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Comparison of Performance Analysis and Emission Characteristics of Conventional and Piezoelectric Fuel Injection.

Pradeep N R[1*], Hemanna K B [2*]
1*2,BIET college,
1* pradeepbiet@gmail.com , 2* hemannakb@gmail.com

ABSTRACT

In this study, we conducted experimental investigations using a single four-stroke water-cooled DICI engine. We tested it in two modes: conventional direct injection and high-pressure piezoelectric direct injection, using both diesel and Pupae-biodiesel as fuels. We compared the performance and emission characteristics of the mechanical direct injection (MDI) engine under varying load conditions with the high-pressure piezoelectric direct fuel injection (PDI) system engine, considering both neat diesel and biodiesel. During the tests, the engine was operated at a constant speed of 1500 rpm, and load conditions were adjusted accordingly. We maintained the optimum injection timing and injection pressure for the experiments. In the MDI mode, we used an injection timing of 23° CA for both diesel and biodiesel. In the PDI mode, we used 11° CA for both diesel and biodiesel. Injection pressures were set at 260 bar for MDI and 1200 bar for PDI, irrespective of the fuel type (diesel or biodiesel).

Keywords - Pupae-biodiesel, Mechanical Direct Injection, Piezoelectric Direct Fuel Injection.

1. Introduction

Internal combustion engines used to employ mechanical injectors for their combustion operation. This choice was driven by its simplicity, ease of operation, and cost-effectiveness. However, mechanical injection systems had their limitations. For instance, their injection pressure was limited to 200-280 bar, which resulted in increased engine exhaust emissions due to inadequate fuel atomization during combustion. They also had slow response times due to the reliance on mechanical plungers. Inaccurate fuel metering led to lower fuel efficiency and increased engine noise.

In response to these limitations, electronic fuel injection with solenoid injectors became the preferred choice. This technology allowed for injection pressures exceeding 500 bar, resulting in better fuel atomization, optimized combustion, and reduced exhaust emissions. Solenoid injectors also offered faster response times due to the use of solenoid valves and precise fuel metering, leading to less engine noise and improved fuel economy. However, solenoid injectors had their own drawbacks, such as being limited to a maximum of 5 injection pulses per cycle and challenges in controlling fuel delivery during valve closure.

To address these issues, advanced electronic fuel injectors known as piezoelectric fuel injectors were developed. These injectors offer numerous advantages over solenoid valves, including rapid switching with up to 7 injection pulses per cycle and a wide injection pressure range of 300-2000 bar. This high injection pressure results in superior fuel atomization, ensuring efficient combustion and effective spray penetration for optimal fuel-air mixture utilization. When paired with an engine control unit (ECU), piezoelectric injectors allow for multiple injections within a combustion cycle, promoting efficient combustion. This, in turn, leads to cleaner exhaust emissions and increased power output.

Multiple injections also contribute to reduced noise levels during combustion by gradually increasing the temperature, as opposed to a sudden temperature spike. Piezoelectric injectors stand out for their precision in fuel metering, leading to improved combustion, better fuel economy, and reduced emissions of pollutants such as carbon monoxide (CO), unburnt hydrocarbons (UHC), oxides of nitrogen (NOx), and smoke [1-5].

2. Biodiesel Production

Biodiesel derived from pupae oil was manufactured via a conventional transesterification process using potassium hydroxide (KOH) as the catalyst, as illustrated in Figure 1.

The surplus methanol employed in the process was initially reclaimed through a batch distillation procedure, and it was then allowed to undergo a settling phase. The glycerin, which settled at the bottom, was separated, while the top layer was subjected to multiple water washes to eliminate any remaining alkali content. Subsequently, this upper oily layer was subjected to a batch distillation process at a temperature of 120°C to remove any residual moisture. The final product was collected following these steps.

The process flow for the production of biodiesel is presented in Figure 2.

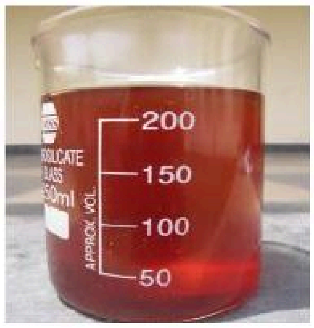

Fig 1. Pupae Biodiesel

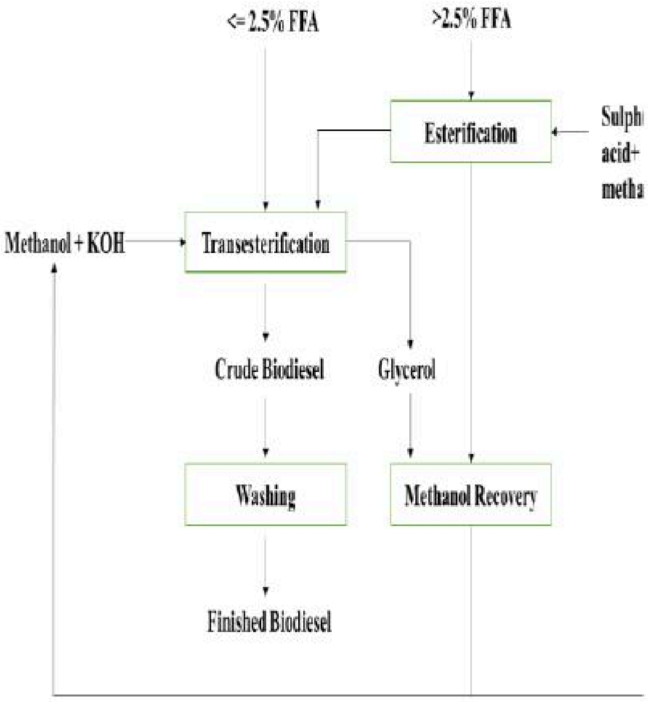

Fig 2. Process flow for biodiesel production

3 Performance Parameter

Figure 3 illustrates the relationship between brake thermal efficiency (BTE) and brake-mean effective pressure (BMEP) for both MDI and PDI engines. As the load increases, there is a consistent improvement in brake thermal efficiency. However, it's worth noting that when running on biodiesel, both conventional and piezoelectric injection engines exhibit lower brake thermal efficiency across the entire load spectrum compared to diesel operation. This can be attributed to biodiesel's higher viscosity and lower heating value.

In contrast, electronic injection operation delivers higher brake thermal efficiency compared to conventional engine operation. This improvement is primarily due to the higher pressure in piezoelectric injection, resulting in better atomization, especially in MDI mode. This is evident from the maximum brake thermal efficiency values observed, which are 33.87% and 32.17% for diesel and biodiesel when using a PDI engine, and 29.6% and 27.7% for diesel and biodiesel with MDI engine operation.

Moving to Figure 4, we examine the impact of brake-mean effective pressure on exhaust gas temperature for MDI and PDI engines. Using PDI mode operation with higher injection pressure leads to elevated cylinder temperatures, resulting in higher exhaust temperatures. This effect is most pronounced in PDI mode at higher loads, where exhaust temperatures reach 465°C and 447°C for diesel and biodiesel, compared to 353°C and 339°C for diesel and biodiesel in MDI mode operation.

4 Emission Parameters

Figures 5 and 6 display how the emissions of carbon monoxide (CO) and unburned hydrocarbons (UHC) change in relation to brake mean effective pressure when using diesel and biodiesel fuels with both MDI (Mechanical Direct Injection) and PDI (Piezoelectric Direct Injection) engines. Notably, the CO and UHC emissions are notably lower when utilizing the piezoelectric injection method. This reduction is primarily attributed to the higher injection pressure, which enhances combustion, improves fuel atomization, and reduces ignition delay. Additionally, higher temperatures during diffusion combustion expedite the oxidation of UHC and CO. Biodiesel, due to its superior ignition characteristics and increased oxygen content, results in significantly lower CO and UHC emissions [11-14].

Moving on to Figure 7, it illustrates the changes in nitrogen oxides (NOx) emissions with respect to brake mean effective pressure when using diesel and biodiesel fuels with MDI and PDI engines. In this case, NOx emissions tend to increase with high-pressure piezoelectric injection. This is due to faster combustion and the higher temperatures attained during the engine cycle. The formation rate of NOx is dependent on both temperature and the oxygen content of the fuel. When comparing biodiesel to diesel, biodiesel generates less heat (lower lower heating value, or LHV). Consequently, the exhaust gas temperatures of biodiesel and its blends are lower than those of diesel fuel. However, the higher oxygen content in biodiesel results in the production of more nitrogen oxide compounds compared to diesel fuel [15].

Finally, Figure 8 represents how smoke opacity changes in relation to brake power when using diesel and biodiesel fuels with MDI and PDI engines. PDI operation, using both diesel and biodiesel, results in reduced smoke compared to MDI engine operation. This reduction is attributed to the higher injection pressure, which enhances fuel atomization and improves combustion. Furthermore, it's observed that enhanced soot oxidation occurs due to the higher combustion temperatures. When using biodiesel fuel, the presence of oxygen molecules and the absence of aromatic and sulfur compounds, in comparison to diesel, improve the local fuel-to-oxygen ratio during combustion, leading to reduced smoke opacity in the exhaust [16].

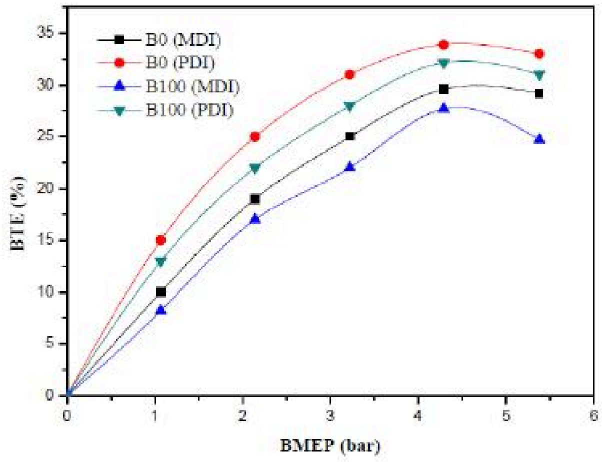

Fig 3. Variation of BTE with BMEP for MDI and PDI modes of operation

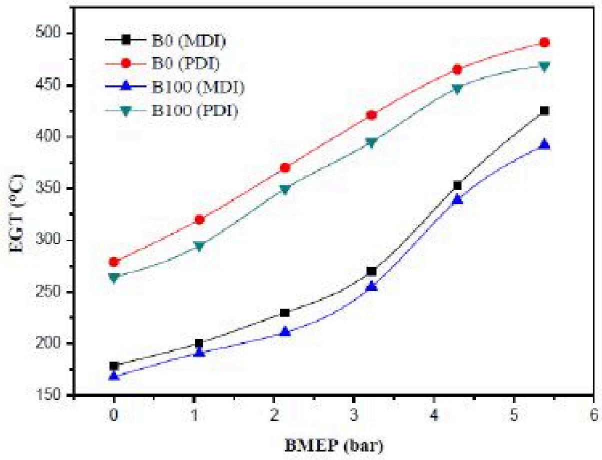

Fig 4. Variation of EGT with BMEP for MDI and PDI modes of operation

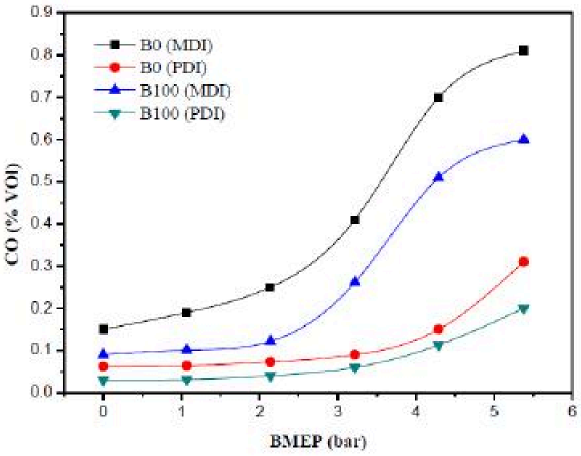

Fig 5. Variation of CO with BMEP for MDI and PDI modes of operation

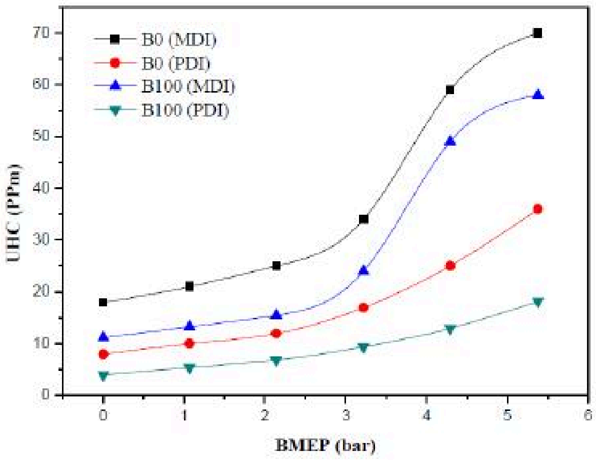

Fig 6. Variation of UHC with BMEP for MDI and PDI modes of operation

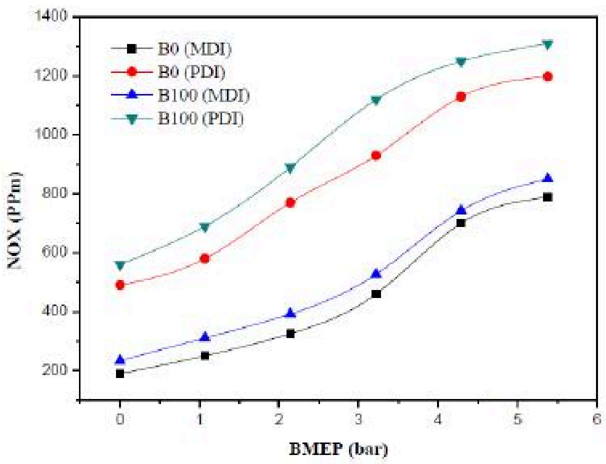

Fig. 7. Variation of NOX with BMEP for MDI and PDI modes of operation

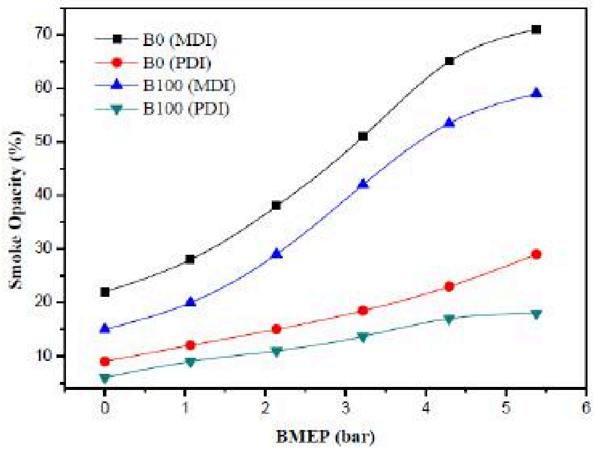

Fig. 8. Variation of smoke opacity with BMEP for MDI and PDI modes of operation

5. Conclusion

The PDI mode of engine operation generally yields improved engine performance and lower gas emissions, except for NOx emissions compared to the MDI mode of operation. As the injection pressure increases, brake thermal efficiency improves, reaching a maximum value at optimized injection timings before declining with further pressure increases. The highest brake thermal efficiency, 33.87%, was achieved with an injection timing of 11°CA BTDC and 1200 bar injection pressure in PDI mode, surpassing MDI mode.

Biodiesel shows lower brake thermal efficiency than diesel in both MDI and PDI modes. The highest brake thermal efficiency observed was 29.6% and 27.7% for diesel and biodiesel in MDI mode, and 33.87% and 31.51% for diesel and biodiesel in PDI mode.

However, NOx emissions increased with higher biodiesel content in diesel fuel, with a substantial rise of 61.4% for diesel and 68.2% for biodiesel in PDI mode compared to MDI mode.

On the other hand, UHC, CO, and smoke emissions decreased with increased biodiesel concentration in diesel fuel and increased loading conditions. These emissions also decreased with injection pressure initially, reaching a minimum value before increasing at optimized injection timings in both MDI and PDI modes. Notably, there was a reduction in UHC (57.6% and 73.5%), CO (78.6% and 78.4%), and smoke emissions (64.6% and 68.2%) for diesel and biodiesel, respectively, in PDI mode compared to MDI mode.

In summary, using pupae biodiesel and its blends, especially for extended engine operation, appears to be more favorable than using neat diesel. This approach can reduce the environmental impact of transportation, decrease reliance on crude oil imports, and offer new business opportunities for sericulture enterprises during periods of excess sericulture production. It could be a promising solution for addressing air pollution concerns in India.

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