higher than the biodiesel governs in the higher spray atomization and results in the shorter spray tip penetration.

Grimaldi and Battistoni studied the characteristics of spray which are highly influenced by the shape of the hole present in the nozzle. Injection pressure impact and timing of injection fuel studied and researched by Agarwal on macroscopic spray parameters in CI engine with single cylinder that is furnished by high pressure injection system and charged with mineral diesel and karanja bio-diesel. It is observed that larger spray area and longer spray tip penetration at higher injection pressure of fuel than at lower pressure of injection. Agarwal also observed that decrease in the injection timing results in increase of particulate average size. Bohl investigated that when the density of the fuel is lowest, the impact in spray penetration depth is shorter and the cone angle is considered as highest , amplifying the fuel air mixture. Zhu investigated the effect Of ambient pressure and injection pressure with laser technique for fluorescence and observed that mass flow rate can be increased with injection pressure increased. Moon studied with X-ray technique is used to investigate the influence of pressure on dynamic field spray and observed increased spray velocity could be achieved with increase in injection pressure.

Desantes studied the Velocity of spray tip penetration and reacting fuel spray is expanded by using various hydrocarbon fuels(n-heptane, 80% of n-heptane, n- dodecaneblend of 20% isooctane). They observed that velocity of spray tip in the influence of reacting conditions are exceeded than examined in inert condition. Park investigated the emulsified fuel of diesel and water in the combustion chamber of diesel and observed the spray characteristics of the fuel. At room temperature, To shortened the spray penetration length by enhancing the water content in the emulsified fuel. At 4MPa of pressure and room temperature, the wetting probability of water mineral emulsified fuel is higher than the mineral fuel. Temperature of the combustion chamber is always higher than the ambient temperature of the room. so the significance of the wall for wetting in the actual practice condition is of minor importance. He also observed that in the constant volume combustion spray chamber using diesel fuel, angle of spray decreases with injection from extreme values of the injection at the beginning. Due to reduction of the effect of interaction with gas and fuel evaporation process in the combustion chamber, fuel spray tip penetration is actually increased. Jia studied the effect on the penetration length by injection pressure and their observation showed that penetration could be increased with higher injection but there will be no difference in spray cone angle. Some researchers investigated the effect of back pressure on spray parameters. Their results showed that back pressure influences the spray characteristics such as shorter the spray tip penetration and other factors are also affected. The main purpose of this study is the Macroscopic spray parameters studies using constant volume combustion chambers with diesel, bio-diesel, blend of diesel and Bio-diesel. There is vast scope for this investigation for the betterment of engine design because spray parameters are a cruel part for analysis of combustion chambers. CI Engine will have well functionality when the various spray parameters are enhanced. Combustion of fuel need to be enhanced for better

outcome of the engine and have higher efficiency. Combustion in the combustion chamber is influenced by the characteristics of spray parameters. When the fuel will be combusted completely then the wastage of the fuel and harmful emissions can be controlled and it is most influenced by spray parameters in the CI engine. So macroscopic and microscopic spray parameters need to be enhanced in future for better performance of CI engine.

Experimental setup:

★ Apparatus and procedures for experiment

High pressure and temperature situations are required in the study of macroscopic spray characteristics in a constant volume chamber that is significantly similar to a real Compression ignition IC engine. It requires a constant volume combustion chamber, high pressure spray fuel injection system, and photography system which need to be high speed. Photography systems are collections of high - speed cameras , laser light sources that need to be continuous, data

acquisition and processing.

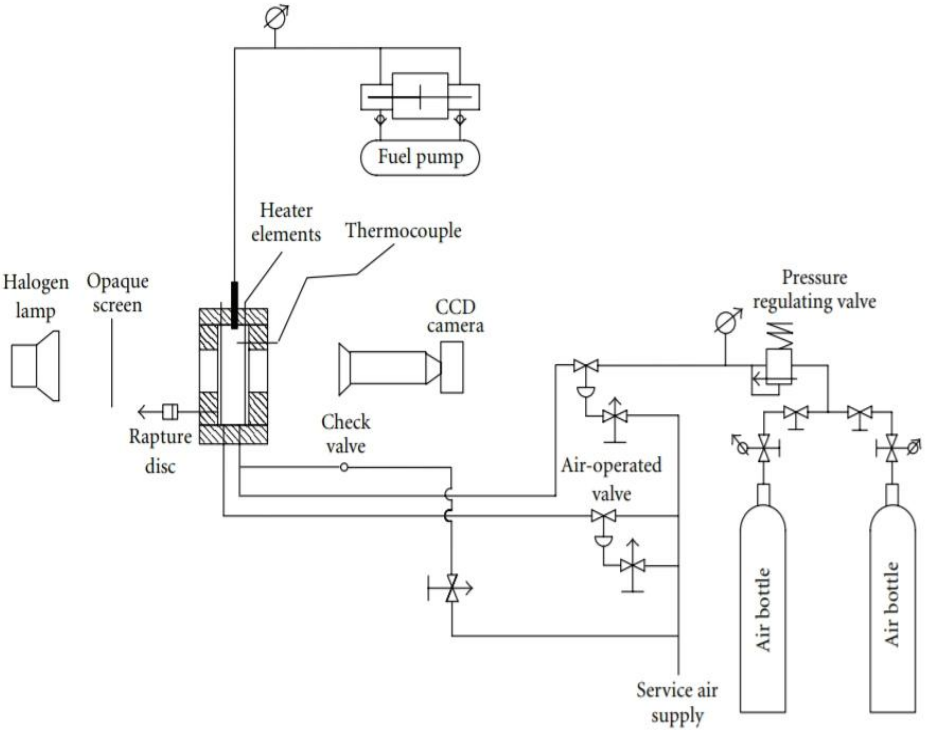


Fig3- schematic view of the experiment setup

The camera required for capturing and recording spray fuel images. Attributes of high pressure spray fuel injection system are air compressor, fuel injector, small diameter injection nozzle single holed , pressure need to be created in the chamber also so a source need for ambient pressure. A common rail system is also needed to supply high pressure fuel through the nozzle. Constant volume spray combustion chamber needs to be made in a

manner to withstand the high pressure of about 4 MPa and fuel is injected into the chamber from the injector. On the other hand at the top of the chamber a safety valve , fuel injector and pressure gauge is placed. For recording the image and measuring optical calculation four optical round windows are installed with the assistance of flanges on the constant volume spray

combustion chamber. N_2 Is used for providing ambient pressure. Injector energizer is operated with a small diameter nozzle (0.3mm) and about 700 microseconds injection duration in pulsed. High speed camera and laser light beam are situated perpendicular to each other. To achieve polarized light from the laser light is obtained when the laser light passes through the axis of the spray fuel nozzle. When the experiment starts, the polarized light proceeds through the fuel spray nozzle droplet and by high speed camera captures the lightened area of the fuel coming from the nozzle. From the starting and ending of the first visible fuel droplet picture the time starts and ends respectively positioned at the injector hole. Within a few seconds the whole injection process was recorded for the start and end of one absolute injection process. All the significant spray parameters data captured and recorded were prepared in the computer for the analysis of the image processing.

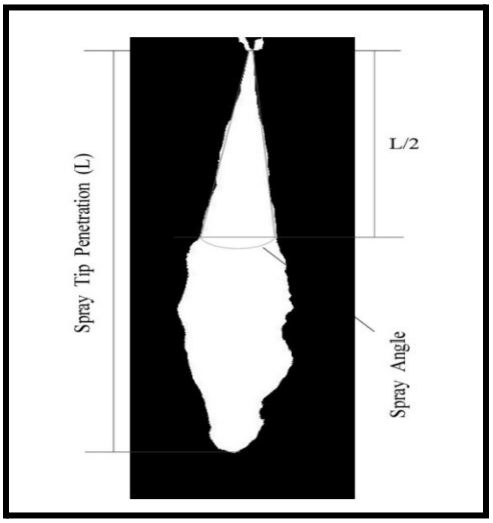
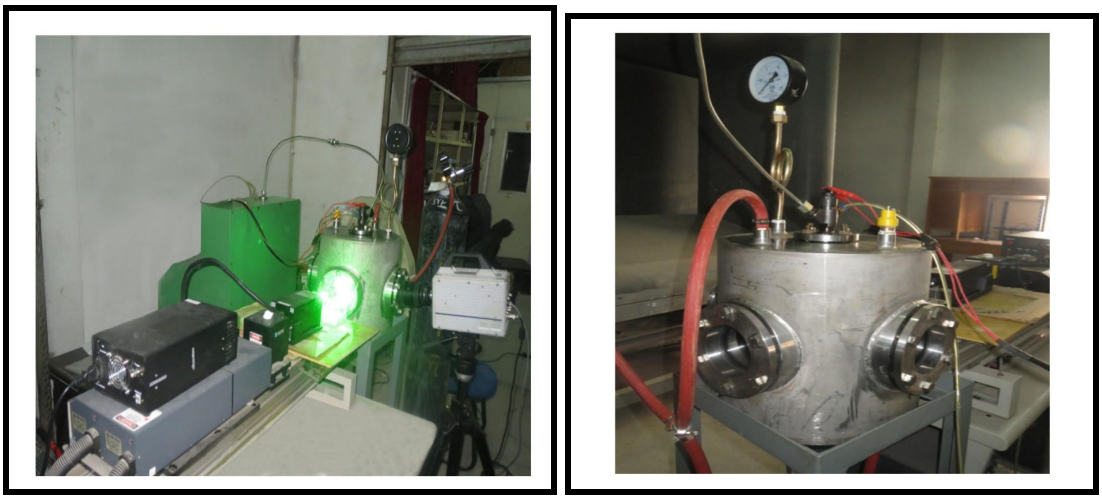


Fig4- spray tip penetration and spray cone angle.



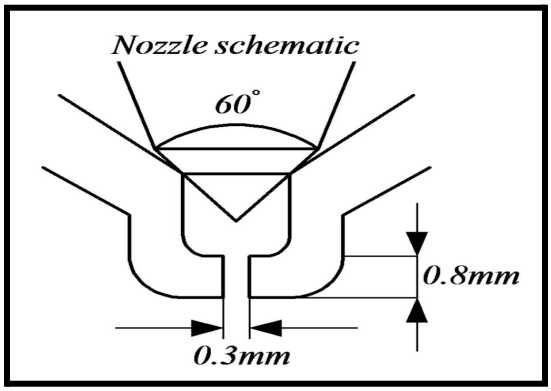


Figure 5(i)photography setup(high speed camera);(ii) constant volume combustion chamber; (iii) fuel nozzle (schematic).

★ **Fuel situation and working**

For the experiment in the observation of macroscopic spray characteristics various fuels are used for examination of spray parameters that are diesel oil , biodiesel and drainage fuel. The fuel ismixed with the diesel in many ratios and those ratios are BD(0,20,50,80,100) volume by volume in mixture of bio-diesel with diesel. The meaning of BD0 is that 0% of bio-diesel is mixed with 100% of diesel likewise for BD20 , 20% of bio-diesel is mixed with 100% diesel and further for the rest of BD 50 (50% bio-diesel in 50% diesel), BD 80(80% bio-diesel in 20% diesel)and BD 100(100% bio-diesel in 0%

diesel) respectively. A magnetic stirrer is used for making the mixer homogeneous of bio-diesel and diesel that is done for 10 minutes. The mixture is stored to examine the physical stability and solubility of the fuel mixture in a glass. Precipitation is not observed in any of the mixture.

Table1- The physical properties of diesel and biodiesel are:

Properties (40°C)	**Diesel**	**Bio-diesel**
Density (g/ml)	0.84	0.87
Kinetic viscosity (mm^2/s)	2.46	4.19
Surface tension (mN/m)	24.5	32.4
Cold filter plugging point (°C)	4	10
Flash point temperature (°C)	75	165
Cetane number (CN)	47.7	49

With an increment of 10 MPa, the injection pressure is substituted from 60 to 100 MPa. And the increment in ambient pressure is 0.2MPa and varies from 0.1MPa to 0.9MPa.

Table2- The condition for experiment and physical measurements are:

Injection system	Common rail fuel injection system
Fuel	Diesel, bio-diesel, bio-diesel-diesel mix (BD20,BD50,BD80)
Nozzle type	Mini sac nozzle
Hole number	Single hole

Diameter of nozzles	0.3mm
Injection pressure (MPa)	60,70,80,90,100
Pulse injection duration(micro sec)	700
Ambient pressure(MPa)	0.1,0.3,0.5,0.7,0.9
Ambient temperature(K)	293

Table3 Quantity of fuel in each injection for separate injection pressure in the presence of ambient pressure 0.1MPa are :

Injection pressure (MPa)	**Fuel injection qualities (mg/injection)**				
	BD0	**BD20**	**BD50**	**BD80**	**BD100**
60	**17.06**	**16.78**	**16.615**	**16.45**	**16.23**
70	**42.50**	**41.94**	**41.54**	**41.14**	**40.58**
80	**68.04**	**67.11**	**66.46**	**65.81**	**64.93**
90	**93.54**	**92.28**	**91.38**	**90.49**	**89.29**
100	**119.03**	**117.44**	**116.30**	**115.16**	**113.64**

Reference for the tables above- Hongzhan Xie, Lanbo Song, Yizhi Xie, Dong Pi, Chunyu Shao and Qizhao Lin- An Experimental Study on the Macroscopic Spray characteristics of Biodiesel and Diesel in a Constant Volume Chamber (https://www.researchgate.net › 2822...

(PDF) An Experimental Study on the Macroscopic Spray …)

Result and discussion:

Spray Tip Penetration: The distance between farthest axial location of spray boundary and the tip of the nozzle is known as Spray Tip Penetration. A value of threshold of light intensity should be selected to demarcate the spray boundary. Hence the spray tip penetration and spray angle will be measured. As we proceed, the tip penetration keeps on increasing after being injected by the injector with a speed growth trend during the early injection stage. It is followed by a small and slow smoothing process. Higher injection pressure leads to an increase in penetration, leading to a bigger tip penetration for the given time elapsed. There were important differences between the values of penetration under different pressure of injection. An increase in penetration is caused by higher injection pressure. That leads to a longer tip penetration for the same given time. The density of air in the chamber of constant volume increases with increase in ambient pressure. Ixen result in more shear resistance provided to the droplet velocity near the tip of the spray. That leads to the decrease in spray tip penetration. Similar pattern is observed of spray tip penetration to the blend ratio increase. However this is a very small change in ambient pressure. Hence, there was a slight trend in ambient pressure of 0.1MPa and 0.3 MPa where BD100 showed a shorter tip penetration compared to other fuels while BD20 had a longer one. The shorter penetration of BD100 is due to decrease in velocity of biodiesel which is exiting from the nozzle surface. It may be caused by

relative viscosity and surface tension of biodiesel.

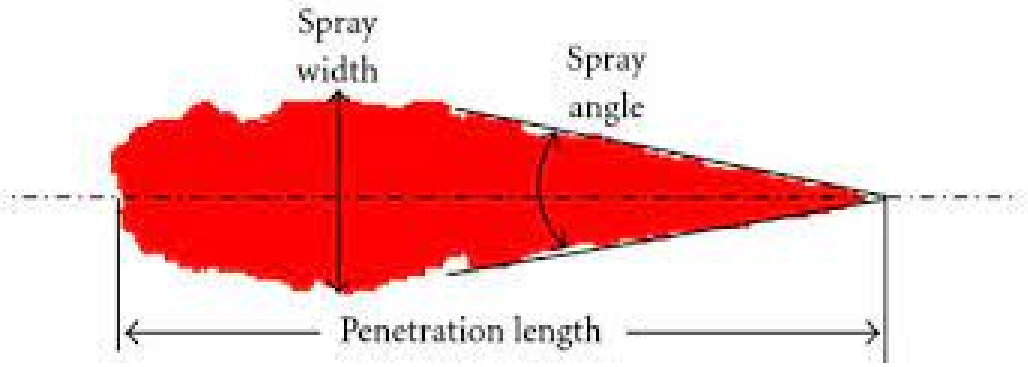
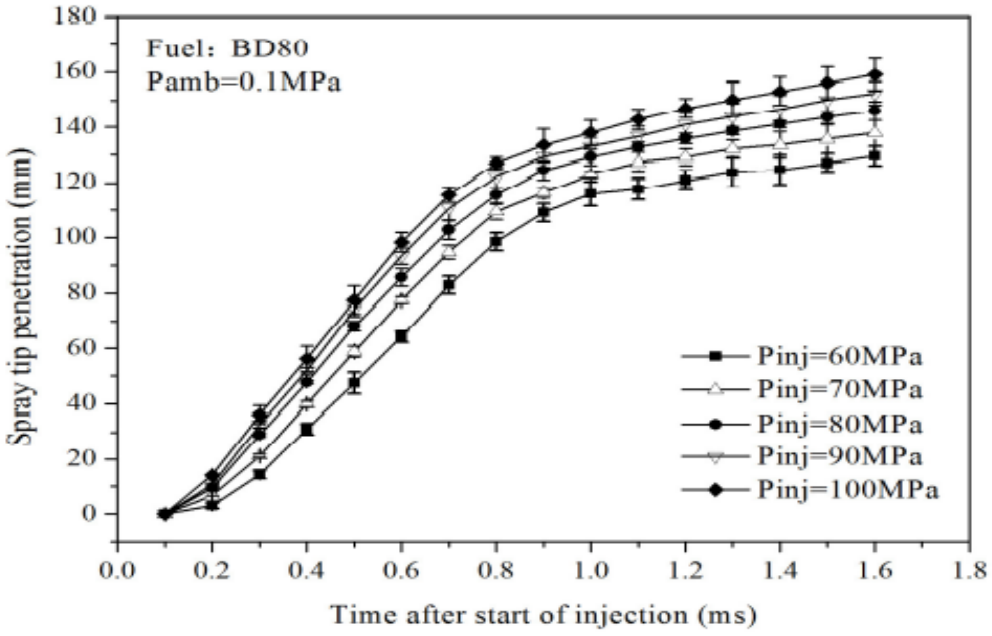
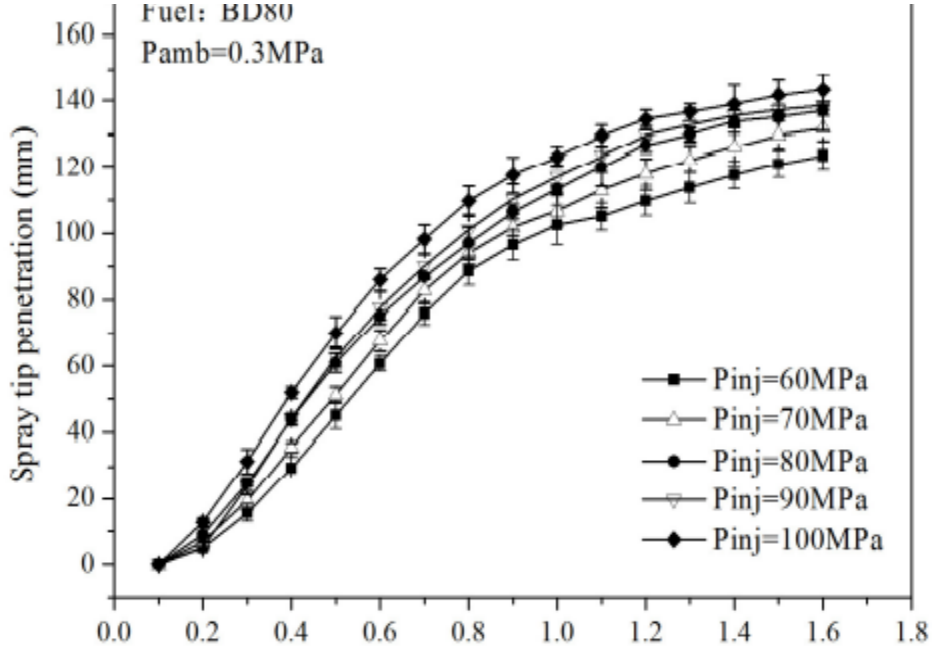


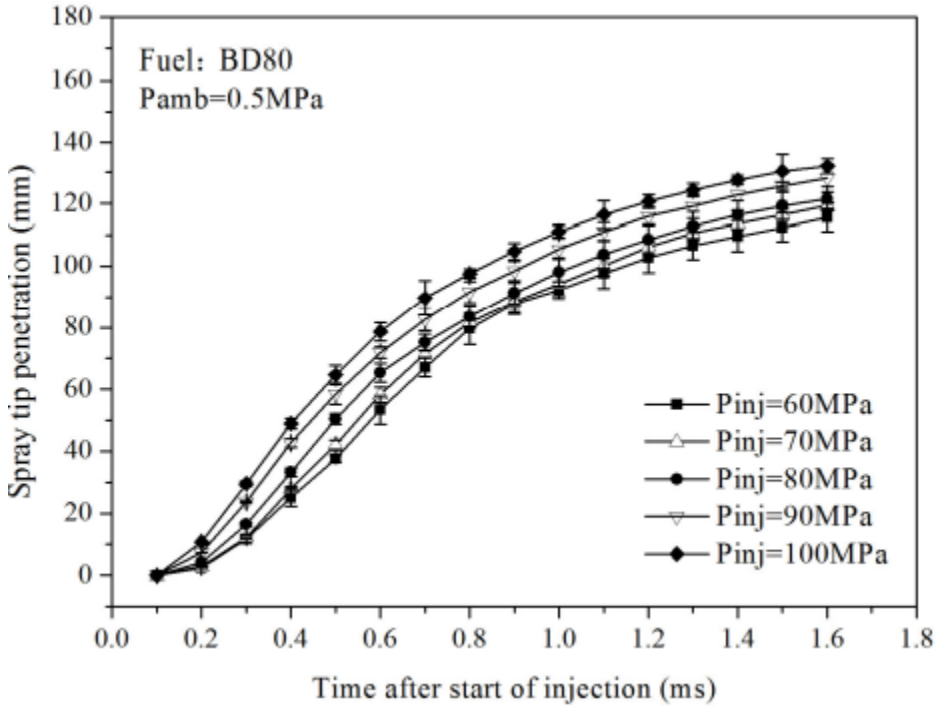
Fig6- penetration length ,spray width,spray angle



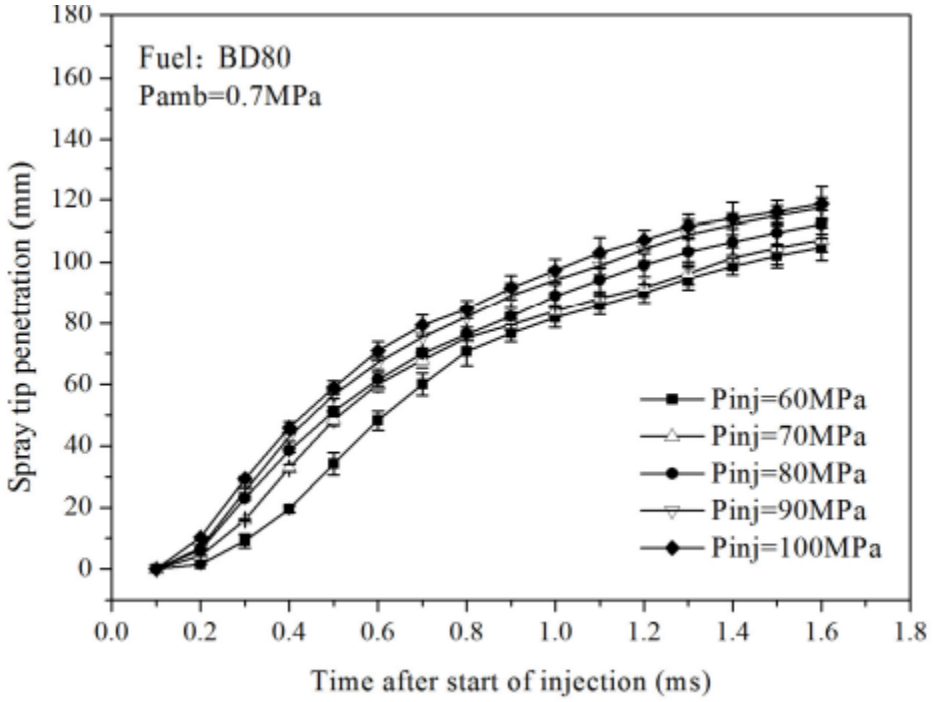
Graph1. Time after start of injection vs spray tip penetration



Graph2- Time after start of injection vs spray tip penetration



Graph3- Time after start of injection vs spray tip penetration



Graph5: Time after start of injection vs spray tip penetration

Spray Angle : It is defined as the angle between the line which is tangent which describes the approximate spray boundaries at half and to the tip of penetration from the orifice of discharge. The spray angle is one of the important parameters for the spray quality. As it describes the development of spray in the radial direction. Since the spray angle is quite stable hence the angle of spray is same as average angle. The increase in injection pressure strengthened the dispersion of spray and secondary pulverization and it promoted the spray process in both axial as well as in radial direction. Since the spray angle remains a bit stable hence the pattern of spray angle is same as average angle.

Average Spray Angle : It can be defined as the average of all angles that are found from the images during a pulsating injection. When the injection pressure increases the average angle increases slightly with it but it increases significantly with ambient pressure. When the injection pressure is increased it helps to provide better spray dispersion and also a secondary pulverization that results in promotion of the spray process in both direction radial as well as axial. But it increases faster in radial direction and results in increase of the spray angle. In the constant volume chamber, the increase in pressure results in higher ambient density which makes the resistance of fuel spray better. Hence the development of spray in the axial direction is stopped, that led the increase in mass flow to go in radial direction results in remarkable increase in spray angle.

Spray Area: The area which is covered by spray in the images is known as Spray Area. These can be used to reflect the quality of air-fuel mixing. The area that is obtained from the sum of total effective pixels and the area of spray. The abscissa axis is set as tip penetration of spray instead of time for the main motive is elimination of influence on spray area of injection time. The area of spray draws as exponential curves with the tip penetration of spray.

Summary:

Macroscopic spray parameters studies using a constant volume combustion chamber was the objective of this term paper. There are two main categories for investigation of spray behavior that are microscopic and macroscopic. Macroscopic spray parameters are spray

tip penetration, spray cone angle, spray area while microscopic spray parameters are spray droplet velocity at penetration, droplet size distribution. At different ambient pressure and injection pressure in the constant volume spray combustion chamber, macroscopic spray characteristics are experimental examined of diesel and biodiesel with BD(0,20,50,80,100) mixed with diesel. High speed photography system is used for the image analysis of spray that are spray tip penetration, spray cone angle, spray area. Constant volume spray combustion chamber needs to be made in a manner to withstand the high pressure of about 4 MPa and fuel is injected. Small diameter spray (0.3mm) and at 700 microseconds fuel injection system is required in a constant volume chamber.

With the experimental data , here are following observations :

1. The spray area increases continuously with the increase in tip penetration of spray.
2. With the increasing blend ratio the spray tip penetration gave variation.But due to this the spray spray angle and average angle reduced and the spray shape became small.
3. Pressure ambient increased the eak average tip velocity and spray tip penetration decreased.
4. The increase in the pressure of injection leads to the spray tip penetration, spray area, peak of average tip velocity and spray volume increased.
5. As spray tip penetration increases the spray volume also increases.

6. The main properties that inhibit the breakup of a jet of liquid and atomization are viscosity, spray characteristics and surface tension.
7. An average angle we get from other fuels but from hundred percent diesel we get a larger spray angle.

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