Master's thesis

GCI 조건에서 정적연소기를 이용한 가솔린 바이오디젤 혼합의 분무 및 연소 특성에 관한 연구

An Experiment Study on Spray and Combustion Characteristics of Gasoline-Biodiesel Blends under GCI Conditions in a Constant Volume Combustion Chamber

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A Dissertation

Submitted to
the Graduate School of University of Ulsan
In partial Fulfillment of the Requirements
for the Degree of

Master of Science

By

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The Graduate School of
University of Ulsan
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Dec. 2020

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Abstract

An Experiment Study on Spray and Combustion Characteristics of Gasoline-Biodiesel Blends under GCI Conditions in a Constant Volume Combustion Chamber

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This paper investigates the physical properties of spray development and combustion characteristics using the gasoline - biodiesel blend in the Gasoline compression ignition (GCI) engines simulated using the Constant volume combustion chamber (CVCC). There are few studies on the spray and combustion characteristics of ignition delay of gasoline and biodiesel blended by optical investigation. In this work, we performed a comprehensive study focused on the spray characteristics and ignition delay of the GB blended under a wide range of experimental conditions simulating engine operating conditions. Gasoline (90%)-biodiesel (10%) blended, gasoline (80%)-biodiesel (20%) Blended and pure gasoline were used as fuel in this study. Spray characteristics including spray development, spray cone angle and spray penetration length were investigation, and the results are in line with the trend of the previous studies. The results are evaluated based on images analyzed from the spraying process under injection pressure ranging from 400 to 900 bar. At same injection pressure and during the same injection duration, GB has spray impingement faster than gasoline. In addition, according to the spray penetration length experimental results can be obtained that when the injection pressure increase, the time of spray impingement is shortened. Other parameters that are essential factors influencing ignition delay, such as ambient gas density, and ambient temperature, were also investigated. These

results provide data support for the optimization and improvement of the combustion process of GB blended fuel under GCI engine conditions and lay the foundation for application to the next generation of engines.

Acknowledgement

I would like to express my unfeigned thanks to my respected supervisor Prof. Lim Ocktaeck for his continuous support in every possible way. His fruitful comments during our research progress meeting help me a lot to prepare my experimental facility on time. I am always thankful to him for providing a well-equipped experimental laboratory with a highly enjoyable working environment. His motivation, immense knowledge and continuous guidance encouraged me all the time for amalgamating my total research work in this thesis paper.

Besides my advisor, I am gratefully obligated to the rest of my thesis committee: Prof. Sangwook Lee and Prof. Yoon Ho Lee for their strenuous efforts to go through my thesis. Also, their insightful comments and encouragement on my thesis presentation motivate me to widen my research area.

An exceptional thanks to Mr. Nguyen Ho Xuan Duy, Ph.D. candidate who advise and supports me a lot during my experimental setup preparation. Moreover, I would like to thank my fellow lab in Smart Powertrain Laboratory for their friendship and support. I am very much grateful to the University of Ulsan for giving me such an excellent research environment and financial support.

Many special thanks to my beloved father and mother, thank you for your consistent understanding and support. Last but not the least, I would like to thank my extended family members and close friends for their love, support and understanding.

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Abbreviation and nomenclatures

Ar: Argon

C_2H_2: Acetylene

N_2: Nitrogen

O_2: Oxygen

CI: Compression ignition

SI: Spark ignition

CVCC: Constant volume combustion chamber

GCI: Gasoline compression ignition

GDCI: Gasoline direct-injection compression ignition

ID: Ignition delay

LTC: Low-temperature combustion

NI: National Instruments

NOx: Nitrogen oxide

PM: Particulate matter

PRR: Pressure rise rate

HC: Hydrocarbons

Contents

Chapter 1. Introduction

1.1 Background

Energy is the basic guarantee of today's social development and the basic driving force of social and economic growth. At the same time, energy is also one of the important material bases for the survival and development of human society. At present, fossil energy is still the main energy in today's world. Fossil energy mainly includes oil, coal, natural gas and so on. Let's take China as an example. China is a country rich in oil, gas and coal. In total terms, China is rich in fossil energy reserves. China's proven and recoverable oil reserves account for about 2.3 percent of the world's reserves, natural gas for about 09 percent and coal for about 11.6 percent. Yet China's per capita reserves of fossil fuels are still lower than the world's per capita reserves. With the rapid growth of China's economy, the demand for energy also increases sharply, and the security of energy supply has become one of the important factors to ensure the sustainable and stable development of China's economy. At present, China's most prominent energy problems are insufficient domestic oil production and reserves and a high dependence on overseas oil. At present, China's automobile industry plays an important role in petroleum consumption [1]. In addition to some petroleum used as chemical raw materials, the petroleum consumption of transportation industry accounts for about 50% of the total petroleum consumption.

Since the automobile was born in the late 19th century, the development history of the automobile industry has been more than 100 years. From the 1990s, China's automobile industry began to develop rapidly. After entering this century, China's automobile industry has entered a stage of rapid development. In 2010, China's total automobile sales volume reached 18.06 million units, with a year-on-year growth of 32.37%, and its output reached 18.2647 million units, with a year-on-year growth of 32.44%, ranking first in the world for two consecutive years. It is predicted that the number of cars in China will exceed 200 million by 2020, and the demand for vehicle fuel will also increase rapidly.

With the blowout development of the automobile industry, China is facing the double severe pressure of energy demand and environmental protection. At present, most of the fuel used in cars is gasoline and diesel derived from petroleum. On the one hand, China's dependence on foreign oil imports continues to increase. On the other hand, many Chinese cities in recent years have frequently experienced severe air pollution. Exhaust fumes from cars have become the primary cause of air pollution in cities.

Nitrogen oxide is one of the main pollution sources of urban air. At the same time, the emission of particulate matter in automobile exhaust, especially fine particulate matter, increases rapidly, which reduces the visibility of urban air.In recent years, China's regional environmental pollution has begun to emerge, especially in big cities, the exhaust emissions from car engines have seriously polluted the atmospheric environment. Taking the two largest cities in China as an example, in the period of non-heating in Beijing, the CO, HC and NOx emitted by automobiles in the urban area respectively account for 60%, 86.8% and 54.7% of the total emission. CO, HC and NOx emissions from automobiles in Shanghai have accounted for 86%, 90% and 56% of the total emissions respectively. From the above example, we can clearly see the seriousness of urban automobile exhaust pollution. On the one hand, exhaust pollution from automobile engines will worsen the human living environment and harm human thermal health; on the other hand, the emission level of automobile engines will also have an important impact on the sales and competitiveness of engines and automobiles.

To sum up, faced with the energy crisis, environmental pollution and stricter automobile emission regulations, the automobile started. The energy conservation and emission reduction of machinery has become a hot issue concerned by the government, automobile enterprises and academia. Improving fuel economy, reducing exhaust pollution and developing new energy have become the top priorities in the current internal combustion engine industry.

Clean alternative fuels and efficient and low pollution combustion methods have always been one of the hotspots in internal combustion engines. For the whole automobile industry, the research of clean alternative fuel has a broad development prospect. Large-scale deployment of clean alternative fuels would not only get rid of the limitation of oil reserves, but also make it easier to implement more stringent emission regulations, thus gaining a place in the fierce market competition. Therefore, the study of clean alternative fuels has extremely important background and far-reaching social and economic effects for alleviating energy crisis and reducing air pollution.

1.2 Objectives of the study

The objectives of this study are as follows:

(1) The main purpose of this research is to improve the spray and combustion characteristics of the GCI engine fueled by a gasoline-biodiesel blend.

(2) The effects of different injection pressures and ambient gas density in gasoline-biodiesel blended fuel on spray development, spray penetration length and spray angle were experimentally studied.

(3) The effects of different injection pressure, ambient gas temperature and ambient gas density on the ignition delay of gasoline-biodiesel blended fuel were experimentally studied.e

Chapter 2.literature Review

2.1 GCI engine

In terms of thermodynamics, CI engines are similar to SI engines. The cycles of these two engines include air intake, compression, heating, expansion, and exhaust, but there are still some differences. In CI ignition engines, air is usually compressed during the intake process, and its compression ratio is between 12 and 20, so the temperature of the air becomes very high during the combustion process. In a compression ignition engine, the air is first compressed to a high temperature with a high compression ratio, and then liquid fuel is injected, and the high temperature of the air is used to ignite the fuel. Because the CI engine has a very high compression ratio, it has the highest thermal efficiency among all internal combustion engines and external combustion engines. However, CI engines are generally diesel engines that use diesel as fuel. Due to the high cetane number of diesel, the automatic ignition speed of diesel is very fast, resulting in high soot emissions and high nitrogen oxide emissions. Under the background of increasingly stringent environmental protection requirements in countries around the world, it seems particularly worrying.

CI engines need to control PM and NOx. Generally, after-treatment systems similar to SCR systems are used to control emission problems, which also affects the economic performance of CI engines. In addition, the occurrence of ignition knock limits the upper compression ratio, thereby limiting the efficiency of SI engines that use gasoline as fuel. In this case, GCI engine technology has aroused people's interest.

GCI is a combustion strategy that belongs to low-temperature combustion. GCI engine is CI engine fueled with low reactivity, high octane number ,and high volatility fuel, such as gasoline[1-5]. In the CI engine, because the fuel is directly injected into the cylinder, and the fuel and air can be mixed quickly, and there is no restriction on throttling, the compression ratio is much higher than that of the SI engine. This allows CI engines and GCI engines to have good efficiency. Compared with ordinary diesel combustion, the low-temperature GCI combustion strategy has quite a good advantage in terms of emissions. Because gasoline is used as fuel, soot emissions can be lower; because of low-temperature combustion, nitrogen oxide emissions can reach a lower level. Another reason why low nitrogen oxide emissions can be achieved is the stratified combustion of fuel, which makes flame propagation basically non-existent in GCI [6]. Coupled with pure compression combustion without spark plug ignition, flame propagation is prevented, and low temperature and low nitrogen oxide emissions are achieved. In the research of many scholars on this subject, there are many names for this combustion strategy, such as gasoline direct injection compression ignition and gasoline direct compression ignition. In this experiment, we call it gasoline compression ignition, or GCI.

In addition to certain advantages in terms of emissions, GCI engines perform well in other areas. First of all, because it uses gasoline as a fuel, which is currently widely used by the public, there is no need to worry about fuel restrictions when it is promoted and applied. Secondly, more gasoline consumption can balance the demand for gasoline and diesel in many countries and reduce greenhouse gas emissions, thereby contributing to the reduction of global warming. Furthermore, the application of gasoline as a fuel in the engine does not require modification of the engine, which reduces the resistance to popularization and application. Finally, the compression ratio of CI engines is much higher than that of SI engines, which provides higher efficiency and economical and practical capabilities.

2.1.1Why choose CI engine?

In this study we used GCI combustion mode. Here we first talk about why CI engines are used instead of SI engines.

We can know from some studies that the efficiency of diesel engines is much higher than that of gasoline engines [7]. This is because gasoline engines can only operate at a low compression ratio of 8 to 11, which leads to the efficiency of gasoline engines. It is much lower, which is a major limitation for gasoline engines.

However, compared with the SI engine, the CI engine does not produce knock under high load, so it can run better at a higher compression ratio. Secondly, the operation of the CI engine to adjust the load can be controlled by reducing the amount of fuel injected, rather than by managing the air quality in the combustion chamber. The last reason is that the performance of the CI engine is closer to an ideal cycle. This is because when the CI engine is compressed, only air is compressed, not the mixture of air and fuel .

Despite these obvious advantages, CI engines still have high emission problems that cannot be ignored ， Particulate matter (PM) formed mainly in fuel-rich areas and as a result of high-temperature combustion produce Nitrogen oxides (NOx) [8]In contrast, SI engines using gasoline as fuel can achieve low emissions of nitrogen oxides and particulate matter, but the undesirable point is relatively low engine efficiency.

In order to meet the more stringent emission requirements, researchers have to constantly look for new solutions to enable engines to achieve clean emissions while maintaining performance and power[9].Advanced technologies such as follow-on systems or reprocessing systems are being rolled out to address and control these engine emissions. However, these technologies are too complex and expensive, and even reduce the major advantages of CI engines. Therefore, in the long run, finding new combustion concepts and diversified combustion strategies is a feasible way to reduce the emission of engine pollutants. So, researchers have had to focus on the sources of pollution - fossil fuels and their alternatives.

In recent years, a variety of new combustion strategies have been proposed, including LTC. LTC is a famous combustion concept in CI engines, which reduces combustion temperature by enhancing air-fuel mixing and intake dilution, making it possible to reduce nitrogen oxide and particulate matter (PM)[10] . Gasoline compression ignition (GCI) is a new combustion concept in the broad classification of low-temperature combustion. This new ignition method is to burn hydrocarbon fuels with high volatility and low sensitivity to spontaneous combustion under high pressure [11-16]. The most promising LTC approach is to add a fuel with higher vaporization and a lower cetane number，such as gasoline, to a CI engine in GCI mode, as this concept can produce high thermal efficiency and low emission characteristics[5, 17-19]. The higher-octane number of gasoline gives it greater resistance to autoignition combustion, which gives the air-fuel more mixing time before ignition and improves the fuel pre-mixing process. On the other hand, gasoline is also highly volatile, which helps reduce the formation of combustion-rich regions. It is the combined effect of these two properties that lead to a reduction in PM and NOx [18].

Therefore, because of these objective reasons, we have to think about a new combustion strategy, so that it can not only have the same excellent efficiency as the CI engine, but also have the same emission reduction characteristics as the SI engine[2]. This is because of people's thinking, GCI engine came into being.

Nowadays, the GCI engine is considered to be the most promising method, because the use of this concept can produce high thermal efficiency and low emission behavior.

2.1.2Advantages of GCI engine

Gasoline with high volatility and long ignition delay can make the air and fuel homogeneity mixed, which allows the GCI engine to run at low fuel injection pressure. Therefore, low-pressure fuel pumps can be equipped on models using GCI combustion strategy, which greatly reduces the cost and complexity of the fuel injection system. The lower fuel injection pressure improves the GCI combustion stability under partial load, which will greatly help reduce CO and HC emissions. By controlling the fuel stratification level, it is possible to avoid the occurrence of fuel over-mixing and over-dipping of the GCI engine, which will help the smooth operation of the GCI engine under high load.

GCI technology helps to reduce pumping losses and can operate under high compression ratio and large throttle conditions, so as to achieve efficiency equivalent to that of traditional diesel engines. Diesel engines use pilot fuel injection to reduce combustion noise under low load conditions, but it will reduce engine efficiency and increase flue gas concentration. But this problem can be solved with fuel, which will provide a longer ignition delay to make up for the previous loss.

It is worth noting that the high HC and CO emissions of GCI engines cannot be ignored and must be controlled by using exhaust gas aftertreatment devices. The focus of the exhaust gas aftertreatment device in the GCI engine is the oxidation of HC and CO, which is much simpler than the control of NOx and PM emissions in a diesel engine, and the required cost is relatively low.

In GCI engines, soot emissions increase as the engine load increases. Even in this case, the emissions of the GCI engine are still much better than that of the CI engine, because the uniformity of the mixture of the GCI engine is much better. In general, compared with modern diesel engines, GCI engines have broader development prospects and better economic performance.

2.1.3Challenges for GCI engine

Under normal circumstances, the cetane number（CN）of gasoline that can be purchased in the market is usually less than about 15. Such a low cetane number makes it difficult for GCI engines to auto-ignite under low load and cold start conditions. Moreover, the extremely low CN significantly prolongs the ignition delay, so the gasoline injection time must be advanced, and the injection should be started early in the compression stroke. Under such conditions, the temperature and pressure in the cylinder are relatively low, and it is difficult to provide the required ambient conditions for ignition, which makes the ignition phenomenon even more difficult.

Therefore, before applying GCI engine technology to commercial vehicles, we need to solve the related problems as shown in Figure2.1.3.1 one by one. However, almost all problems can be solved by optimizing combustion, and it is much simpler than diesel engines. Because of this, the implementation of GCI technology will benefit the reforms of the industry and the automotive industry.

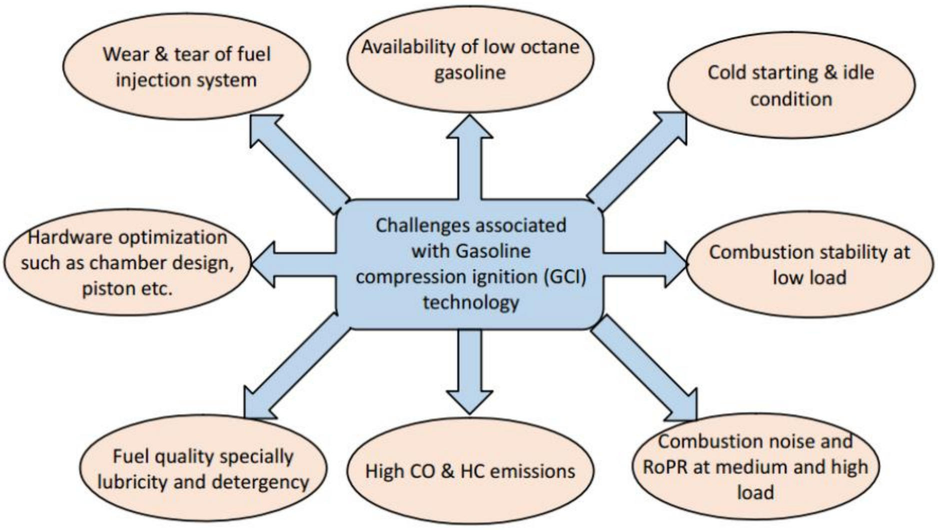

Figure 2.1.3.1: Challenges for GCI engine technology

GCI offers an efficient and eco-friendly combustion technique at a reasonable cost. However, in order to commercialize GCI vehicles in the current market, significant efforts are needed in the following direction:

(1) GCI engines need to improve combustion stability at part loads. GCI engine fuelled with conventional gasoline has poor combustion stability at low loads due to higher ignition delay, lower cylinder pressure and temperature. Operating parameters such as fuel injection strategy, EGR rate, intake pressure and temperature, and piston bowl geometry need to be optimized for effective control of combustion at low loads. Strategies like advanced fuel injection, multiple-injection, low octane fuel usage, negative valve overlap, intake air heating, and EGR usage effectively addresses this issue.

(2) Combustion control at cold start and idle condition is still an issue with GCI technology. In-cylinder environment at this condition (i.e. low pressure and temperature) is not favorable to auto-ignition of low reactive fuels. To over- come this problem, a suitable combination of fuel ignition quality, advanced injection timing, preheating of intake air, EGR, and NVO can be employed.

(3) Optimized injection strategies would be needed to control high noise and high rate of pressure rise at high engine loads.

(4) GCI engines emit lower NOx and PM emissions but higher HC and CO emissions than a diesel engine. Therefore development of an exhaust gas after- treatment system consisting of efficient oxidation catalysts to control HC and CO emissions at low exhaust gas temperature is essential.

(5) Fuel injector (with optimum hole size and number), fuel pump, piston geometry, and inlet port are some of the crucial parts, that are needed to be designed properly for effective implementation of GCI technique. Needed to develop suitable additives to improve gasoline lubricity without affecting engine tailpipe emissions.

In addition to the points mentioned above, we need think about the efforts should be directed to wards the reduction of overall system complexity, and costs, while ensuring easy adaptability of GCI technique to existing CI engines.

2.1.4 Research and current situation of GCI

GCI has made researchers from all over the world very interested, and various research on the concept of GCI have followed. Kalghatgi et al. studied four fuels including diesel and gasoline, and used two different EGR conditions, and obtained the influence of fuel quality on its self-combustion characteristics[2].

The results of Kalghatgi et al. show that it is possible to achieve low NOx emissions, low smoke and dust emissions and high IMEP by using the auto-ignition resistance of fuels with both high octane number and low cetane number performance[2].

Kalghatgi first studied the compression ignition of gasoline. In his research, he made full use of the two characteristics of petroleum gasoline fuel, namely high steam characteristics and high resistance to spontaneous combustion, and then combined with CI engine The advantages of high compression ratio, while achieving almost zero emissions and excellent engine efficiency[20].

According to the research of Cracknell et al.using the GCI combustion strategy, that is, the method of using gasoline to provide fuel for the CI engine, has the following advantages: First of all, as we mentioned earlier, the CI engine is more efficient than the SI/gasoline engine. High, and it is possible to use a wider range of fuels[21]. In addition, the GCI combustion concept uses gasoline that is easily available on the market. Once the concept is promoted, it can be quickly popularized and applied in a short period of time without fuel restrictions.

In another study, Kalghatgi et al. still used the GCI concept, but made some improvements to the GCI concept, and proposed automatic combustion of partially premixed gasoline[20]. The purpose is to make the CI engine work under high load conditions. Can achieve lower smoke and nitrogen oxide emissions. The results show that, compared with all-in-one direct injection, the improved gasoline pilot injection strategy reduces the thermal gravity peak value, making HR to appear retarded with a small cycle variation compared.

Prikhodko et al. did a study on emissions, using a CI engine with diesel mixed fuel in the cylinder. The results show that the dual-fuel RCCI combustion mode can reduce 87% of NOx production and 99% of PM emissions, and the thermal efficiency is 1.7% higher than that of the control group using only diese[22]l. However, compared with the diesel group that uses PCCI combustion, the CO, aldehyde, HC and ketone emissions produced by the dual-fuel RCCI combustion method have greatly increased.

Shi and Reitz used a heavy-duty CI engine in a study, and used a mixture of diesel, gasoline and ethanol (E10) as fuel, and studied the engine's operating conditions under medium and high load conditions[19]. The results of this study show that heavy-duty CI engines using gasoline fuel with an optimized and improved injection system have higher application value than the control group using diesel. There are two reasons for this conclusion. On the one hand, it reduces fuel consumption and saves energy; on the other hand, it is also the most important point because they reduce the emission of smoke and nitrogen oxides.

Ra et al. used the Gasoline Direct Injection Compression Ignition (GDICI) Engine as the experimental object in their research, and used the LTC strategy for research[13]. The experimental results show that due to the high vapor characteristics of gasoline and the lower cetane number, coupled with the reduced combustion temperature due to the use of the EGR strategy, the emissions of NOx and PM have been reduced. GCI fuels can be divided into low-octane fuels and high-octane fuels [23]. High-octane fuel usually refers to petroleum gasoline fuel with an octane number greater than 90. Compared with high-octane fuels, low-octane fuels have many advantages. For example, low-octane fuels have higher auto-ignition capabilities, so they can be used in a larger working range. The common method to obtain low-octane fuel is to mix gasoline and diesel, of course, there are other methods, such as mixing with biodiesel, bioethanol and other cetane improvers[24-27].

2.2 Fuel

Knowing from the name of biodiesel, firstly it is an alternative fuel for diesel, and secondly it is a renewable "green energy."

Biodiesel refers to vegetable oil, such as rapeseed oil, soybean oil, peanut oil, corn oil, cottonseed oil, etc.), fat (such as fish oil, lard, butter, fat, etc.), waste grease or oil with methanol or ethanol by ester conversion of fatty acid methyl ester and ethyl ester.

On the premise of not changing the structure of diesel engines, burning biodiesel can obtain similar power performance and superior emission performance compared with diesel (except NOx emission). In addition, biodiesel and diesel can be mixed and miscible in any proportion. Biodiesel, as an alternative fuel for diesel, has attracted extensive attention from academia and industry.

Large-scale use of biodiesel is of great strategic significance for China's energy security, adjustment of agricultural industrial structure, and comprehensive management of the ecological environment.

Compared with mineral diesel, biodiesel has many advantages[28]:

1. It has good engine low temperature starting performance, and the cold filter plugging point can reach -10℃ without additives.

2. It has good lubrication performance, which can reduce the wear rate of

the fuel injection pump, engine cylinder block, and connecting rod.

3. The flash point is higher than that of mineral diesel, which can be transported, stored and used more safely.

4. The low sulfur content reduces the emissions of sulfur dioxide and sulfide in engine exhaust.

5. It does not contain aromatic alkanes that can cause environmental pollution, so engine exhaust is less harmful to humans when using biodiesel than mineral diesel.

6. The biological decomposition rate is relatively high, which is beneficial to environmental protection.

7. The molecule contains oxygen atoms, which can promote combustion and reduce soot and particulate emissions.

8. The amount of carbon dioxide emitted by combustion is much lower than the amount of carbon dioxide absorbed during plant growth. Therefore, the use of biodiesel will reduce carbon dioxide emissions.

9. Biodiesel is more portable, more accessible and more renewable. As a green and renewable energy, through the efforts of agricultural scientists and biological scientists, the supply of biodiesel will not be exhausted.

10.Biodiesel has a cetane value of more than 100, which makes direct-injection engines better than petroleum-based diesel

There are some main problems facing biodiesel at present:

1.The cost competitiveness of biodiesel cannot be compared with petroleum gasoline or diesel. The cost of biodiesel produced from rapeseed oil is relatively high. Statistics show that the raw material cost accounts for 75% of the production cost of biodiesel. Therefore, the adoption of relatively cheap raw materials and the improvement of conversion efficiency, thus reducing the production cost is a key factor for the large-scale application of biodiesel.

2.Biodiesel is not compatible with petroleum-based engine lubricants.

3.Biodiesel will be corrosive if it comes in contact with brass and copper.

4.The viscosity of biodiesel is 11 to 17 times higher than that of diesel, and because of its greater chemical structure and molecular weight than diesel, the problems of atomization and combustion in the pumping and injector systems of diesel engines are usually more obvious.

5.In the long-term operation of using biodiesel, the adhesion caused by its high viscosity will form deposits inside the syringe and on the ring, and block the filter and pipeline.

6.The current chemical synthesis method to prepare biodiesel has the following disadvantages: complex process, excessive alcohol, the subsequent process must have a corresponding alcohol recovery device, high energy consumption, large equipment input.

7.Unsaturated fatty acids in fat tend to deteriorate at high temperature.

8.Esterification products are difficult to be recovered and the cost is high. The production process has waste lye discharge and so on.

2.2.1 Research and current situation of biodiesel

In the face of energy and environmental problems, in the 1980s, scientists in the United States first proposed the concept of biodiesel, and then scientists in various countries successively carried out research on it. As a result, biodiesel with oil crops as the main raw material and fatty acid methyl ester as the representative component emerged. After that, the United States established a specialized agency ASTM (American Materials and Testing Center) in 1994 to study biodiesel fuel-related standards, and in 1999 tried to promulgate the first biodiesel fuel standard (PS121-1999), and in 2002 and 2003 respectively Amendments were made. In order to promote the development of the biodiesel industry, the US Congress passed the Biodiesel Tax Incentive Act and the Energy Tax Reduction Plan. By the end of September 2008, 176 biodiesel commercial chemical plants were in operation in the United States, with a total capacity of 8.6 million tons/year. At present, this kind of biodiesel is mainly introduced into the automotive market by blending with diesel at a low proportion, with the blending proportion being about 10%-20%. As diesel consumption in the United States is dominated by agricultural machinery and heavy commercial vehicles, more than 100 highway passenger transportation enterprises in the United States have become major consumers of biodiesel fuel.

Europe has a large number of diesel passenger vehicles and the EU countries are relatively short of oil resources, so Europe has become the world's largest biodiesel production and consumption base, consumption total amount of the world biodiesel consumption more than 75%. Different from the current situation in the United States, where soybean is the main raw material of biodiesel, the European Union countries mostly extract biodiesel from rapeseed and follow the EN14214 standard, which was revised based on the German biofuel standard in 1997. European biodiesel bureau statistics show that as early as 2003, European countries biodiesel production has reached 2.1 million tons, ranking the top three countries are Germany, France, and Italy, the output is 48%, 24%, and 20% respectively, the sum of the three for the entire EU biodiesel production of more than 92%. In 2006, EU biodiesel production doubled to 4.9 million tons with a capacity of 6.07 million tons, up 54% from 3.2 million tons in 2005. This figure continued to rise in 2008 and 2009, reaching 7.7 million tons and 8.5 million tons respectively, and the biodiesel market share is planned to reach 20% in 2020.

China's biodiesel industry has also been actively promoted under the support of national policies. The main raw materials used for the production of biodiesel mainly include: rapeseed oil, cottonseed oil, palm oil, castor oil, rice bran oil, pistacia, jatropha, etc. Herbal and woody oils; animal oils such as lard, tallow, and fish oil; waste oils such as water oil and frying oil. As of 20l5, the output is 3.327 million tons/year, and it is planned to be 12 million tons/year in 2020. At present, there are 16 biodiesel processing plants with an annual output of more than 100,000 tons built in China, and more than 150 other small-scale biodiesel manufacturers.

The large-scale production and wide application of fatty acid methyl ester biodiesel are inseparable from its application research on engines. Scholl and Sorenson et al. burned soy-based biodiesel in a direct injection diesel engine[29]. The experimental results show that compared to traditional diesel, when biodiesel is used, changing the nozzle diameter has a greater impact on the engine's power and heat generation rate, and it is in a wider range of working conditions Internal HC and CO emissions are reduced, and there is no significant change in nitrogen oxides. Schumacher and Borgelt et al. applied biodiesel fuel with different blending ratios of 10%, 20%, 30% and 40% to heavy-duty diesel engines respectively[30]. The experimental results showed that with the increase of biodiesel blending ratio, the emission of HC, Co and carbon smoke decreased and that of NOx increased. Postponing the injection time can reduce NO emissions without changing HC, CO, and carbon smoke emissions. Considering the engine emission, power performance, and economy, the best mixing ratio is 20% of the volume fraction of biodiesel.

A large number of tests have proved that biodiesel can significantly reduce HC, CO and soot emissions, but NOx slightly increases[31] . Alfuso et al. found that using rapeseed oil methyl ester on diesel engines increased NOx emissions, reduced HC and CO emissions, and reduced soot [32]. Mei Deqing believes that under the same stable operating conditions, as the blending ratio of biodiesel increases, CO and HC emissions show a linear decline, NOx emissions have increased, and CO2 emissions are basically the same [28]. Zhao Erli analyzed the relationship between NOx emission and EGR rate through simulation and found that NOx emission decreased greatly with the increase of EGR rate, and the reduction of soot emission was small. Yahya et al. used sunflower seed oil methyl ester and diesel respectively on diesel engines and found that CO and HC emissions were lower when methyl ester was used, and particulate matter emissions were reduced [33].

In order to directly apply biodiesel to diesel engines, in addition to engine bench experiments, it is more important to carry out basic research on the visual test of spray combustion to reveal the microscopic spray combustion reaction mechanism for the increase of NOx emissions and raw material costs. CS Lee and SW Park et al. conducted research and analysis on the spray and combustion process of biodiesel and diesel mixed fuel on a common rail diesel engine[34]. The results showed that due to the high viscosity and surface tension of biodiesel, it is mixed with biodiesel. As the ratio increases, the injection rate decreases, the average droplet diameter increases, and the atomization process is relatively weak. The fuel injection penetration distance and fuel injection timing are unchanged from traditional diesel. It is recommended that biodiesel fuel can be used directly without changing the engine hardware system. Pastor et al. studied the distribution of liquid phase penetration in different proportions of mixed fuel, and found that the liquid phase penetration is directly proportional to the proportion of biodiesel in the mixed fuel[35]. Kook et al. used visual diagnosis technology on a high-temperature and high-pressure test bench to compare and analyze the spraying and combustion oxidation process of diesel and biodiesel[36]. The experiment found that the higher the fuel viscosity, the larger the spray cone angle, the shorter the penetration distance and the smaller the flow

Dong Fang, Ding Lingran and others analyzed the lubrication performance of biodiesel from different raw materials, and the biodiesel using soybean oil and palm oil as raw materials had the best effect on enhancing diesel lubrication performance. When the volume fraction of biodiesel is greater than 20%, its lubrication performance is basically the same as that of pure biodiesel. Therefore, the addition of 20% of biodiesel can basically enhance the lubricity of diesel to the best state.

In the past 30 years or so, although extensive research has been carried out on the application of this fatty acid methyl ester biodiesel in diesel engines, which has beneficially promoted the development of the biodiesel industry, more and more studies have also realized that, In addition to the difficulty of NO and high emissions, which has been widely concerned and studied, the first generation of biodiesel is a fatty acid compound, and its chemical structure is significantly different from that of diesel, and its calorific value is relatively low; it is mixed with diesel for trial, and the mixing stability is poor; oxidation stability Poor performance also makes long-term storage prone to deterioration; after long-term use, it will cause corrosion to engine rubber parts; easy oxidation will cause fuel acidification, forming insoluble precipitates that block filters and nozzles. Many of these problems are related to the composition of the oil itself. As a result, it is difficult to fundamentally solve the problem, making the advancement of a generation of biodiesel in the automotive market continue to be hindered.

2.2.2 Biodiesel – gasoline blend

In recent years, as people pay more attention to the GCI combustion mode, researchers have made great progress in experimental and simulation studies in the field of GCI. However, when we want to use gasoline and GCI as the main fuel and combustion mode respectively, there are still many problems to be solved. If we want to enter the practical apply phase of GCI combustion, there is a major problem that we have to face, which is easily be damaged fuel injection systems, especially at high injection pressures[37, 38].This is due to the low viscosity of gasoline. For now, a feasible way to solve this problem in GCI mode is to mix gasoline with other fuels which have high cetane number and high viscosity.

Biodiesel is a good choice. With its high viscosity and high cetane value, it can deal with the problem of vulnerable fuel injection system under high injection pressure, reduce engine maintenance, and improve engine service life. In addition, it contains oxygen atoms, which can promote the combustion of fuel and help reduce the formation of pollution. Moreover, biodiesel can be made from a wide range of raw materials, which can be processed through vegetable oil, animal oil, and even waste oil. Biodiesel is also typical green energy with good environmental protection performance and renewable properties[28].In addition, if you want to mix biodiesel with gasoline, it is also very easy to achieve, only through 2-10 minutes of shaking mixing, can produce a uniform fuel mixture[39].

In general, there is an obvious lack of experimental research on the straight CI engine with gasoline-biodiesel blend fuel, which leads to the limited application of gasoline-biodiesel fuel in the engine field.

To develop the next generation of engines with high efficiency and low emissions, researchers need to find important parameters. The scientific understanding and experiment of fuel injection directly affect the efficient combustion and emission reduction of fuel. The study of spray characteristics and combustion characteristics is the most important part of combustion research. However, under GCI conditions, the spray characteristics and combustion characteristics of different fuels in the engine have not been fully studied.

In recent years, researchers have found that it is a good method to study fuel spray characteristics using constant volume combustion chamber (CVCC) and optical instruments .The purpose of this study was to understand the spray and combustion characteristics of the gasoline - biodiesel (GB) blend under the GCI model use CVCC and provide guidance for further application of GB blend fuel in engines.

In this study, spray and combustion characteristics such as spray penetration length, spray angle, and ignition delay of GB blend fuel are introduced and discussed in this study. In addition, also compared with the spray and combustion characteristics of pure gasoline. At the same time, this study also provides basic data for the simulation research of GB blend fuel, it provides guidance for its practical application, which has important guiding significance for the development of GB hybrid fuel under the GCI model.

2.3 A refinement of previous work

At the Smart Power Train Laboratory at Ulsan University, two predecessors have done part of their research using CVCC, and in my current research, I have studied both spray and combustion properties. Yanuandri found that GB20 had a shorter ignition delay and HC emission in a single cylinder diesel engine, which showed that the blended fuel had great possibility to solve the problem existed in the application of GC I engine.GB05 was investigated experimentally under pilot and main injection strategy and it was found that he presented a better stability of combustion. So, in my research, I chose three fuels and compared the spray and combustion characteristics of each component fuel. In Shubhra's study, he studied the spray characteristics with the spray pressure of 40Mpa as a stage. I think the span of the spray pressure is a little large, and a more detailed study on the impact of the spray pressure is needed, so I conducted the experiment with 10Mpa as a stage.

On the other hand, for the ignition delay, due to the use of biodiesel and gasoline fuel blend is becoming more common, understand characteristics under different biodiesel fraction is very important, so I choose GB 00,GB10and GB20, by using PRR method to get the ignition delay. At the same time, in order to simulate under the LTC combustion mode of the small engine conditions, the ambient gas density and ambient temperature were selected showed in table.

Table 2.3.1 A comparison with previous studies

	Mr Shubhra	Dr.Nam	Current study
Research part	Spray	Combustion	Spray and Combustion
Focus	Spray development Spray angle Spray penetration length	Ignition delay Lift off length	Spray development Spray angle Spray penetration length Ignition delay
Fuel type	GB00 GB05 GB10 GB20	GB 20	GB00 GB10 GB20
Injection pressure	40Mpa 80Mpa 120Mpa	30~130Mpa	40~90Mpa
Ambient gas density	10kg/m3 20kg/m3	5kg/m3 15kg/m3	10kg/m3 15kg/m3
Ambient gas temperature	-	800~1200K	900-1000K

Chapter 3.Experiment setup

3.1 CVCC System

In this study, all experiments were conducted in a constant volume combustion chamber (CVCC)that can withstand high temperature and pressure. CVCC has the characteristic that the combustion products do not need to work on the external environment, so the actual combustion temperature can be higher, which makes the combustion efficiency higher. At the same time, CVCC can also realize a series of chemical and thermodynamic conditions, thus simulating different engine conditions.

Figure 1 is a detailed introduction diagram of the constant volume combustion chamber (CVCC) used in this experiment. By studying the assembly of the CVCC by other researchers[40, 41], the CVCC was improved according to various objective factors, and the stability of the equipment was improved, thus providing the possibility for the accuracy and repeatability of the experiment. The CVCC as a whole is cylindrical in length and diameter of 335mm and 300mm. In the middle of the cylindrical combustion chamber, there is a cubic space of 105mm in length, width, and height, which serves as the combustion area. The optical visible length of the CVCC is about 100mm, which fully meets the requirements of the spray experiment.

CVCC is a container made of stainless steel (SUS304). The choice of stainless steel material has the following considerations: the physical properties of the material can prevent corrosion and oxidation; and it is reliable and can withstand extreme environments due to combustion, such as high pressure and high temperature.

The CVCC is composed of six surfaces that can be disassembled and assembled. During our use, fans were installed on one side, injectors on one side, and gas piping on the other. The transparent quartz window used in this experiment is installed on both sides of the CVCC and it provides possibilities for optical access. The diameter of the quartz window is 121.5mm and the thickness is 51mm.In this CVCC, a total of eight heaters are installed in the cavity, in order to accurately control the ambient temperature we set to remain unchanged.

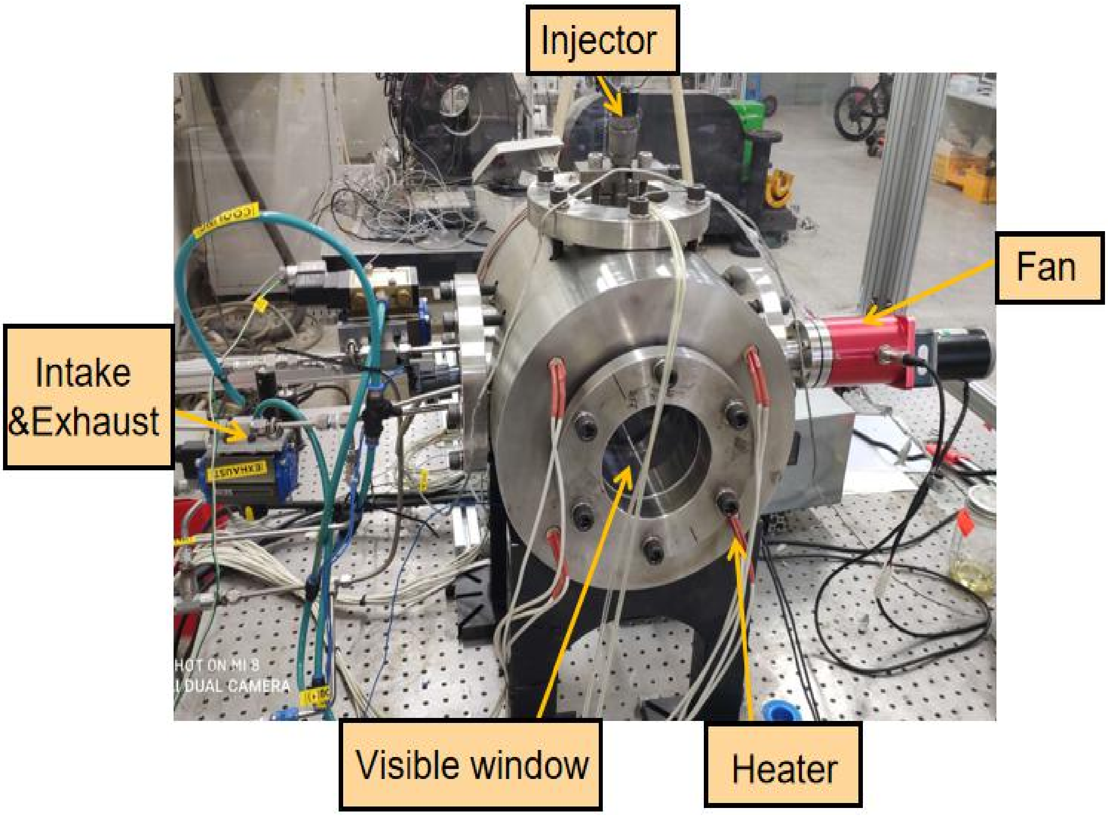

Figure.3.1.1: CVCC indicator diagram of each part

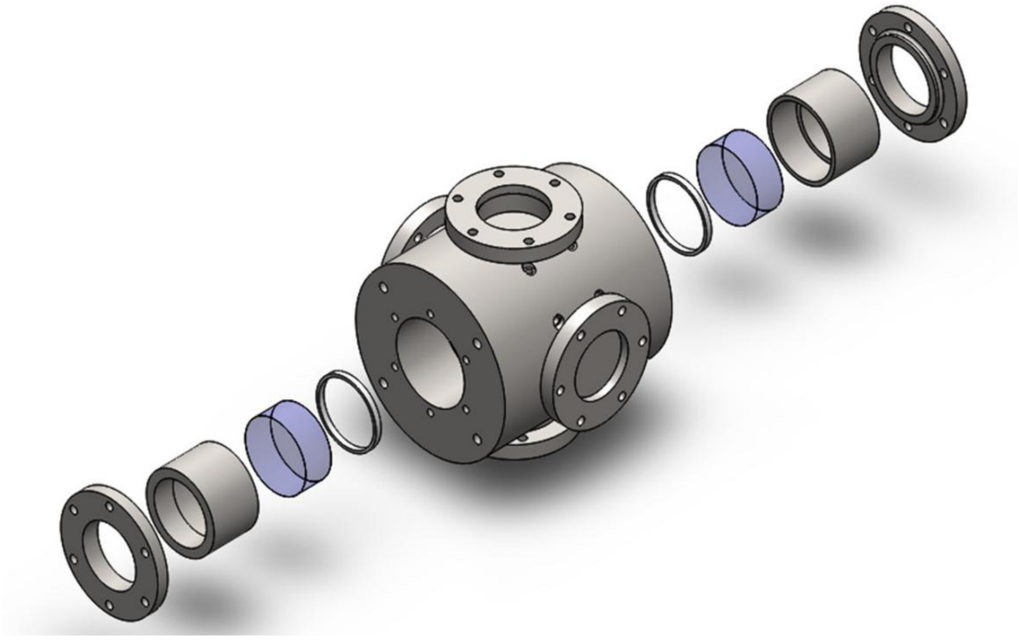

Figure.3.1.2: CVCC pump body decomposition diagram

CVCC is an experimental device that simulates spark ignition and spray combustion. A dynamic pressure sensor (Kisler 6001) is placed at the bottom of the chamber, and the pressure range can be measured from 0 to 250bar.

The dimensions of the main combustion chamber, sensor data and auxiliary conditions are shown in Table 3.1.1.

Table 3.1.1

An overall information of the test system and additional equipment

Basic parameter		Unit
shape of the internal chamber	115*115*115	mm
Window aperture	110	mm
Injector mounting	Top window	
Number of spark plugs	1	
Spark plug position	Side window	
Combustible gas fill	Sequential	
Mixing fan location	Side window	

Measurement Condition			
	Minimum	Maximum	Unit
Ambient density	1	20	bar
Ambient temperature	15		K
Oxygen concentration	0	0.21	Vol fraction
Wall temperature	293	443	K
Fuel temperature	Ambient	309	K
Injection pressure	400	900	bar
Injection duration	1500		μs

Auxiliary system		
Name	Model	Rang
Proportional valve	Burkert 2875(only N2), Burkert287	0-25,0-16 bar
Intake Valve	Pneumatic ball Valve	0-10 bar
Exhaust Valve	Pneumatic ball Valve	0-10 bar
Vacuum pump	Spaemax Rocker 400	0.5mbar Hg
Ignition coils driver	Mobiq Ignition Coil Driver	
Sprak Plug	Denso IRIDIUM(SK16PR-A11)	
Mixing Fan	Propeller type magnetic driven fan	

Sensor & Data Acquisition		
Name	Model	Rang
DAQ & control software	NI PXI 1042Q & LabVIEW	
Static gas pressure sensor	Peizo resistive Kristler 4045A50	0-50 bar
High Pressure calibrator	Sensys PSHHCO20BCPG	0-20 bar
Low pressure calibrator	Sensys PSHHCO02BCPG	0-2bar
Dynamic gas pressure sensor	Peizo resistive Kristler 6056A	0-250 bar
Vessel temperature sensor	Thermocouple K type	
Module for Pressure measuement	NI 9237	
Module for Proportional Valve	NI 9238	

In this experiment, the running process of CVCC is carried out in the sequence as shown in Figure 3.1.3, which is a cyclic process.

When we do the experiment, we can turn the CVCC operation on or off by simply clicking the "Start/Stop" button. Subsequently, the system will be run in a predetermined order, including cleaning, filling, pre-combustion, fuel injection, and cleaning.

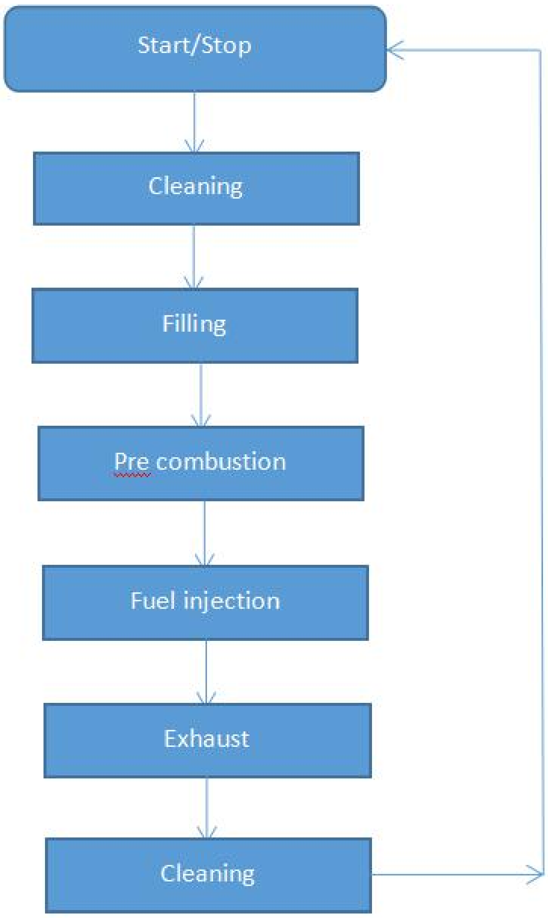

Figure 3.1.3: Running process of CVCC

The CVCC operation is fully automated, but unexpected occurrences are inevitable during gas filling. For example, the pressure sensor cannot transmit accurate signals and does not transmit data to the controller after a long period of operation, which leads to the system's inability to make correct judgments, which leads to the filling of too much combustible gas C_2H_2, which leads to the detonation and thus threatens life.

Therefore, it is necessary to use diagnostic procedures to prevent accidents during gas filling. The design of the diagnostic application is shown in Figure3.1.4, broken down into the following five steps.

Step 1: Without any connection error, the program will check the connection and performance of the sensor under atmospheric conditions. Before the start of the experiment, two pressure sensors, one of which is connected to the outdoor atmosphere and one to the combustion chamber, under normal circumstances, the value of the two sensors should be close to 0; if it is not 0, it means that the connection or the sensor itself has Problem; Afterwards, the system will display a warning message and stop running.

Step 2: Check the argon filling. After the argon filling process is over, the diagnostic process starts immediately. The pressure sensor in the combustion chamber will detect and receive the pressure value and compare it with the target value we set. If the system judges that the error between the two is less than 0.001 bar, the argon filling process is considered to be no problem; on the contrary, if the error exceeds the threshold value we set, the system will issue a warning message and stop running.

Step 3 : Check the filling of acetylene . The specific process is similar to step 2.

Step 4: Check the filling of oxygen. The specific process is similar to step 2.

Step 5: The program checks the nitrogen filling. This is the last step of the entire diagnosis process, and this step will also be used to check the chamber leakage. When the nitrogen filling is completed and all valves are closed, if the pressure in the combustion chamber is found to be more than 0.02 bar from the target value, it will be regarded as an error in the gas filling process, or there is a leak in the combustion chamber. If the difference does not exceed 0.02bar, the filling process is deemed to be completed and the gas conditions for the pre-combustion process are already available.

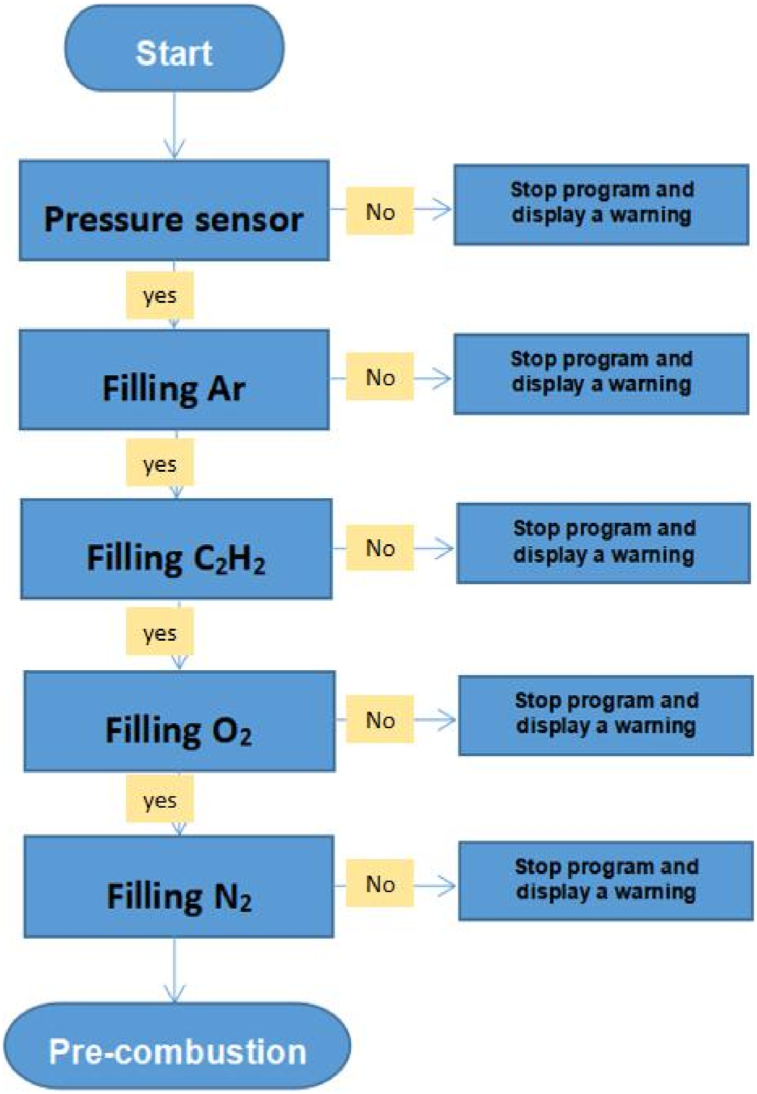

Figure 3.1.4: System diagnosis flow chart

3.2 Supply System

Then through the use of a gas filling system controlled by Burkert 8605 valve, put the argon (Ar), combustible acetylene (C_2H_2), oxygen (O_2), and nitrogen (N_2) required for the experiment are sequentially injected into the combustion chamber according to the pre-calculated volume fraction. This simulates the high temperature and high-pressure environment inside the engine and can study spray and combustion characteristics well.

Under the target density conditions we set, by setting the pressure fraction of the reactants, we can control the combustion environment we want, creating the possibility for subsequent spark ignition. After experiencing spark ignition, there is a sufficiently high pressure and temperature environment in the combustion chamber to provide the possibility of fuel injection and auto-ignition.

In the premixed combustion stage, we selected four gases as reactants. They are Argon (Ar), Acetylene (C_2H_2), oxygen (O_2), and Nitrogen (N_2). In terms of combustible gas selection, although C_2H_4 is also a good choice, and C_2H_4 is more volatile than C_2H_2, we still chose C_2H_2. This is because the reduction in the content of hydrogen molecules helps reduce water production, thereby It reduces the condensation that occurs in the visible window and reduces heat loss. Another point to note is that acetylene is composed of C-C triple bonds, which leads to its own instability. Under pressures exceeding 200kpa, explosive dissociation will occur, which is the knocking, which is extremely dangerous and needs to be avoided. When a knock occurs, the mixture burns at such a rapid rate that the pressure in the combustion chamber rises abnormally, accompanied by the sound of an explosion. It may even cause the explosion of the pipeline, which will do immeasurable harm to the safety of human beings. Therefore, when filling gas, we need to pay special attention to the order of gas filling. In order to prevent the mixing of unnecessary gases in the experiment, nitrogen must be used to clean the combustion chamber before the gas filling process starts. In order to ensure safety, in this experiment, we chose acetylene as the first sequential fill into the cavity. In order to avoid explosions, oxygen is arranged to enter the combustion chamber at the end. To keep the temperature constant, the gas filling process must proceed slowly.

In addition, because the four gases are separately injected into the combustion chamber, The mixing of gas temperature and gas requires a mixing fan to help, so we installed a fan on the side of the CVCC to complete the gas mixing task.

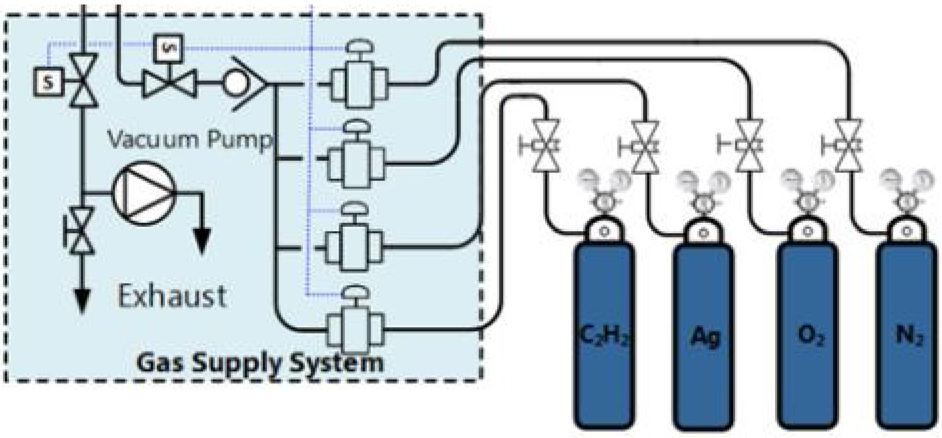

Figure 3.2.1: Schematic diagram of gas supply and exhaust system

In addition, in this experiment, equipped with a high-pressure common-rail fuel oil supply system, including a single injector, the solenoid drive (ZB - 5100), and the controller (ZB - 8035), These devices can increase the fuel sample pressure up to 1600bar and maintain a stable pressure value, thus providing the possibility for the sample fuel to be steadily injected into the CVCC. In this experiment, data collection and system control were controlled by a computer produced by National Instruments, which came with the Labview program and had functions of controlling the temperature in the cavity, gas filling process, ignition time, injection duration, and data storage.

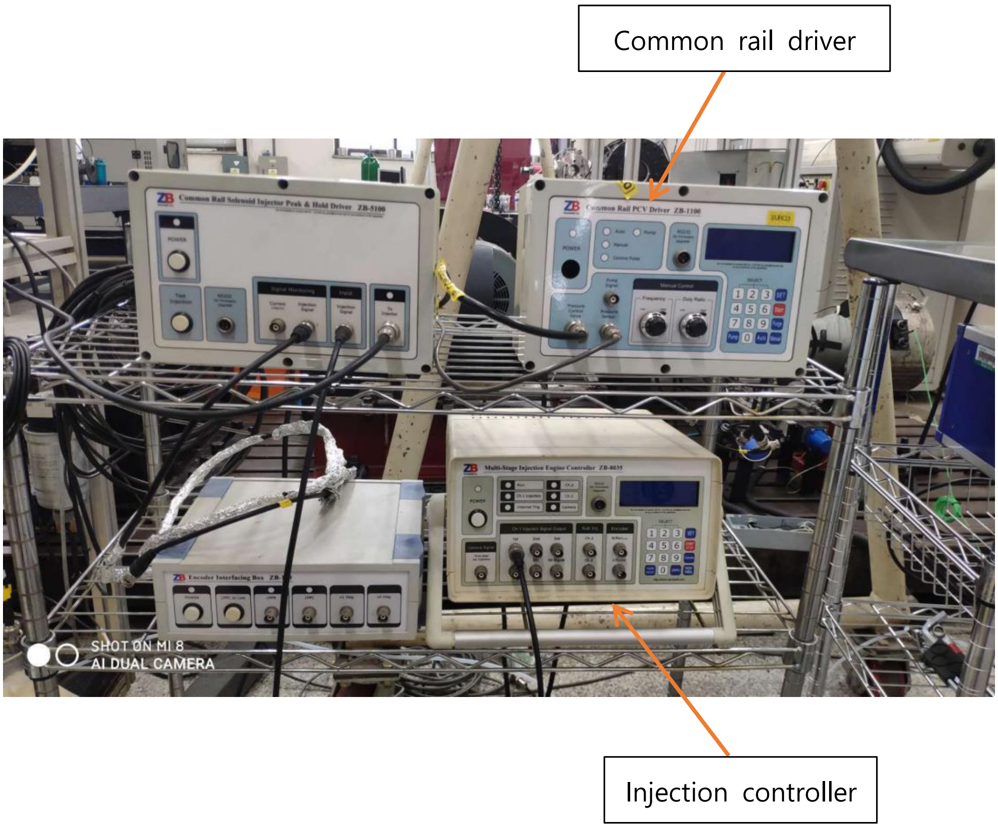

Figure 3.2.2: Schematic diagram of fuel supply control system

3.3 Data acquisition

In this experiment a high speed, high resolution, high - frequency pressure transducer (Kistler, 6056 a) and a charge amplifier (5018 b), has realized the dynamic pressure measurement. The high-pressure dynamic pressure sensor is responsible for recording the pressure trajectory of the heat released by fuel combustion. The charge amplifier then amplifies and converts the signal of the pressure sensor into a digital signal, which is automatically saved in an excel file.

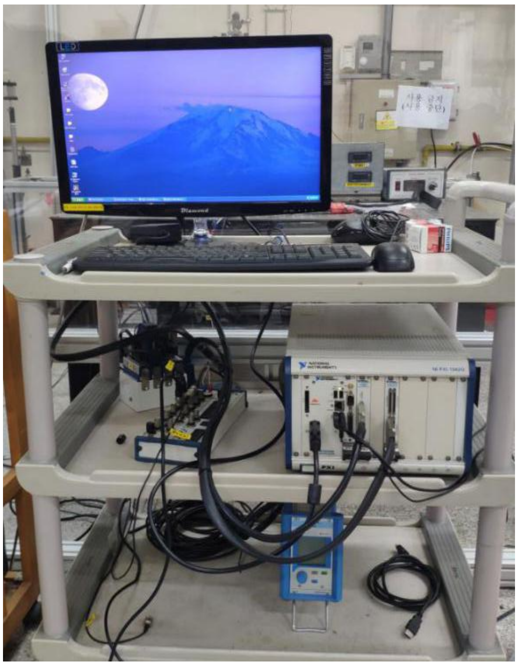

Figure 3.3.1: Physical picture of data acquisition and control system

In this study, we used the Z-type Schlieren method to obtain spray images. This is a pure spray experiment method. Because the spray partly blocks the light passing through it, the image of the spray displacement can be easily obtained. In addition, easy to see the liquid area and evaporation area is one of the reasons why we chose this method.

For the Z-Type setup, we used a high-powered 150W halogen light source (model KLS-150H-RC-150E). Light from the source diverts through a pair of cylindrical lenses and hits a first concave lens with a diameter of 150mm and a focal length of 2000mm, which collimates the light. The beam then passes through the CVCC and is refocused by a second concave mirror, where the light from the second mirror is fed directly into the knife-free camera lens to capture the transient spray image. The Photron high-speed camera SA3 is set at the quasi-value point, equipped with a 650nm objective lens (AF Micro-Nikkor, aperture f/1.8), capturing images at a speed of 10,000 frames/second with a resolution of 512,256 pixels. The schematic diagram of the optical device and the injector position is shown in Figure 3.3.2.

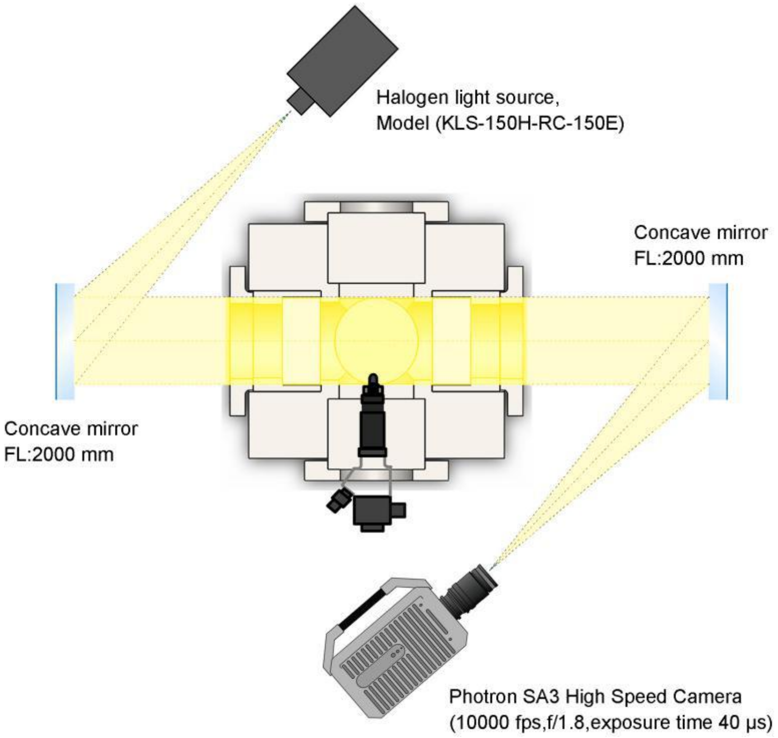

Figure. 3.3.2: Optical arrangement for the macroscopic spray visualization.

3.4 Experiment condition

The fuel temperature, ambient gas density, ambient temperature, injector position, optical device and light intensity remained unchanged throughout the experiment. The experimental conditions and all relevant parameters are shown in Table 3.4.1. All experiments need to be repeated 5 times under each condition, this time in order to reduce the error and get a better average result.

Table 3.4.1. Experimental test matrix

Fuel type	GB00,GB10,GB20
Injection pressure (MPa)	40-50-60-70-80-90
Ambient gas density (kg/m^3)	10，15
Injector type	Bosch CRIN 2
Injection duration（μs）	1500
Chamber body temperature (K)（Non-vaporizing condition）	298
Chamber body temperature (K)（combustion condition ）	398
Oxygen concentration (%)	15%
Ambient temperature (K)	900，1000 K
Fuel temperature (K)	308
Injector nozzle type	Single-hole
Frame rate (frames/sec)	10000
Exposure time	1/25000 (40 μs)
Random reset	150
Image resolution	512 × 256 pixels

In this study, the pressure sensor we used is named thermodynamic quartz pressure sensor, model 6061B. The pressure sensor uses a highly stable quartz element, which is very suitable for thermal dynamic measurement of small internal combustion engines.

The specific parameters are sorted out as follows:

Table 3.4.2: Technical data of pressure sensor.

Connector Type	BNC neg.	TRIAX neg.
Measuring range FS	pC	±2...2200000
Measurement uncertainty		
Ranges FS <10 pc	%	<±2
Ranges FS <100 pC	%	<±0,6
Ranges FS≥100pC	%	<±0,3
Drift, measuring mode DC(Long) at 25C, max. relative Humidity RH of 60 %(non-condensing)	pC/s	<± 0,03
at50,max. relative Humidity RH of 50 %(non-condensing)	pC/s	<± 0,3
Max. common mode voltage between input and output ground	V	<±25
Overload	%FS	± 110

The gasoline fuel used in this experiment was purchased from the commercial channel of South Korea's S-Oil. The biodiesel used in this experiment is made from soybeans and purchased from industrial sources.

A total of three different fuels were used in this study, two of which were gasoline-biodiesel blend fuel and one pure gasoline (GB00).GB10 is a mixture of 10% volume fraction biodiesel and 90% volume fraction gasoline.GB20 is a blend of 20% by volume fraction biodiesel and 80% by volume fraction gasoline.

Both the gasoline and diesel are kept in lab Companion's thermostat, and the fuel needs to be mixed and vibrated and rotated for 5-10 minutes before we do the experiment. Table 3.4.3 shows the physical properties of the fuel used in this study[42-46] .

Table 3.4.3

Property	Unit	Test method	GB00	GB10	GB20	B100
Density at 15 °C	kg/m3	KS M ISO 12185:2003	712.7	732.2	757.1	882.3
Lubricity	µm	KS R ISO 12156-1:2012	548	282	236	189
Cloud point at 15 °C	15 °C	KS M ISO 3015:2008	−57	−32	−16	3
Pour point	°C	ASTM D6749:2002	<−57	<−57	<−57	<1
Kinematic viscosity at 40 °C	mm2/s	KS M ISO 3104:2008	0.735 [42]	1.084 [43]	1.4338 [43]	4.229
Heating value	MJ/kg	ASTM D240:2009	45.86	44.92	43.6	39.79
Surface tension at 20 °C	mN/m	ASTM D971:2009	21.56 [44]	20.26 [45]	21.53 [45]	31.7 [46]
Stoichiometric air-fuel ratio	-	14.7	14.7	14.488	14.276	12.58
Blend ratio	-	1.0	1.0	0.90	0.80	–

3.5 Definition

In general, under non-vaporization conditions the ambient gas is in a weak turbulent state, so the background is almost constant [47]. However in the case of high fuel injection pressure, an injection image will reveal a shock wave [48]. In an experimental process the most important stage of image capture analysis is image processing, which includes the threshold, image segmentation, and various seed functions. In this experiment a self-programmed MATLAB code was used to process each image to visualize the non-vaporizing shadow attached to each vibration wave.

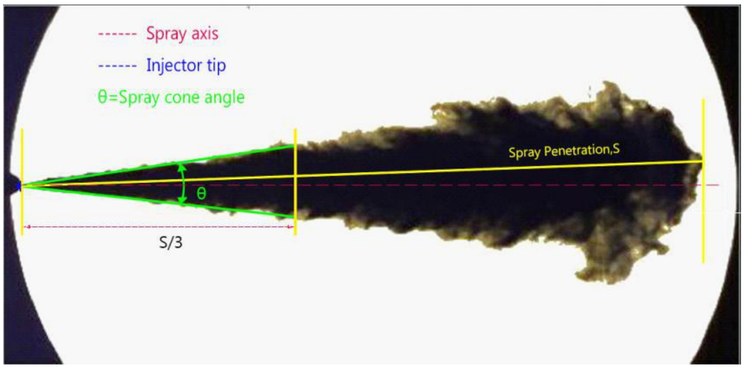

Figure.3.5.1 Spray definitions from the image captured from a single-hole nozzle, using GB10 fuel under 50-MPa fuel injection pressure and 15-kg/m^3 ambient gas density.

In this study, we defined the length of the yellow line shown in the figure as the spray penetration length, that is, from the nozzle to the farthest end of the spray. The position shown by the green line in the figure represents the size of the spray cone angle. The formula of spray cone angle is shown as (3-1).

S = Spray tip penetration

$$\boldsymbol{\theta} = \text{Spray cone angle} = 2\arctan\left[\frac{A}{\left(\frac{S}{3}\right)^2}\right] \qquad \textbf{(3-1)}$$

In this experiment the fuel injection start time was determined by measuring the current of the injector solenoid. As shown in Fig. 3.5.2, during the entire experiment process the pressure curve consisted of two parts, each with one peak. The pressure rise in the first part was caused by the gases (acetylene and others) pre-injected into the chamber, which the spark plug could ignite. This created a high-temperature, high-pressure environment in which auto-ignition could occur. After cooling down, the actual fuel was injected into the chamber when a predetermined pressure and temperature injection point was reached. Subsequently, after auto-ignition, the second pressure rise occurred, at this time, the maximum pressure rise rate reaching its maximum value during the whole process. The time point represented by this value was the time of the auto-ignition start. Thus, we defined the ignition delay as the time interval between the start of the injection and the maximum pressure rise rate achieved during the experiment.

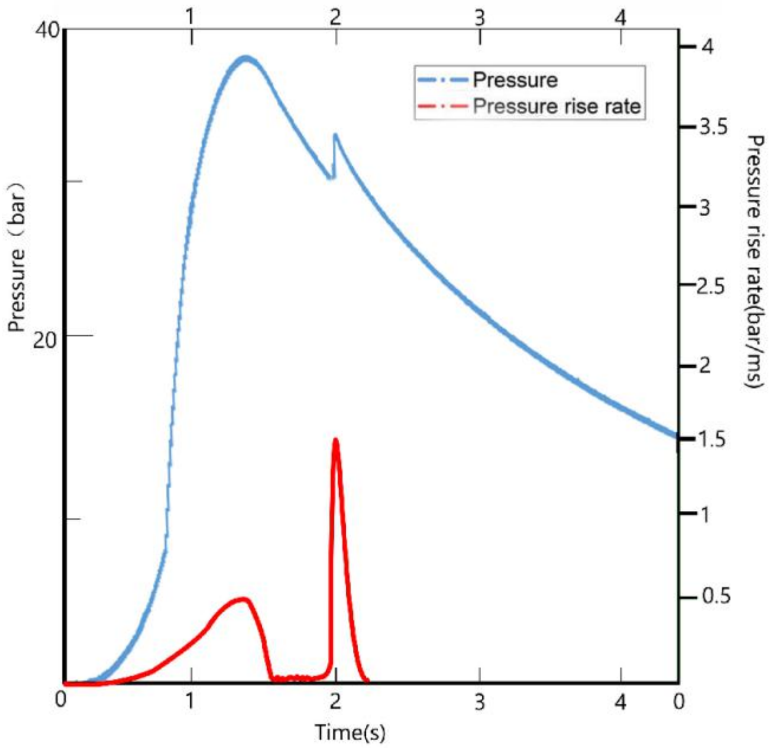

Figure.3.5.2: Schematic diagram of Definition of ignition delay used in this study.

Chapter 4. Results of Spray characteristics

The most important factor affecting engine combustion is the quality of the fuel-air mixture in the cylinder. The formation of this mixture is closely related to the environment in the cylinder, the spray characteristics of the fuel, and the atomization effect. The spray characteristics of the fuel significantly affect its operation and the emissions in the engine. As previously mentioned, the injection pressure, the atomization state of the engine, and the physical properties of the biodiesel itself will directly affect the combustion and working characteristics of the fuel in the engine, which in turn determine the fuel economy and emission performance of the engine. Therefore, the spray characteristics of gasoline-biodiesel mixed fuel in GCI engines are the key factors affecting efficient and clean engine combustion.

4.1 Spray development

The spray development images of GB00, GB10, and GB20 under 50.70.90MPa and different ambient densities (10 kg/m^3 and 15 kg/m^3) are shown in Figures4.1.1~6. The mixed fuel spray form clearly changed with the change of the mixture ratio of biodiesel in the gasoline fuel, which proves that the addition of biodiesel had a certain influence on the spray characteristics. From spray formation to complete spraying, the spray development process was continuous and expanded along the centripetal axis. At the beginning of the injection, the fuel liquid entered the still air, moved outward from the nozzle, and its speed slowed down rapidly as the air accumulated.

The influence of the physical properties of the fuel on the spray was also manifested by the structure of the spray. As time went on, the spray length of the GB20 was longer than that of the GB10, which in turn was longer than that of the GB00. This is attributable to biodiesel having a higher viscosity than gasoline. When the injection entered the stable phase and the nozzle was not completely closed, the spray momentum also affected the extension of the jet end.

It can be seen from the image that the density of the gas environment had a great influence on the development of spray. Compared with 10 kg/m^3, at 15 kg/m^3 the time for the spray to reach the chamber wall was greatly prolonged. This was due to the increase in ambient gas density, which caused air resistance to the spray development, resulting in slower spray development. Secondly, the spray area in the 15 kg/m^3 state was much larger than that in the 10 kg/m^3 state, which was also caused by the increase in environmental pressure.

Because we have done too many experiments on jet pressure, here we extract 3 groups of examples from the range of 40-90 MPa injection pressure to illustrate the development of spray.

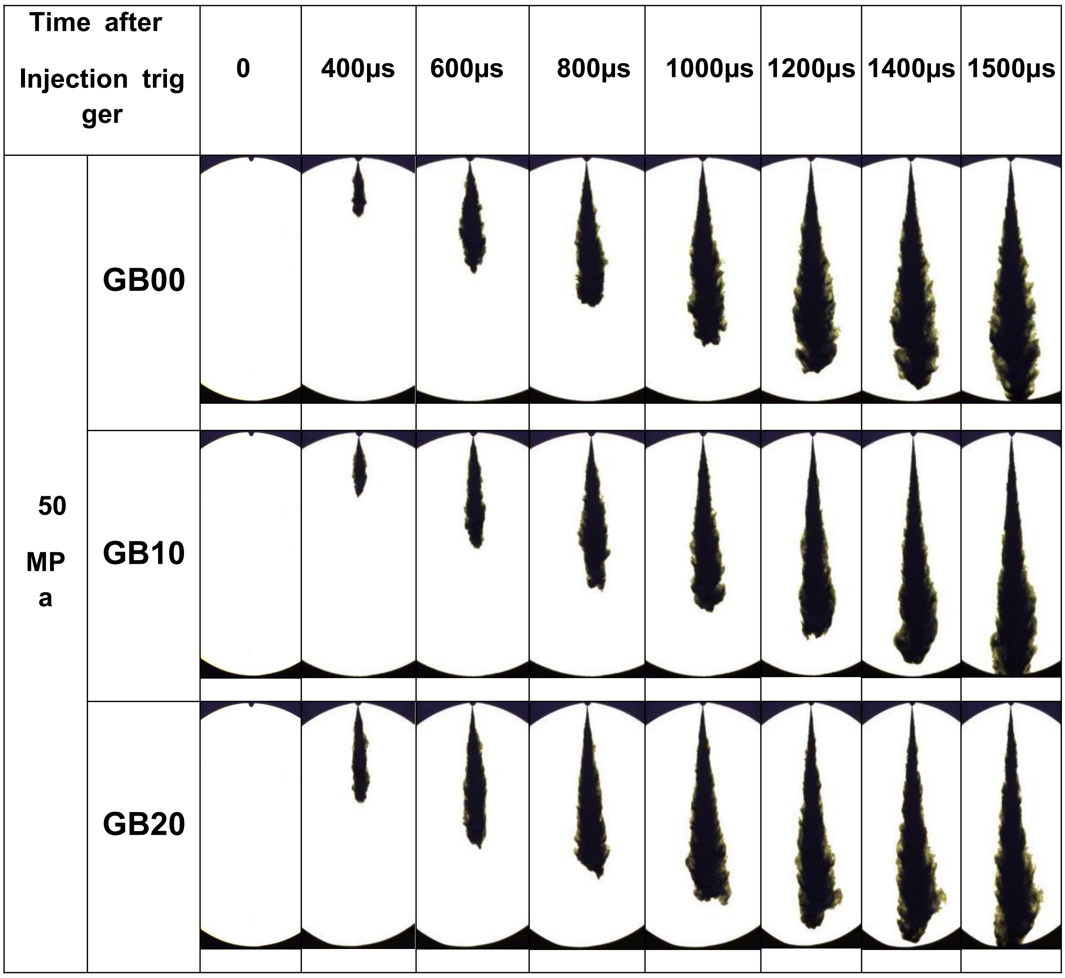

Figure.4.1.1: Spray development under 50 MPa injection pressure of GB00, GB10, and GB20 with 10-kg/m^3 gas density.

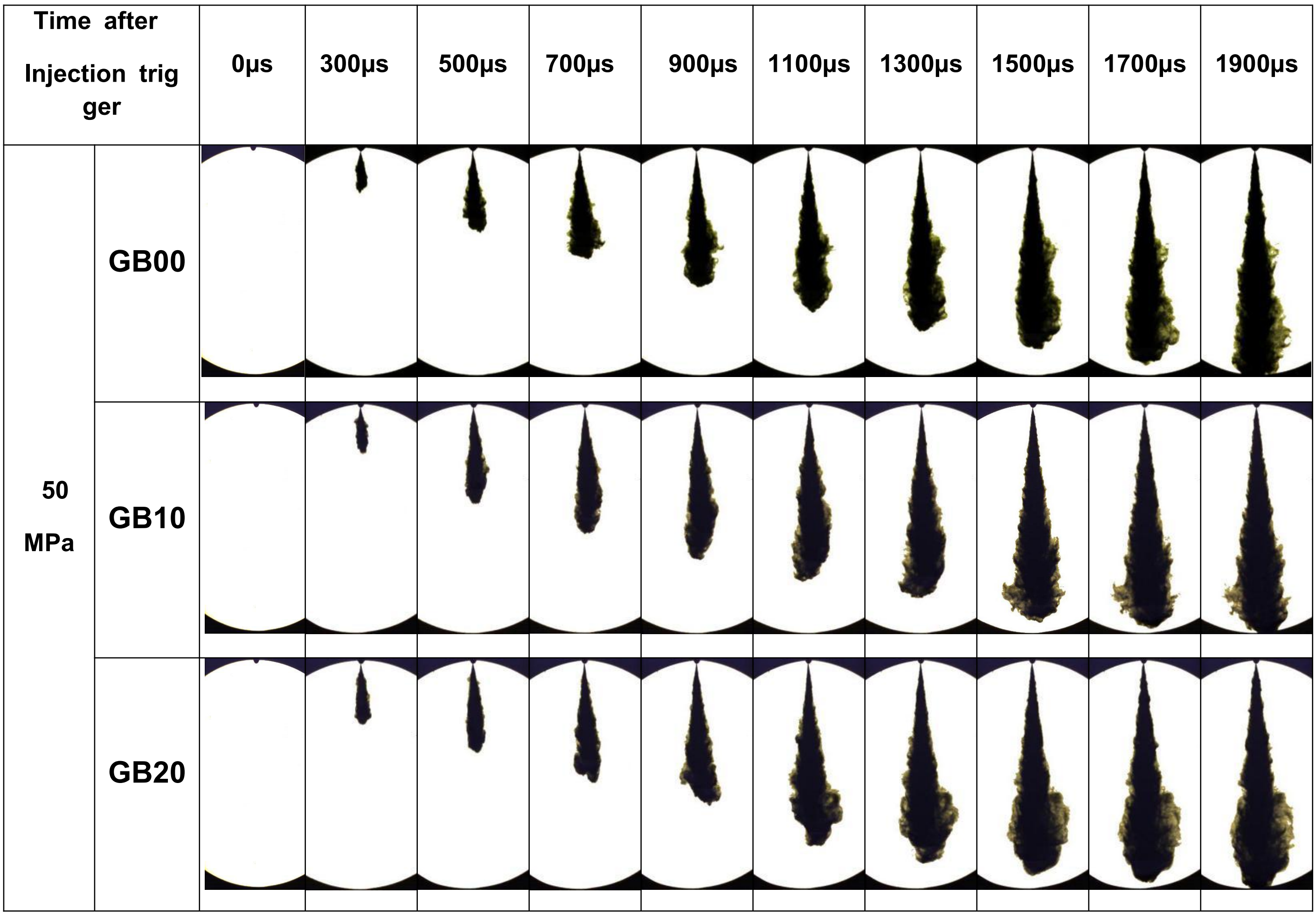

Figure.4.1.2: Spray development under 50 MPa injection pressure of GB00, GB10, and GB20 with 15 kg/m^3 gas density.

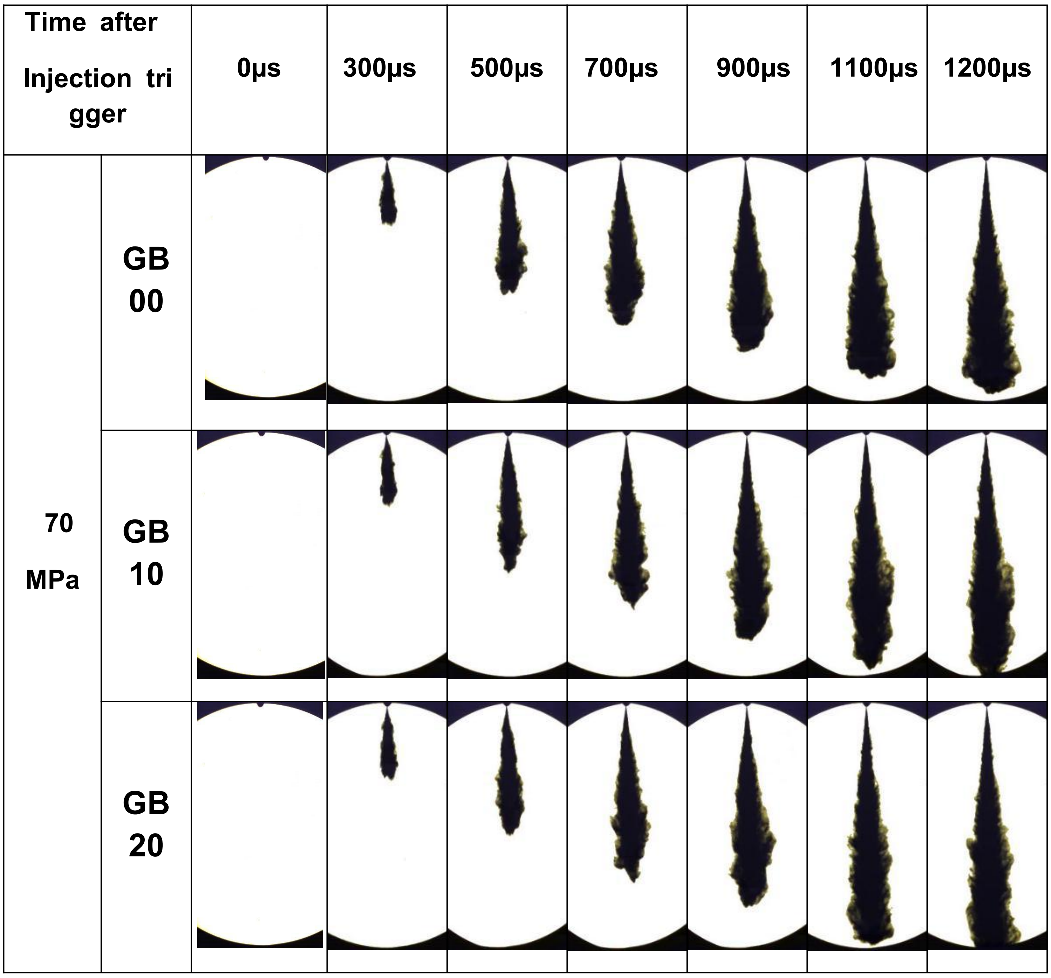

Figure.4.1.3: Spray development under 70 MPa injection pressure of GB00, GB10, and GB20 with 10-kg/m^3 gas density.

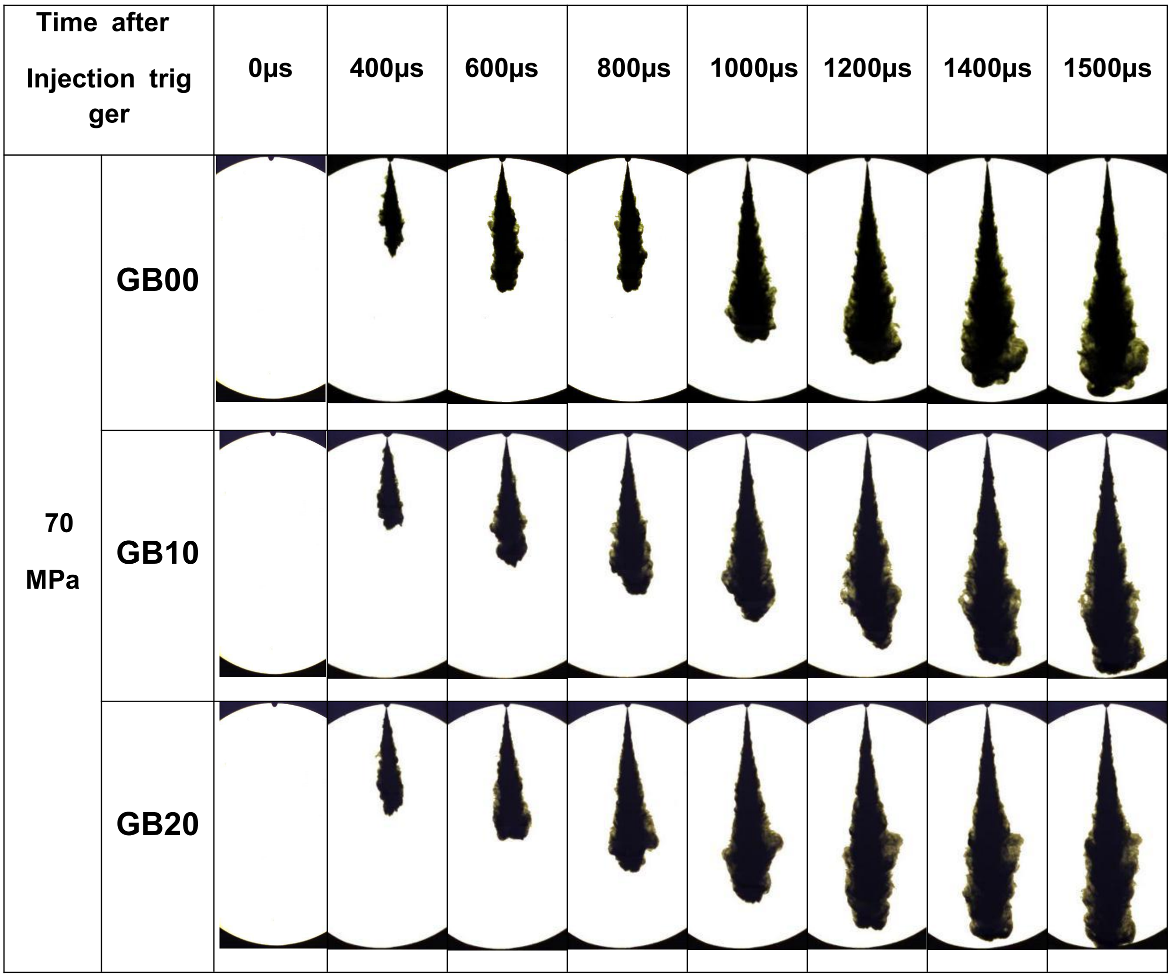

Figure.4.1.4: Spray development under 70 MPa injection pressure of GB00, GB10, and GB20 with 15 kg/m^3 gas density.

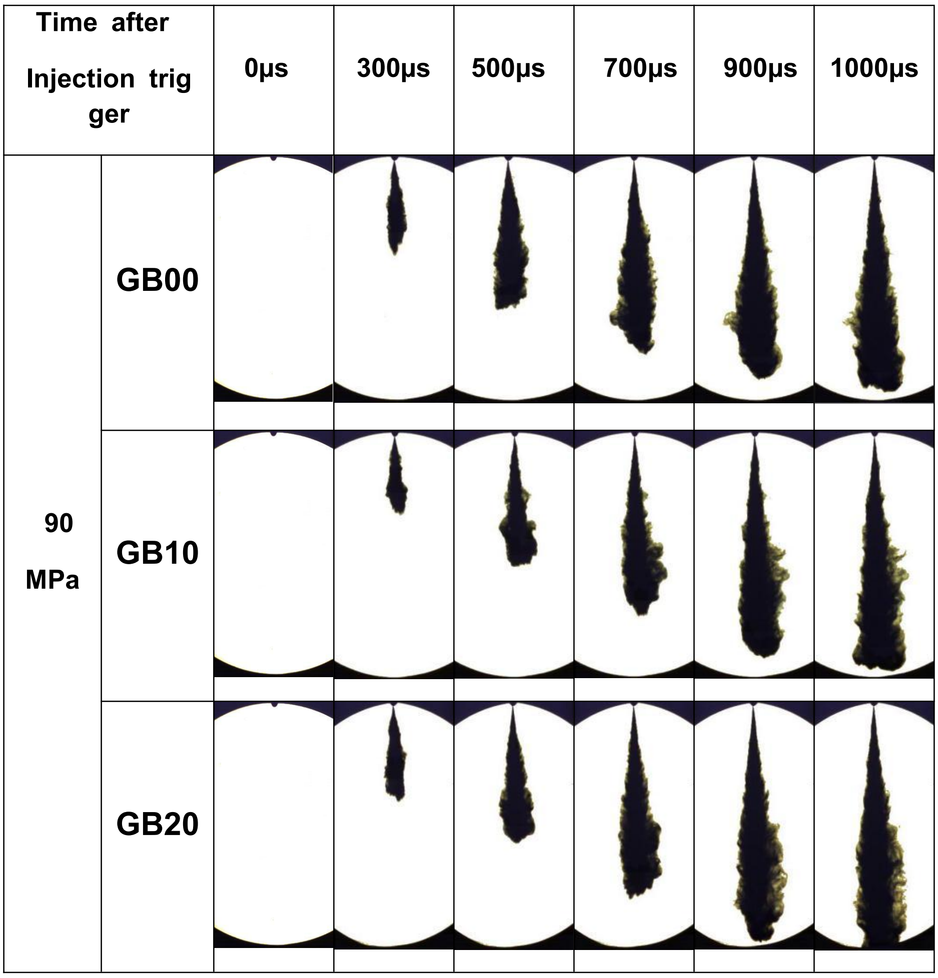

Figure.4.1.5: Spray development under 90 MPa injection pressure of GB00, GB10, and GB20 with 10 kg/m^3 gas density.

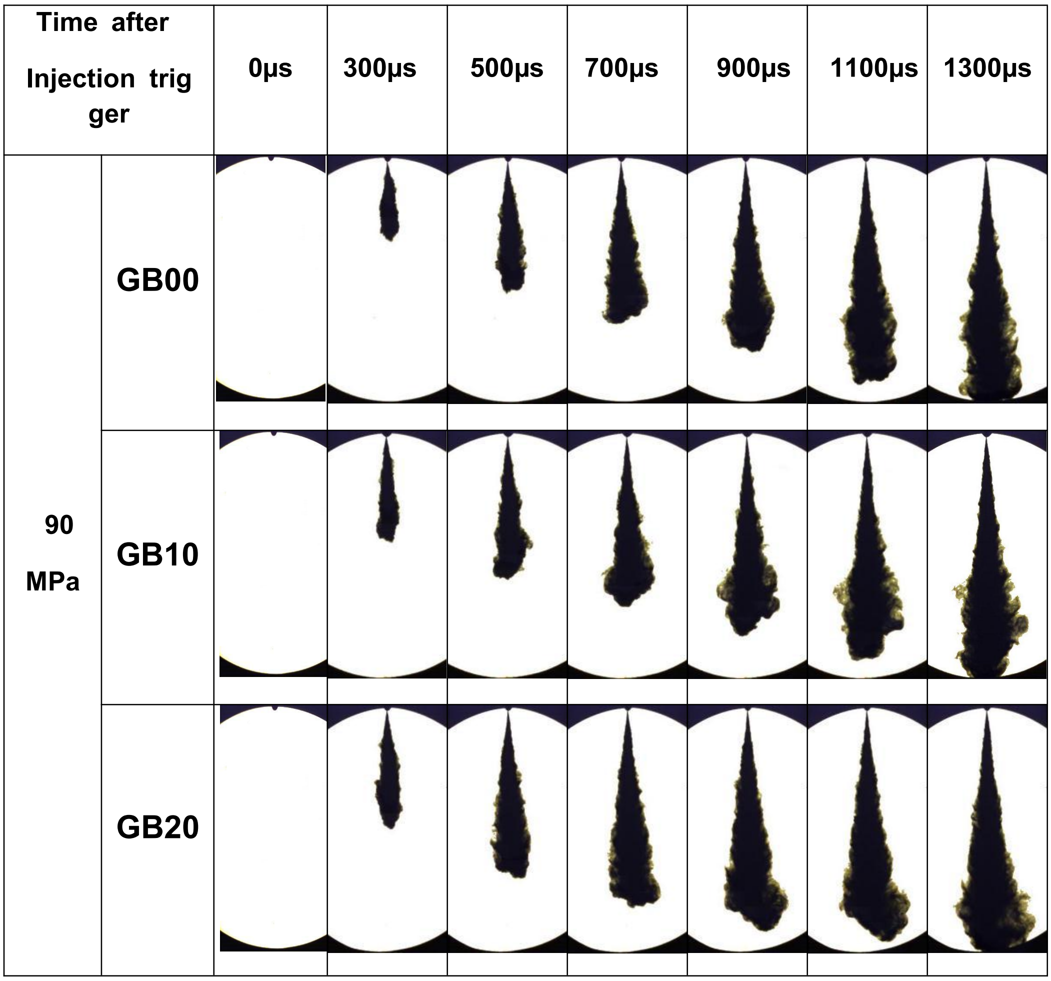

Figure.4.1.6: Spray development under 90 MPa injection pressure of GB00, GB10, and GB20 with 15 kg/m^3 gas density.

4.2 Spray penetration length

Figure4.2.1~6 shows the time change of the penetration length of the spray under the conditions of injection pressure of 40 – 90 MPa, fueled with GB00, GB10, and GB20 at 10 – 15 kg/m^3 ambient gas density and injection duration of 1,500 µs.

As shown, the ambient gas density had a great influence on the spray penetration length because the increase in the ambient gas density slowed down the development of the spray. This implies that the increase in the ambient gas density created resistance to the development of the spray. In addition, as the injection pressure increased, the time for the most distal end of the spray to reach the same spray distance became shorter and shorter. The spray length results demonstrated that as the proportion of biodiesel in the blended fuel increased, the viscosity and surface tension of the blended fuel increased, so it was difficult to quickly decompose and disperse the blended fuel, resulting in an increase in the size of the spray droplets. The larger the size of the spray droplets, the greater their momentum and the less the resistance to forward movement, which led to an increase in the speed of the spray. Therefore, at the same time point after injection, as the mixing ratio of biodiesel increased, the penetration distance of the tip increased.

It is generally known that under the same injection duration and the same ambient conditions, the injection pressure is proportional to the volume of the fuel. Therefore, the injection pressure causes increases in the spray penetration length after injection, which can be considered a consequence of the increase in fuel mass flow and spray momentum.

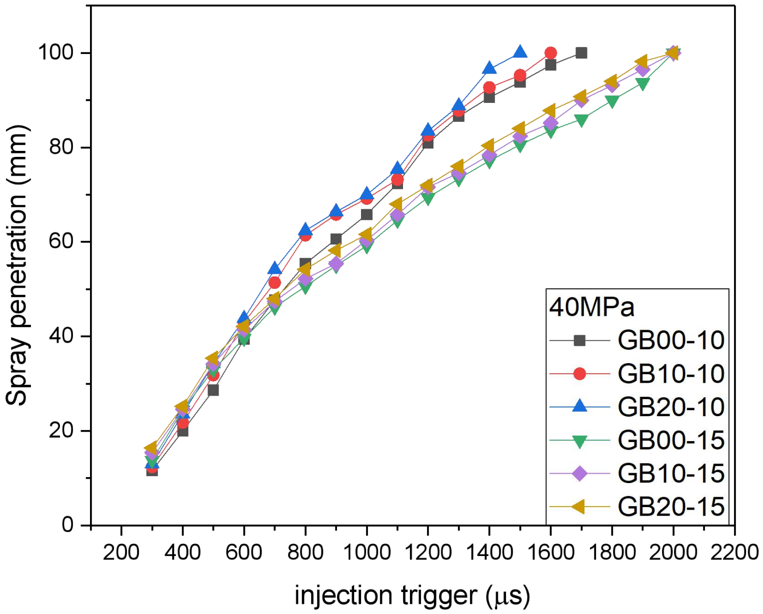

Figure.4.2.1: Spray penetration length for GB00, GB10, and GB20 at 10 to 15 kg/m^3 ambient gas density under 40 MPa injection pressures.

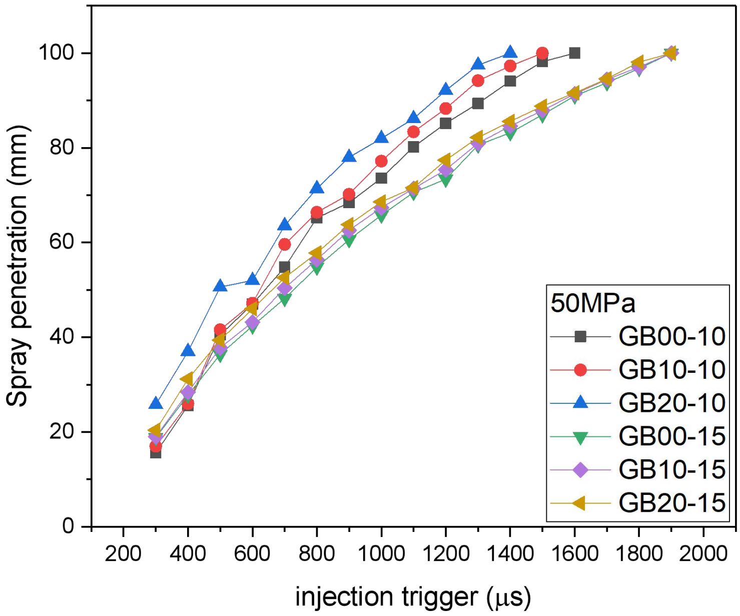

Figure.4.2.2: Spray penetration length for GB00, GB10, and GB20 at 10 to 15 kg/m^3 ambient

gas density under 50 MPa injection pressure.

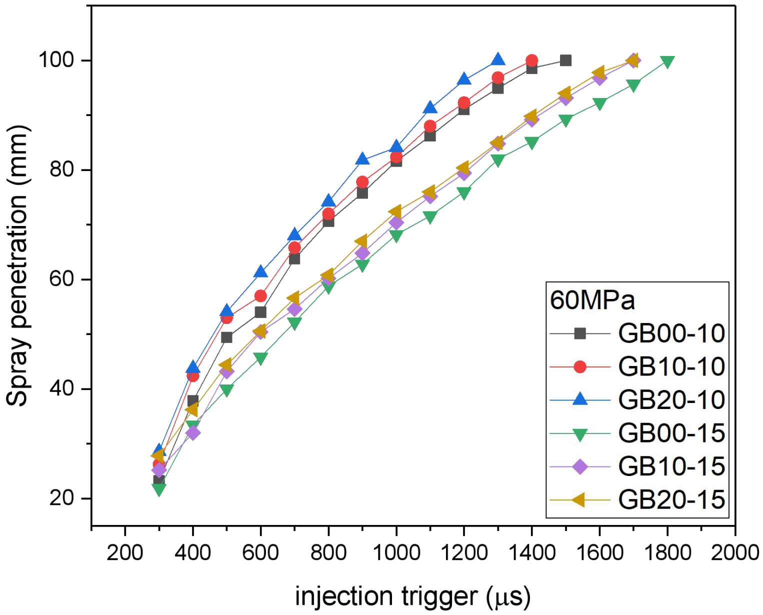

Figure.4.2.3: Spray penetration length for GB00, GB10, and GB20 at 10 to 15 kg/m^3 ambient gas density under 60 MPa injection pressure.

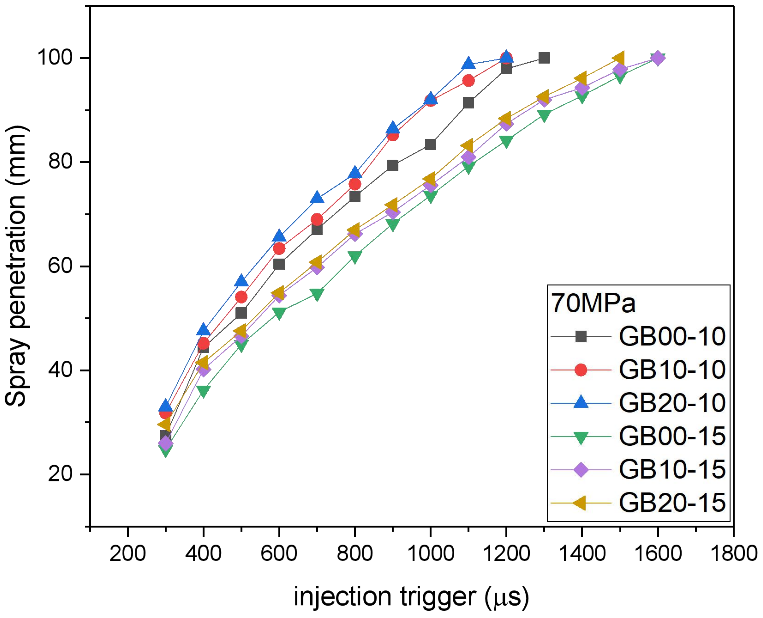

Figure.4.2.4: Spray penetration length for GB00, GB10, and GB20 at 10 to 15 kg/m^3 ambient gas density under 70 MPa injection pressure.

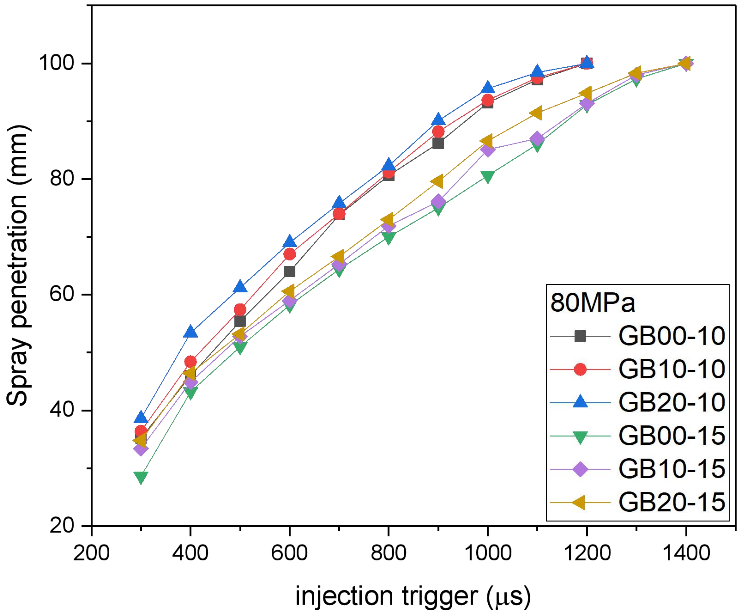

Figure.4.2.5: Spray penetration length for GB00, GB10, and GB20 at 10 to 15 kg/m^3 ambient gas density under 80 MPa injection pressure.

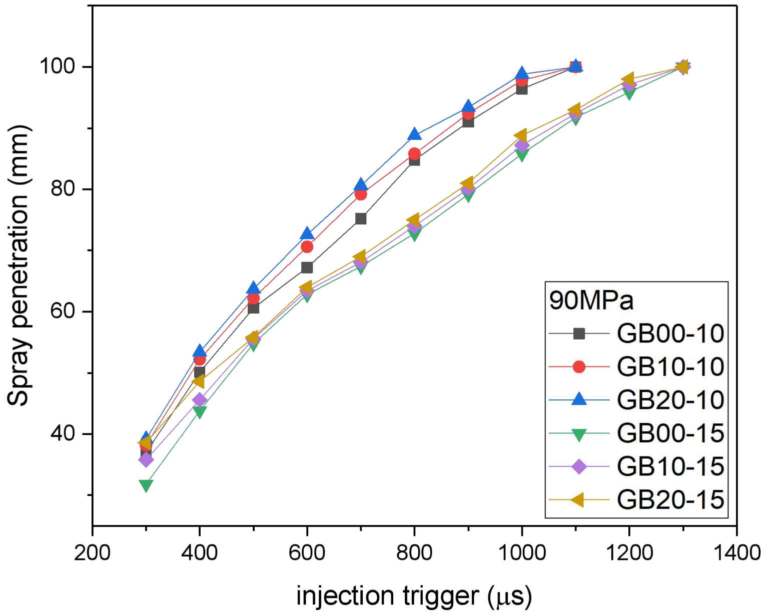

Figure.4.2.6: Spray penetration length for GB00, GB10, and GB20 at 10 to 15 kg/m^3 ambient gas density under 90 MPa injection pressure.

4.3 Spray angle

Figure4.3.1~6 shows the time change of the spray angle of the spray under the conditions of injection pressure of 40 – 90 MPa, fueled with GB00, GB10, and GB20 at 10 – 15 kg/m^3 ambient gas density, and injection duration of 1,500 μs.

The results show that the size of the spray cone angle was inversely proportional to the injection pressure. The most obvious stage of the spray cone angle change was the initial spray formation stage; in the latter half of the spray stage the spray cone angle did not change much. In addition, as the proportion of biodiesel in the fuel increased, the viscosity and surface tension of the fuel also increased, and the fuel was difficult to decompose and disperse. Therefore, the size of the spray droplets increased, and the spray cone angle decreased.

The reason for the decrease in the spray cone angle caused by the increase in the ambient gas density was that the higher spray pressure reduced gas entrainment, thereby increasing the ratio of the spray pressure to the ambient pressure, which led to a decrease in the cone angle.

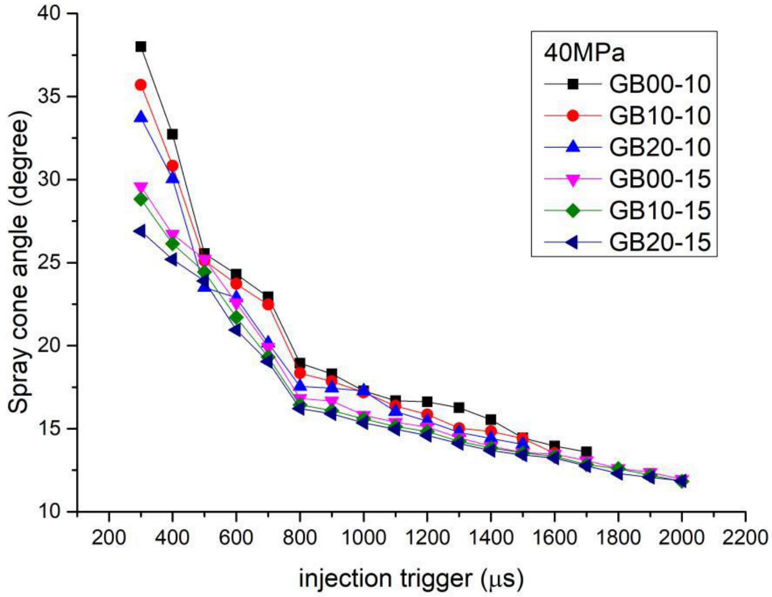

Figure4.3.1: Spray angle for GB00, GB10, and GB20 at 10 to 15 kg/m3 ambient gas density under 40 MPa injection pressures.

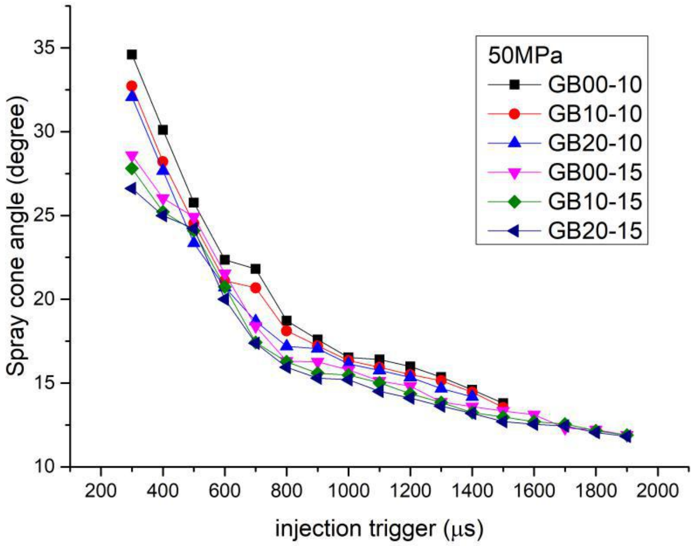

Figure4.3.2: Spray angle for GB00, GB10, and GB20 at 10 to 15 kg/m3 ambient gas density under 50 MPa injection pressures.

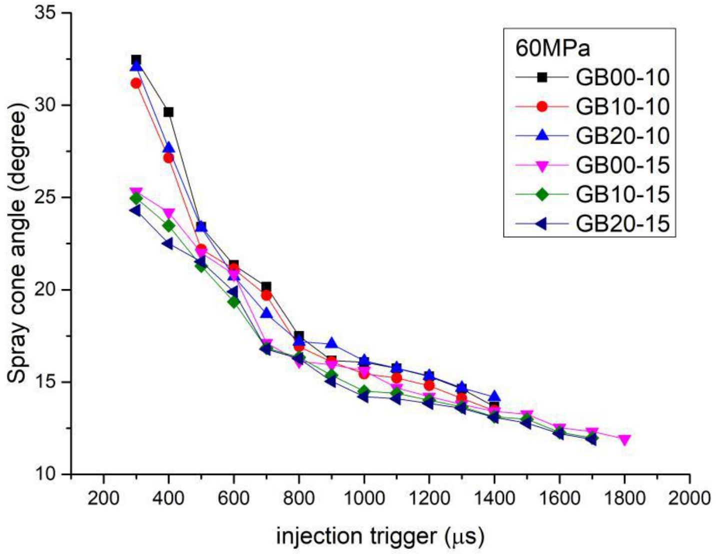

Figure4.3.3: Spray angle for GB00, GB10, and GB20 at 10 to 15 kg/m3 ambient gas density under 60 MPa injection pressures.

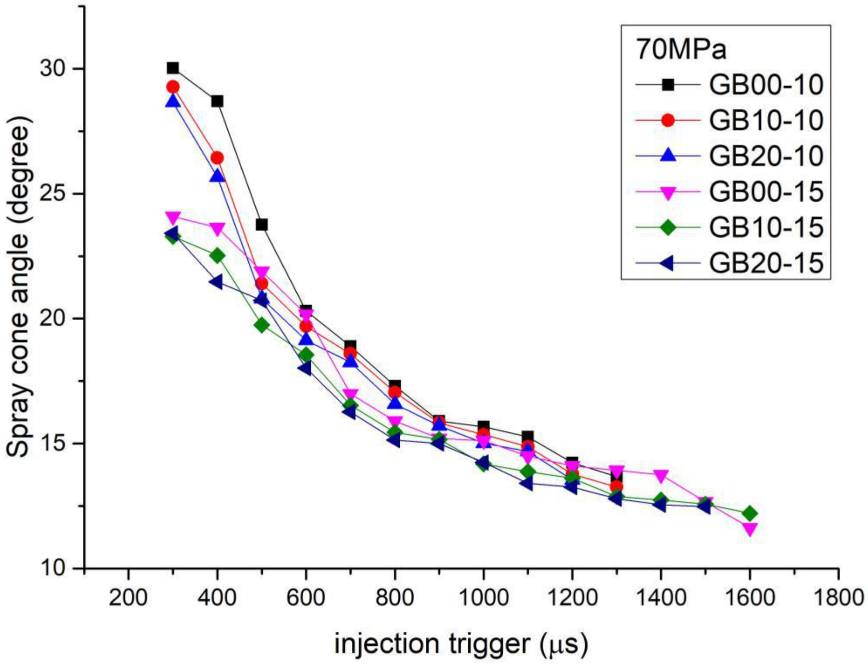

Figure4.3.4: Spray angle for GB00, GB10, and GB20 at 10 to 15 kg/m3 ambient gas density under 70 MPa injection pressures.

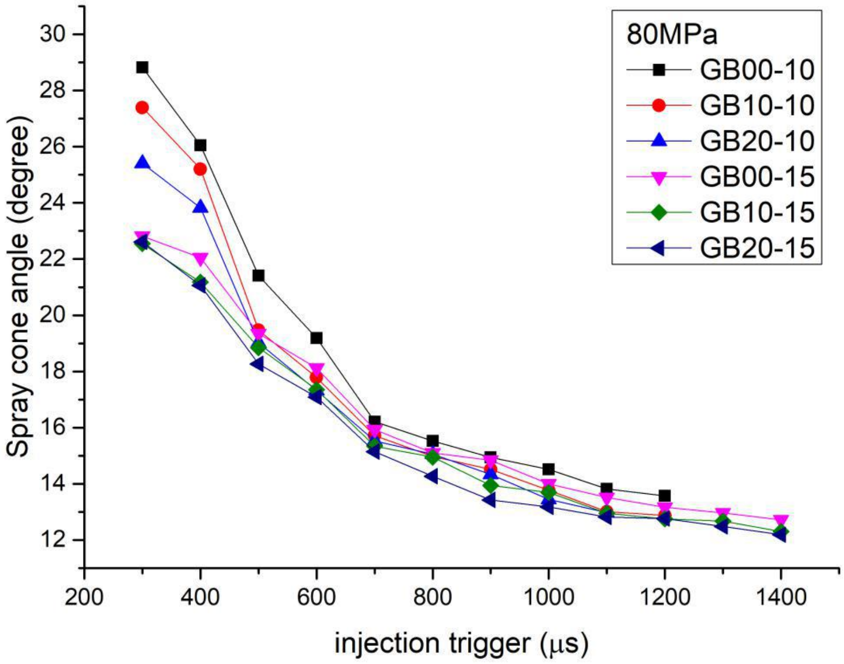

Figure4.3.5: Spray angle for GB00, GB10, and GB20 at 10 to 15 kg/m3 ambient gas density under 80 MPa injection pressures.

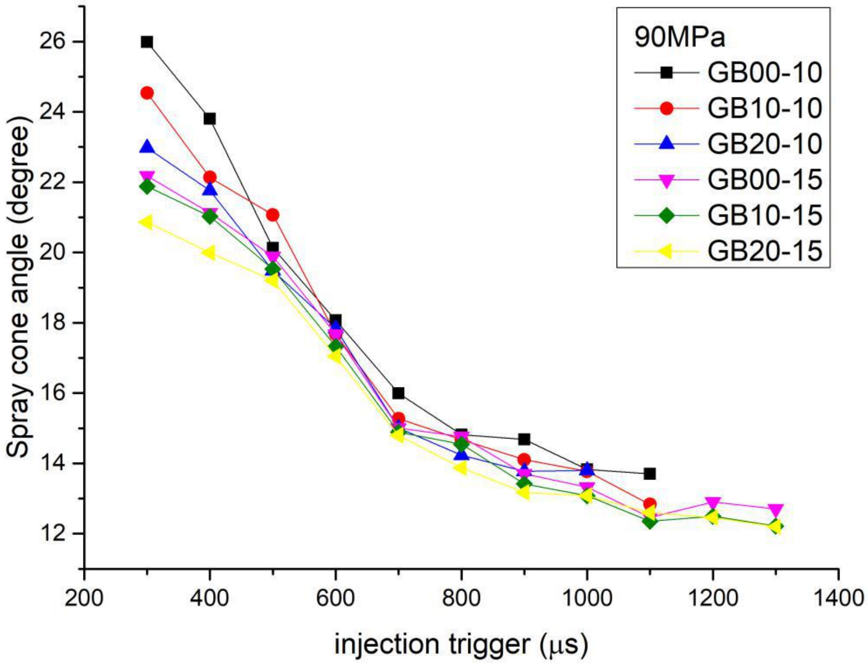

Figure4.3.6: Spray angle for GB00, GB10, and GB20 at 10 to 15 kg/m3 ambient gas density under 90 MPa injection pressures.

Chapter 5. Results of Combustion characteristics

Combustion characteristics are related to the combustion process, and different fuels exhibit different characteristics according to their properties and chemical composition.

5.1 Ignition delay

Ignition delay is defined as the time delay between start of liquid fuel injection and ignition.

The ignition delay period consists of physical delay, wherein atomization, vaporization and mixing of air fuel occur and of chemical delay attributed to pre-combustion reactions. Physical and chemical delays occur simultaneously. This is different from the combustion performance of the fuel, which influences the efficiency of the engine. The ignition delay of a combustion spray is important from the viewpoint of preparing the fuel before injecting into the engine as well as selecting optimum injection timing. So, the ignition delay strongly influences on combustion characteristics and the exhaust emissions of CO, NOx, PM and exhaust particle number (PN) was investigated[49]. The ceiling on NOx is dipping to such a low level that accurate prediction of ignition delay has become important even if it is small. A strong positive correlation was found between ignition delay duration and CO emissions. For both sets of fuels, CO emissions increased with increased ignition delay, at both timings and both loads.

The delay affects the pressure and temperature of combustion, which both affect the formation of especially NOx. It also affects the engine efficiency and therefore the amount of all pollutants if not the concentration of NOx formed. Delay period is one of factor in starting of combustion and hence time available for complete combustion of fuel. As delay period increases, the time for combustion decreases hence will increase chance for incomplete combustion. Which will result in formation more carbon particle. There is a difference between delay of combustion and delay of ignition. Delay of combustion leads to reduced NOx when reduced peak temperature simultaneously, reduced CO because of increased time for CO2 conversion, increased particulate matter because of increased time for particles building, low effect on HC, but can lead to a certain increase of HC. Delay of ignition leads to high pressure increase and thus high temperatures: high NOx and CO emissions, low particulates, eventually lower HC. Cetane number is closely linked to the ignition delay of a fuel, which is one of the most critical factors controlling the combustion characteristics in compression ignition engines. Improper ignition delay in an engine can cause changes in combustion phasing, which can have detrimental effects. The most common symptom of improper ignition delay is decreased power output. Excessive ignition delay can also lead to extreme pressure rise rates and combustion stability issues, which can drastically decrease the life of an engine.

We used GB00, GB10, and GB20 under two different ambient gas densities (10 kg/m^3 and 15 kg/m^3) in a temperature range of 900 – 1,000 K to conduct experimental research on ignition delay. The fuel injection duration time was 1,500 μs.

5.1.1Effect of biodiesel blend ratio

The experimental results clearly demonstrated that as the proportion of biodiesel in the mixed fuel increased, the ignition delay decreased, which is because the high cetane value of biodiesel leads to the increase of the cetane value of the mixture, thus reducing the ignition delay, which proved that the addition of biodiesel helped to improve the auto-ignition capability.

According to Yanuandri, 80%/20% blends of biodiesel and petroleum fuels have the best effect on auto-ignition[39]. On the other hand, in terms of PM emissions, a smaller proportion of biodiesel produces a longer ignition delay, which helps improve the fuel and air mixing process. This provides more time to mix the air and fuel, which in turn improves the air-fuel combustion that contributes significantly to reduce carbon. Therefore, because of the rapid combustion characteristics of biodiesel, mixing gasoline with a smaller amount of biodiesel has greater potential to achieve high efficiency and low engine emissions.

5.1.2Effect of ambient temperature

Considering the influence of ambient temperature on ignition delay, we found that as the ambient temperature increased, the ignition delay of the three fuels was significantly reduced. Higher ambient temperature helped accelerate the reaction rate, leading to our conclusion that a higher temperature helps reduce ignition delay.

5.1.3Effect of injection pressure

As the injection pressure increases, the ignition delay increases because the higher injection pressure promotes the fragmentation of fuel droplets, resulting in produce more and smaller droplets, accelerating the evaporation of fuel, and the expansion of the spray area, resulting in a drop in the temperature of the air-fuel mixture. The lower temperature reduces the reaction rate, leading to an increase in ignition delay.

5.1.4Effect of gas density

The ambient gas density was another parameter that affected the magnitude of the ignition delay. We conducted experiments under ambient gas densities of 10 and 15 kg/m^3. We found that as the gas density increased, all three fuels showed a decrease in ignition delay; This was because as the gas density increased, the collision energy and collision frequency of the gas molecules also increased, and the increase in molecular collision intensity and frequency increased the rate of chemical reaction. Therefore, higher gas density was shown to significantly reduce the ignition delay over the entire experimental temperature range of 900 to 1,000 K and density range of 10 to 15 kg/m^3.

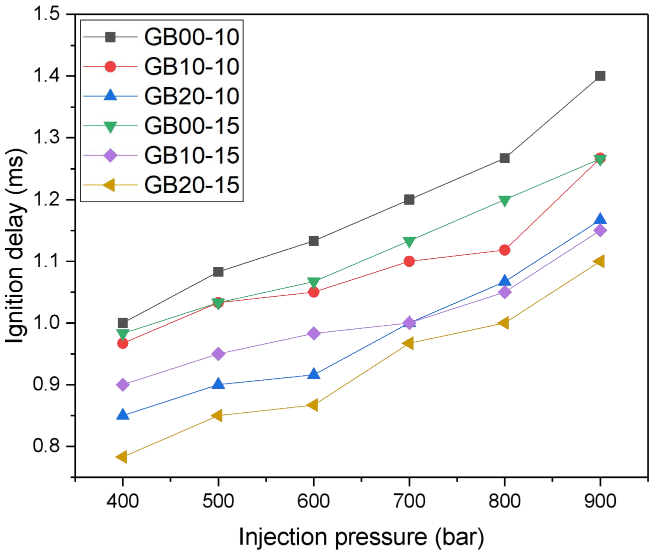

Figure5.1.1: Ignition delay for GB00, GB10, and GB20 at 10 to 15 kg/m^3 ambient gas density, 15% oxygen content, and ambient temperature of 900 K under 40 to 90 MPa injection pressures.

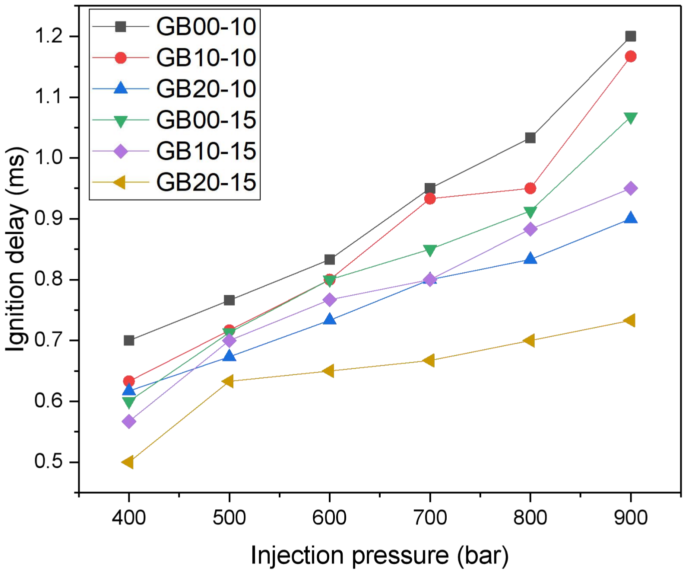

Figure5.1.2: Ignition delay for GB00, GB10, and GB20 at 10 to 15 kg/m^3 ambient gas density, 15% oxygen content, and ambient temperature of 1000 K under 40 to 90 MPa injection pressures.

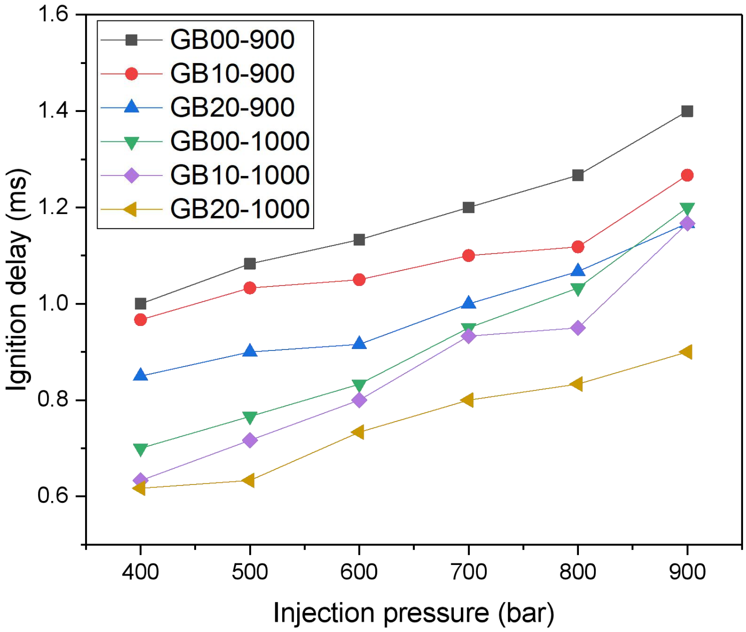

Figure5.1.3: Ignition delay for GB00, GB10, and GB20 at ambient temperatures of 900 to 1,000 K, ambient gas density of 10 kg/m^3 with 15% oxygen content, under 40 to 90 MPa injection pressures.

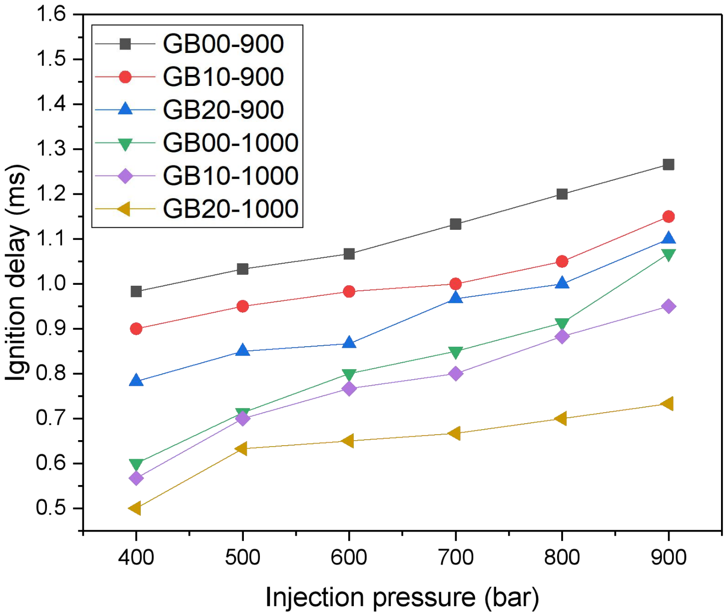

Figure5.1.4: Ignition delay for GB00, GB10, and GB20 at ambient temperatures of 900 to 1,000 K, ambient gas density of 10 kg/m^3 with 15% oxygen content, under 40 to 90 MPa injection pressures.

6. Conclusions

We studied the spray visualization results and theoretical predictions of experimental data pertaining to the spray characteristics and combustion characteristics of GB00, GB10, and GB20 gasoline-biodiesel blends. Our main conclusions are summarized as follows :

1. Injection pressure was directly proportional to the spray length and inversely proportional to the spray cone angle.
2. The spray length and cone angle clearly changed with changes in the ambient gas density and biodiesel ratio.
3. As the proportion of biodiesel in the gasoline increased the ignition delay decreased. This is due to the higher cetane number of biodiesel, which increases the auto-ignition capability of the mixture.
4. When the ambient temperature and ambient gas density increased, the ignition delay decreased because those two factors helped increase the collisions between molecules and accelerate the reaction rate.

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