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# EFFECT OF FUEL INJECTION PRESSURE ON COMBUSTION CHARACTERISTICS OF GASOLINE-BIODIESEL MIXTURES IN A RAPID COMPRESSION AND EXPANSION MACHINE

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**ABSTRACT**
*In this research, experimental investigations were conducted to determine the characteristic of two Gasoline-Biodiesel mixtures (G90B10 and G80B20) on rapid compression and expansion machine (RCEM) that have similar characteristics with Compression Ignition (CI) engines. Different fuel injection pressures between 800-1400 bar were applied. The result shows that G90B10 has higher fuel injection rates than G80B20 at fuel injection pressure from 800-1400 bar. The G80B20 has a shorter ignition delay than the G90B10 at the same fuel injection pressure between 800-1400 bar. G90B10 has a lower burn or combustion duration than G80B20 due to a higher calorific value of the former. The fuel blend G90B10 displays its best enhancement of brake thermal efficiency (BTE) when the start of combustion (SOC) occurred near the top dead center (TDC): 32.40% at 1000 bar while G80B20 shows its best enhancement of BTE when the SOC occurs near the top dead center 56.3 % at 800 bar.*

**Keywords:** Biodiesel, Gasoline, brake thermal efficiency, Top dead center, Rapid compression expansion machine, Fuel injection pressure.



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## 1.0 INTRODUCTION

Biodiesel is an oxygenated fuel with long-chain fatty acids derived from animal fats, waste greases, and vegetable oils [1-3]. It has important characteristics such as being renewable, biodegradable, non-flammable, non-explosive, and non-toxic [4-6]. Recently, biodiesel has been used in compression ignition (CI) engines (diesel engines) as a substitute for diesel fuel or as biodiesel–diesel blends because of its compatibility with diesel fuel [7]. Biodiesel requires minimal or no modifications if used in diesel engines and can potentially result in more stable combustion [8-9]. There has been worldwide concern over the increasing global warming due to the release of greenhouse gases (GHGs) of which transportation as one of the sectors of our economy is a major contributor since it produces almost one-third of the GHGs, viz. carbon dioxide ($CO_2$), and other emissions from fossil fuels utilization [4]. Hence, both short-term and long-term solutions must be proffer which gives rise to alternative fuels that have recently gained much attention because they are renewable, environmentally friendly, economically viable, and can meet the end-user's fuel and power demands under appropriate configurations. Therefore, these fuels are currently being researched and integrated into heavy- and light-duty vehicles in many developed and developing countries. Among these alternative fuels, biodiesel has been considered a feasible substitute for conventional diesel fuel due to its renewable, non-toxic, and biodegradable characteristics [10-12]. Biodiesel is also compatible with current engine configurations and manufacturing infrastructures.Consumer purchasing power in recent years, has increased, due to economic improvements leading toincreased demand for vehicles and electric devices around the world, which will significantly increase the use of fossil fuels. Sources of fossil fuel are finite; therefore many people have been conducting research to utilize renewable energy as an alternative to the use of fossil fuels. Biodiesel is such an alternative fuel; it can decrease the usage of conventional petroleum diesel over the long term since it is produced from animal fat and vegetable oil [13].

A very intriguing possibility for this study is the compression ignition (CI) engine technology. Only compressed air is utilized in the compression step because it injects fuel close to the top dead center (TDC), which is where an engine's piston is when it is at the top of its stroke. The performance of the CI engine is superior to the spark ignition (SI) engine because this creates an optimum cycle in the system during combustion. Due to the enormous energy that can be produced, CI engines can also be configured with a high compression ratio, making them popular in industrial engines and vehicles [14].

Numerous renewable energy sources have gained popularity over the past 20 years. Alternative fuels have been thoroughly investigated for the transportation sector, including vegetable oils, biodiesel, and straightforward alcohol blends with diesel. Diesel machinery can be operated with biodiesel blends containing 20% or less without major modifications. Although pure biodiesel (B100) can be used, it may need to undergo some engine modifications to prevent maintenance and performance issues. According to a statement published by the Volkswagen Group, a number of its vehicles are compatible with B5 and B100 rapeseed oil-based fuels as well as the European Norms (EN) 14214 standard. No warranty will be voided if the designated biodiesel kind is used in its vehicles [15]. Due to worries about "production difficulties," Mercedes Benz forbids diesel fuels that include more than 5% biodiesel (B5). In addition to being used in diesel vehicles, biodiesel is also used in generators, railroads, and other forms of transportation. However, the high emissions from diesel fuel, which is mostly used for CI, have become a significant environmental problem and have prompted the adoption of tight emissions rules in a number of nations. Compared to diesel fuel, gasoline is a clean fuel with lower post-combustion pollutants [13]. Numerous investigations on gasoline compression ignition engines have been conducted in an effort to use gasoline fuel in diesel engines to increase their power output over spark engines which is the major motivation for this investigation. Due to its reduced emissions, gasoline is now a viable alternative to diesel. According to Putrasari et al research's [16], the thermal efficiency and combustion time of mixed gasoline-biodiesel are nearly identical to those of diesel. Numerous studies have shown that blending biodiesel into regular petroleum diesel reduces environmental pollution but also lowers thermal efficiency and brake power due to increased knocking [15]. Due to their great thermal efficiency and low emissions, gasoline compression ignition (GCI) engines are promising and have attracted a lot of research interest [17-18].

Fuel with a low cetane number or high volatility can be used to achieve low-temperature combustion (LTC) [19-20]. A fuel-rich zone is less likely to develop as a result of LTC's reduced NOx emissions and improved air-fuel mixing, which eventually results in a decrease in particulate matter [21]. Due to its high octane rating, which results in a strong auto-ignition resistance, gasoline is a viable option for LTC. This results in a longer ignition delay and a more uniform mixing of air and fuel. Additionally, a fuel's volatility determines how easily it can evaporate. A better air-fuel mix and a lower local equivalency ratio were as a result.

Pure gasoline has low lubricity [22] and a higher vapor pressure, both of which over time will affect a common rail system [23]. When used in a GCI, biodiesel has a great chance of solving the low lubricity issue with gasoline. Additionally, adding biodiesel will improve combustion due to its high oxygen concentration [24]. An investigation was carried out to evaluate the GCI engines' combustion behavior when using a blend of gasoline and biodiesel as a fuel. It was shown that blending biodiesel with regular petroleum diesel improves combustion stability and lowers the necessary intake temperature [25].

There has been ongoing study on enhancing engine efficiency and performance for many years. An investigation into the impact of a nanomaterial additive on blends of diesel and n-heptanes in a diesel engine revealed an improvement in engine performance [26]. A study on how fuel injection pressure affected a diesel engine was carried out and it was discovered that higher fuel injection pressure reduced the brake-specific fuel consumption (BSFC) and improved the brake thermal efficiency (BTE) at low speeds [27]. The principal determinant of fuel stratification inside the chamber and a major influence on the combustion process, varying the injection pressure appears to be a potential technique to improve combustion characteristics. Smaller fuel droplets are delivered via higher fuel injection pressure, increasing the surface area to volume ratio. This results in a more complete combustion due to enhanced fuel's capacity to vaporize.

In this research, the combustion characteristics including the effect of fuel injection pressure between 800-1400 bar on the fuel injection flow rate, ignition delay, burn duration and brake thermal efficiency of two blends of gasoline-biodiesel mixes G90B10 and G80B20 on Rapid compression and expansion machine (RCEM) are studied.

## 2.0 Brief Literature Review

### 2.1 Biodiesel

Due to its qualities being quite comparable to those of diesel fuel, particularly in terms of cetane number, biodiesel has become extensively commercially available all over the world [28]. Vegetable oils can be used to create standard biodiesel through the processes of blending, emulsification, thermal cracking, and transesterification. Fatty Acid Methyl Esters

(FAME), often known as biodiesel, are produced specifically when vegetable oil is transesterified with alcohol.

However, biodiesel contains five methyl esters components with longer carbon chains than regular diesel fuel [29]. As a result, the higher viscosity may cause operating issues and filter clogging, particularly in cold climates. Additionally, biodiesel degrades up to four times more quickly than diesel fuel [30], harming the injection system's components and causing issues like injector coking or injector deposits, particularly in high-pressure fuel pumps [30]. On the other hand, biodiesel is renewable and its oxygen content, which is typically over 10% in mass, may effectively reduce engine-out emissions of unburned hydrocarbons (UHC), carbon monoxide (CO), and particulate matter (PM) in modern CI engines [31], with only a slight increase in the emissions of nitrogen oxides (NOx) [32-35].

## 2.2 Fuel Blend

### 2.2.1 Addition of Biodiesel

Due to its compatibility with diesel fuel, biodiesel has been utilized in compression ignition (CI) engines (diesel engines) as a diesel fuel substitute or in biodiesel-diesel blends in recent years. If utilized in diesel engines, biodiesel requires little to no modification and may produce more stable combustion [36-37]. Although utilizing biodiesel has been shown to have advantages on engine test stands, commercially, it is only blended at low levels with diesel because standards need to be set and validated before raising the proportion of biodiesel in fuel blends that are used [38, 39, 40]. Additionally, it has been established that the usage of biodiesel-diesel mixes in diesel engines exhibits various behaviors when operating at low to high engine horsepower, blending ratios, and other operating circumstances. To clearly determine the best use cases, more research into the mixing strategy is necessary. It is also important to note that certain studies have suggested difficulties with biodiesel, such as mixing problems caused by the fuel's higher viscosity and reduced evaporability, which can lead to carbon buildup, piston ring adhesion, soot generation, and inferior combustion characteristics [38, 41]. In the end, problems including decreased engine performance, shorter service intervals, and higher tailpipe emissions are thought to be probable [42].

### 2.2.2 Addition of Gasoline

Some tactics, such as fuel additives [43], fuel preheating procedures [44], and engine design optimization methods [45] have been suggested to address the difficulties associated with blending biodiesel with diesel. But putting such methods into practice is expensive [38]. It has recently been stated that adding gasoline to diesel-biodiesel blends shows promise in addressing the aforementioned issues related to diesel-biodiesel use [46]. With the right controls in place, this newly created mixing strategy can improve combustion behavior [47]. The majority of these enhanced characteristics brought on by the gasoline addition have been linked to modifications in the physicochemical properties [46, 48]. In other words, the improvement in physicochemical qualities makes it possible to mix fuel more effectively, create better-premixed areas, and, as a result, produce engines with lower emissions. Additionally, adopting a multiple injection approach in conjunction with EGR has led to decreased NOx and PM emissions [49].

## 2.3 Energy Conversion Efficiency and Emission Level of Internal Combustion Engine Factors

Spray mixing and combustion processes are regarded as the major factors that determine the energy conversion efficiency and emission level of internal combustion engines [50].

Improving spray atomization and optimizing the combustion process are becoming more and more important for enhancing engine performance, and reducing fuel consumption and pollutant emissions [51].

## 3.0 METHODOLOGY

The method used by Setiawan et al. [52] has been adopted completely. Typically, the experiment was conducted on Rapid Compression and Expansion Machine (RCEM) with similar characteristicstoa Compression Ignition (CI) engine for a gasoline-biodiesel (GB) blend of 10% and 20% by volume with varying fuel injection pressure between 800bar - 1400bar. The G90B10 (90% gasoline and 10% biodiesel) and G80B20 (80% gasoline and 20% biodiesel)were prepared in a Clean glass container and stirred vigorously for a minimum of 15 minutes to 20 minutes to obtain a homogeneous mixture. The injection flow rate was measured to analyze the capacity of injection in every cycle. The injection pressure was varied with constant injection duration which resulted in different amounts of fuel injected into the chamber. The injection pressures were 800, 1000, 1200, and 1400 bar produced from a common rail and a high-pressure pump controlled by a common rail as depicted below.

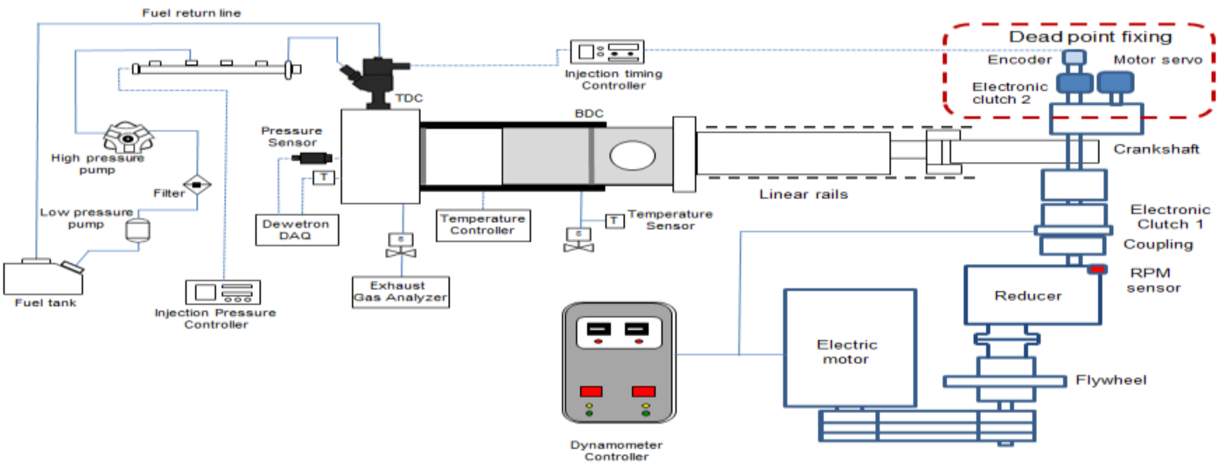


Figure 1: Schematic diagram of rapid compression expansion machine

## 4.0 Result and Discussion

Figure 2 shows the fuel injection flow rates of the G90B10 and G80B20 fuel blends with the fuel injection pressure at 800-1400 bar. It is observed from Figure 2 that G90B10 has higher injection rates than G80B20 because of its lower biodiesel content. G90B10 has injection rates values of 0.015, 0.017, 0.021, and 0.023 mL/cycle at fuel injection pressures of 800, 1000, 1200, and 1400 bar respectively while the injection rates of 0.013, 0.016, 0.019, and 0.022 mL/cycle are for G80B20 at the same respective fuel injection pressures. The different injection rates are a result of the different densities and viscosities of the gasoline and biodiesel. It is a fact that a higher viscosity fuel which is the one with higher biodiesel content will definitely have a lower fuel injection flow rate. Viscosity affects the fuel injection flow rate by raising both the viscous friction force and hydraulic force at the leakage passage while the density of the fuel affects only the hydraulic force. However, Figure 2 also shows that the effect of density and viscosity on the fuel injection flow rate is lowered by using higher injection pressure.

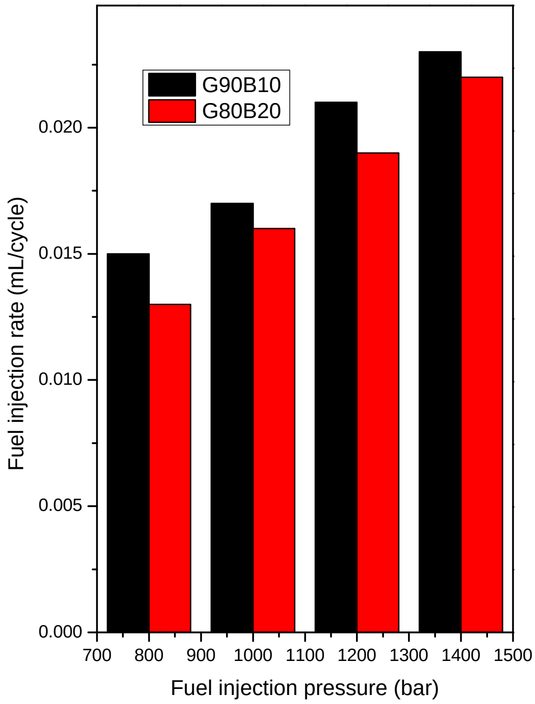


Fig 2: Fuel injection rates of G90B10 and G80B20

Figure 3 displays the result of the ignition delay at the fuel injection pressures of 800-1400 bar. The ignition delay in a diesel engine is defined as the time interval between the start of injection and the start of combustion. The two components of this delay period are (a) the physical delay caused by the atomization, vaporization, and mixing of the fuel and air, and (b) the chemical delay caused by the pre-combustion reactions. There are simultaneous chemical and physical delays (Lakshminarayanan and Yogesh, 2010). The result in Figure 3 shows a very long time delay for G90B10 ignition delay at 800 and 1000 bar fuel injection pressure. The ignition delay for G90B10 at 800, 1000, 1200, and 1400 bar of fuel injection pressure are 17, 14, 11, and 7 °CA while the ignition delay for G80B20 at the same respective fuel injection pressures are 13, 10, 7, and 4 °CA respectively. The ignition delay is reduced at higher fuel injection pressure applied to the engine. Besides, the ignition delay is observed to reduce to shorter times due to the high content of biodieselas in the case of G80B20 in this research. Therefore high fuel injection pressure and high biodiesel content reduce and shorten ignition delay making the engine ignition process faster (Satiawan et al., 2020). An increase in fuel injection pressure leads to a rise in cavitation-the main breakup and then fuel atomization making the engine ignition faster by shortening the ignition delay.The fuel's ability to auto-ignite is influenced by the cetane number; increasing the biodiesel proportion in a gasoline-biodiesel fuel mixture will raise the cetane number high thereby improving the fuel's capacity to auto-ignite against compression which will enhance the auto-ignition speed and engine performance. The G80B20's higher biodiesel content and higher cetane number will speed up the ignition by shortening the ignition delay and then improve engine performance than G90B10.

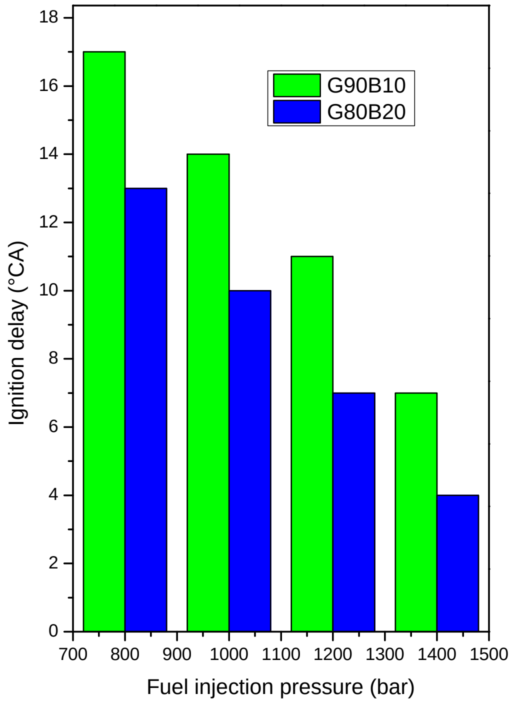


Fig 3: Ignition delays of G90B10 and G80B20

The combustion duration of G90B10 and G80B20 with different fuel injection pressures is displayed in Figure 4. The burn duration at 800, 1000, 1200, and 1400 bar for G90B10 is 32, 30, 27, and 31 ° CArespectively while that for G80B20 at 800, 1000, 1200, and 1400 bar is 34, 30.5, 31, and 35 ° CA respectively. The G90B10 has a lower burn or combustion duration than G80B20 due to a higher calorific value of the former.

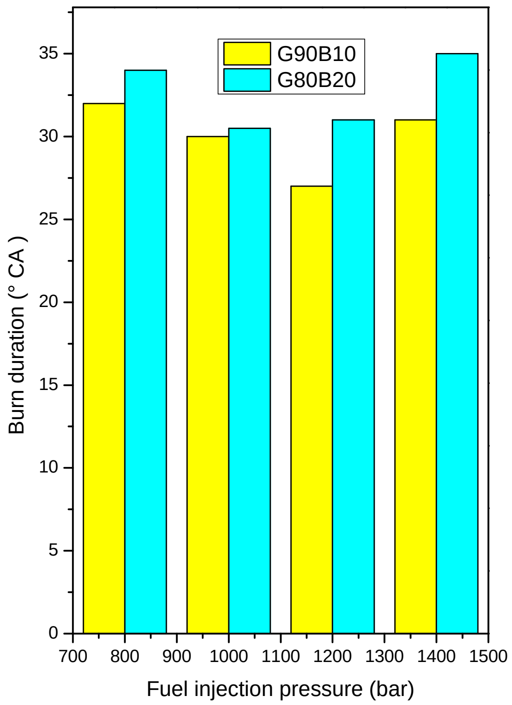


Fig 4. Burn Duration

The brake thermal efficiency (BTE) of the engine using G90B10 and G80B20 with fuel injection pressures of 800-1400 bar is shown in Figure 5. The BTE values for G90B10 at 800-1400 bar are 18, 32.40, 22.51, and 22.50 % while the BTE values for G80B20 at 800-1400 bar are 56.30, 45.24, 38.63, and 33.21 %. The fuel blend G90B10 displays its best boost of BTE when the start of combustion (SOC) occurred near the top dead center (TDC): 32.40% at 1000 bar while G80B20 shows its best boost of BTE when the SOC occurs near the top dead center 56.30 % at 800 bar. The decrease in BTE is seen in both fuel mixes G90B10 and G80B20 at higher pressures.

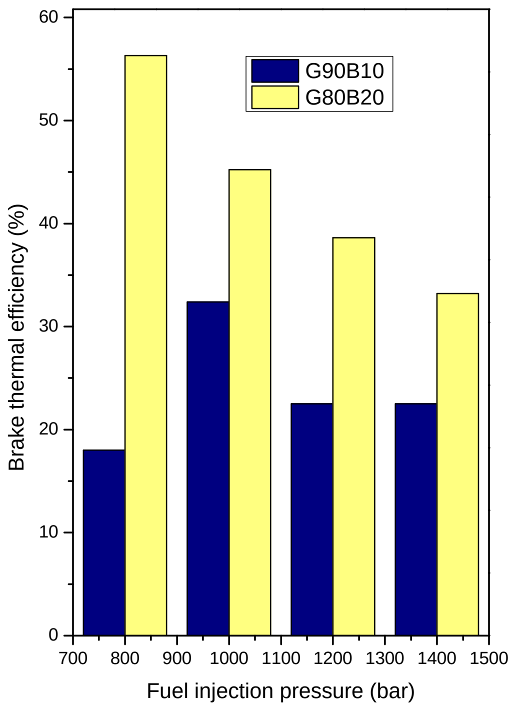


Fig. 5. Brake thermal efficiency

## 5.0 CONCLUSION

There is an increase in the fuel injection flow rate as the fuel injection pressure increase from 800-1400 bar for both blends G90B10 and G80B20. The ignition delay reduces as the fuel injection pressure increases. High fuel injection pressure and high biodieselcontent (G80B20) reduce and shorten ignition delay making the engine ignition process faster. The G90B10 has a lower burn or combustion duration than G80B20 due to a higher calorific value of the former. The fuel blend G90B10 displays its best boost of BTE when the start of combustion (SOC) occurred near the top dead center (TDC): 32.40% at 1000 bar while G80B20 shows its best boost of BTE when the SOC occurs near the top dead center 56.3 % at 800 bar.

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