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PORT INJECTION OF DIESEL, BIODIESEL, AND PETROL IN A COMPRESSION IGNITION DIRECT INJECTION DIESEL ENGINE TO MITIGATE NITROGEN OXIDES AND SOOT EMISSIONS

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ABSTRACT

The internal combustion engine is critical to modern society's development. Spark ignition engine (SI) and compression ignition engine (CI) now use gasoline and diesel as their primary fuels. As a result of burning these fuels, significant amounts of pollutants are released into the atmosphere, resulting in environmental issues. Internal combustion (IC) engines are widely acknowledged as a significant source of environmental air pollution. The engine's fuel oxidation process not only produces useful power, but also produces significant amounts of pollutant emissions such as carbon monoxide (CO), unburned hydrocarbons (HC), nitrogen oxide (NO_x), and particulate matter (PM). When developing a new combustion process, consideration must be given to: lean homogeneous air-fuel mixture, increased compression ratio, and total and instantaneous combustion, all of which result in Port Injection Compression Ignition (PICI), that is a highly efficient and clean method of combustion. The goal of this research is to conduct an experimental investigation of PICI process of compression in a Premixed Charge Compression Ignition (PCCI) mode with Pilot Injection (PI) as the combustion activator. It was found that when compared to the conventional mode, the PICI mode produces cooler exhaust gas temperatures. Temperatures were lower in the PICI mode with biodiesel and petrol as secondary and primary fuels than in the PICI mode with other fuel combinations. In the PICI mode, the HC emission decreases at higher load with all fuels. In the biodiesel conventional mode, HC emission is minimum than in other modes. For all modes of operation, the specific fuel consumption has reduced with load. Diesel and gasoline have the lowest specific fuel consumption as primary and secondary fuels, respectively. Fuel usage in the PICI mode is lower than in the normal mode.

Keywords: gasoline, diesel, exhaust gas, internal combustion engine, compression process, premixed charge compression ignition.

INTRODUCTION

IC engines are used in modern transportation. We would not have been able to modernize without millions of vehicles on land and sea. When these fossil fuels are burned, they heavily pollute the atmosphere. This engine is extremely polluting. Unburned hydrocarbons, nitrogen oxides, and particulates are produced during the combustion of fuel [1 - 3]. The global importance of IC engine emissions and fuel economy cannot be overstated. By reflecting heat to the earth's surface, CO_2 contributes to global warming. The lungs are irritated by hydrocarbon emissions. Inhalation of particulate emissions, unburned hydrocarbon and soot emissions causes cancer [2 - 4]. Low oxygen levels are linked to health problems, acid rain, and global warming. Strict emissions and fuel economy regulations necessitate the development of efficient IC engines. A growing global vehicle fleet, combined with concerns about potential greenhouse gas emissions from current fossil fuels, has accelerated the adoption of alternative fuels and elevated them to the status of a critical research area. It has the potential to decentralize fuel supply while also reducing pollution. Jarrow oil is a significant source of IC engine fuel. Biodiesel emissions are comparable to fossil fuel emissions because plants absorb carbon dioxide from the atmosphere. Photosynthesis is used by plants to absorb CO_2 and store solar energy. It is emitted after the biomass has been converted to biodiesel and burned [5 - 7]. A portion of the energy contained in CO_2 can be used to power an electric vehicle. PICI technology, which combines the benefits of both spark and compression ignition, has grown in popularity for alternative fuels. The efficiency and low emissions of PICI engines are being studied. PICI engines can compete with diesel engines in terms of efficiency. Natural gas, gasoline, or bioethanol can all be used in PICI engines.

PICI engine

While engine emissions remain a concern, energy conservation is becoming more important. The goal of Port Injection Compression Ignition (PICI) engines is to achieve homogeneous charge combustion with a high compression ratio at lower peak temperatures. In recent years, the diesel engine market has grown rapidly, and already in 2005 it accounted for half of the total car sales in Europe [4, 8, 9]. This increase is most likely due to the diesel engine's superior fuel economy. Other factors, such as the increase in power since turbochargers became widely available on diesel engines, can also account for this progress. Despite this, diesel vehicles are polluted more than gasoline vehicles. Fortunately, the tailpipe emissions of these engines have been reduced. In addition to the newer particulate trap, the older NO_x catalyst continues to be utilized in vehicle exhaust gas systems. While some reducing emissions were effective enough to meet Euro regulations, they have yet to be updated to meet the new Euro regulations. The standard diesel trade-off limit may be exceeded, according to some recent research that was done as a consequence of this.

PICI ignition is influenced by the charge mixture's composition, temperature history, and pressure. As PICI combustion control methods, EGR (Variable Exhaust Gas Recirculation), VCR (Variable Compression Ratio), and VVT (Variable Valve Timing) are all recommended. The time responses of VCR and VVT technologies might be made faster to manage fast transients. The PICI experiment employs cutting-edge diesel technology, with each injector receiving high-pressure fuel from a separate fuel pump [6, 10 - 12]. Each injector does have a solenoid controlled by an ECU, improving engine performance and fuel economy. Injection systems, both mechanical and electronic, can be used directly or indirectly. Because of its low NO_x emissions and high efficiency, the PICI engine is a viable alternative to the traditional engines, combining the benefits of both engines. Premixing air and fuel before cylinder initiation and afterward igniting the combination via compression is the PICI concept. Unlike current engines' turbulent flame propagation or mixing controlled combustion, PICI is a global auto-ignition process. Short combustion durations maximize engine efficiency in the "otto" cycle. Because of the low temperatures within the cylinder caused by global auto-ignition, nitrogen oxide emissions are low (NO_x, the chief precursor to photochemical smog). Engines with PICI combustion can be designed to be as efficient as or more efficient than conventional engines. A lean air-fuel mixture is possible due to the lack of flame propagation. Lean mixtures emit significantly less NO_x than stoichiometric mixtures. Because the mixture is homogeneous, there will be no soot emissions. The main disadvantage of the PICI is its limited operating window because of the lack of direct ignition timing control [8, 13, 14]. In PICI, the chemical kinetics reaction of the air-fuel combination determines the ignition start. In an engine with a low compression ratio, the air-fuel combination should be prepared to a higher temperature to ensure proper PICI combustion. Preheating reduces engine power density by allowing less air-fuel mass flow rate into the cylinder.

Ignition resistance in diesel

Low self-ignition resistance seems to be beneficial for diesel engines, and not for PICI. Early fuel ignition results in fast, loud, and potentially harmful combustion. To avoid premature fuel ignition, the charge should be cooler than usual for diesel fuel. EGR can be externally cooled. EGR reduces the rate of combustion, which reduces combustion knocking. Early ignition is problematic since it complicates the functioning of diesel fuel. Many scientists have examined alternate fuels, like alcohols or compressed natural gas (CNG), with PICI diesel engines [4 - 9, 15]. This approach is similar to previous attempts to build PICI engines from SI engines. The diesel fuel's cetane number determines its ignition quality. The octane number of gasoline rises as ignition resistance increases, whereas the cetane number rises as ignitability grows. Higher cetane fuels necessitate less activation energy, resulting in lower temperatures.

Premixed PICI

In PICI engines powered by diesel fuel, the fuel is injected into the intake air ahead of the intake valve. For starters, using standard diesel compression ratios results in very early ignition and knocking. A compression ratio of 10 - 11 is preferred by the PICI mode [10, 11, 16, 17]. Second, lowering intake temperatures below 130°C causes an increase in smoke emission. PICI requires intake temperatures ranging between 90°C and 130°C [12, 18]. Thirdly, the PICI phase produces a significant amount of unburned HC.

This was accomplished using standard diesel injection and premixed PICI powered by diesel fuel. A GDI injector with a 5 MPa injection pressure has been used to inject diesel fuel into the intake manifold. At high loads, that may result in serious knock issues. To delay auto-ignition long enough for near-TDC Direct Injection to control combustion, a 50/50 MTBE/diesel mixture was used (DI). An intake manifold pintle-nozzle injector was also used to test premixed diesel fuel (12 MPa injection pressure) [13, 19]. The intake air temperature was kept stable at room temperature. Using diesel fuel, on the other hand, increased HC emissions and diluted the lubricating oil. These issues, however, were virtually eliminated by replacing diesel with light naphtha (which distils like gasoline). According to the findings of these studies using premixed fuel, PICI can significantly reduce diesel engine nitrogen and soot emissions. To overcome the challenges of using diesel for PICI, alternative fuel delivery and mixing methods may be required.

Direct fuel injection has three potential advantages over pre-mixing in the intake:

• The increased cylinder temperatures and concentrations aid in vaporization and mixing of diesel fuel. That decreases the probability of premature ignition.

• A well-designed injector can reduce fuel wall wetting, which in turn reduces combustion inefficiency and oil dilution.

• PICI fueling systems are suitable for conventional diesel combustion.

• There is a shorter time for fuel and air mixing, resulting in increased NO_x and PM emissions. Fuel over-penetration can also cause wall-wetting. Finally, because injection timing does not provide the same level of control as in conventional diesel combustion, controlling combustion phasing remains a challenge for early - DI PICI.

Using the performance analysis, the effects of different fuel mixtures in PICI were investigated. Diesel, gasoline, and a pure biodiesel (100 %) were used to determine the optimal mixing ratio for various fuel combinations [14, 15, 20 - 23]. The studies found that operating IC engines in PICI mode reduce emissions, the major requirement for existing regulatory standards, as well as total fuel usage.

This work's objective is to examine emissions, effectiveness, and fuel usage in PCCI mode with diesel engines or biodiesel as the fuel source; to compare the emissions and efficiency of a four-stroke diesel engine operating in PICI mode versus conventional mode.

EXPERIMENTAL

The experimental setup

The experimental setup is depicted in Fig.1. The pilot injection system supplies secondary fuel via the air manifold in PICI mode. The heating and thermostat arrangements for preheating and measuring the air temperature are located on the air manifold, along with the fuel measurement system and pilot injection valve. To keep the ideal temperature of the secondary fuel, it is heated in a 1 kW water bath by an electrical thermostat [16, 24]. The current configuration permits a maximum fuel temperature of 70°C. Diesel and biodiesel are stored at respective temperatures of 50°C and 70°C. An electrical thermostat maintains a maximum air temperature of 75°C. Secondary fuel is injected into the intake manifold close to the inlet valve using an electrical fuel system and a pilot fuel injector with a spray angle of 29° and an inlet air flow rate of 7.1 mL min^{-1}. The fuel

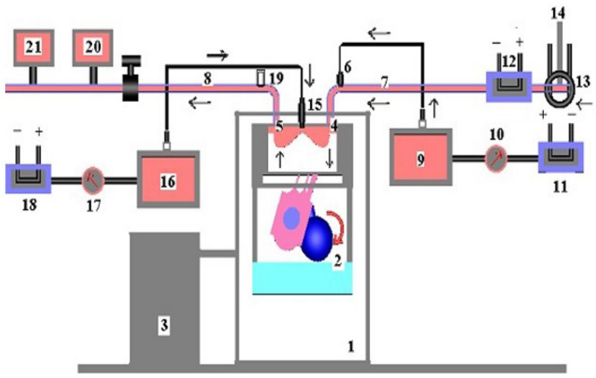

Fig. 1. Schematic of the experimental apparatus: 1 - test engine, 2 - cylinder, 3 - brake dynamometer, 4 - intake valve, 5 - exhaust valve, 6 - pilot nozzle, 7 - intake manifold, 8 - exhaust manifold, 9 - secondary injection fuel pump, 10 - secondary fuel tank with heating and thermostat system, 11 - secondary fuel flow meter, 12 - heating and thermostat system with air tank, 13 - pressure gauge, 14 - meter (hole), 15 - fuel nozzle (primary), 16 - fuel injection pump (primary), 17 - fuel flow meter (primary), 18 - primary fuel tank, 19 - thermocouple, 20 - exhaust gas analyzer, 21 - smoke meter.

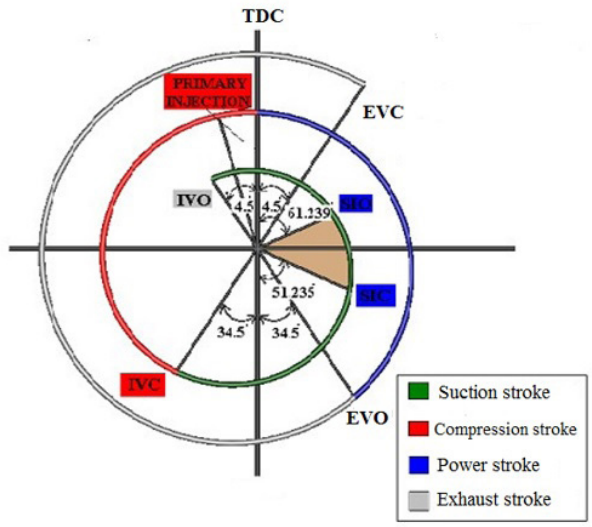

Fig. 2. Valve timing diagram: IVO - Inlet valve open; IVC - Inlet valve closed; EVO - Exhaust valve open; EVC - Exhaust valve closed; SIO - Secondary injection open; SIC - Secondary injection closed.

injection pump maintains a 6.5 bar fuel line pressure.

The diagram of valve timing is depicted in Fig. 2. The pilot fuel injection is controlled by an electronic circuit with a 750 Hz limit switch. A bolt on the rocker arm of the inlet valve activates the limit switch [18, 19, 25]. During the suction stroke, the rocker arm moves 9 mm to control the electrical signal for secondary injection. When the rocker arm is 5 mm from the top, an electrical signal is generated. This signal is used by a variety of control devices to activate secondary fuel injection. The injector receives an electrical signal to close the secondary injection when the rocker arm is 1.98 mm from the bottom [19, 26].

Throughout this research, biodiesel, diesel, and gasoline are employed as test fuels. Using established testing procedures, the characteristics of such samples are determined. These are the characteristics of diesel, gasoline, as well as biodiesel.

Characteristics of diesel, gasoline, and biodiesel

Fig. 3(a) shows the injectors assembly and its elements in detail; the primary and pilot fuel injectors are depicted in Fig. 3(b). A research engine with a single cylinder is utilised to test the PICI diesel. That engine features a variable compression ratio, overhead poppet valves, and an electrical dynamometer fitted on a common bedplate. The engine is designed for reciprocating IC engine education and research. The engine could be utilized as a SI or CI engine with a few simple changes. In this investigation, a CI engine is used (diesel mode).

The lubrication system is a wet sump, with an electric motor driving a gear pump that delivers oil to the crankshaft and big end bearings. To guarantee that all bearings receive clean oil, the pump is equipped with an adjustable relief valve and a full-flow filter. The oil line runs to the top of the cam box, delivering oil towards the camshaft and cylinder head as needed.

In this study, all fuel samples are tested in both conventional and PICI modes. The engine initially runs on primary fuel, either diesel or biodiesel, with no secondary supply of fuel. Under varied loads, performance, fuel usage, exhaust gas temperature, and emissions are all measured. Zero, twenty percent, forty percent, sixty percent, eighty percent, and one hundred percent are the proportions of varying loads [20, 27, 28].

In PICI mode, the pilot injector supplies supplementary fuel to the combustion chamber (PCCI). The rocker ram controls the pilot injector. The position of the rocker arm determines the location of the piston within the combustion chamber. The air is heated to 75°C before entering the combustion chamber. The main fuel is unheated when it enters the combustion chamber.

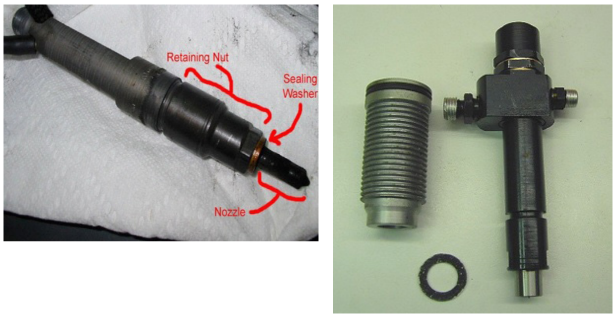

Fig. 3. Photographs of the primary fuel injector (a), a pilot fuel injector (b).

The secondary fuel is heated prior to approaching the intake manifold. The heating is powered by electricity. The suction stroke supplies the secondary fuel. It will produce PCCI during the compression stroke and aid in the ignition of the primary fuel injection, producing PICI. This PICI promotes complete combustion as well as low-temperature uniformity [21, 29].

A five-gas analyzer tests the exhaust gas for HC, CO, CO_2, NO_x, and O_2. The thermocouple and smoke meter are used to determine the temperature and amount of smoke in the exhaust gas. The following modes were used in the experiments: only primary injection is used in this mode. The diesel is only used to power the engine. In this mode, the pilot injector is closed. Preheating the air before combustion is used to measure emissions and fuel consumption.

Mode 1- Diesel conventional mode.

Mode 2 - Biodiesel conventional mode.

Mode 3 - Diesel in port injection as well as in main injection.

Mode 4 - Biodiesel in port injection and diesel in main injection.

Mode 5 - Biodiesel in port injection as well as in main injection.

Mode 6 - Diesel in port injection and biodiesel in main injection.

Mode 7 - Petrol in port injection and diesel in main injection.

Mode 8 - Petrol in port injection and biodiesel in main injection.

Four or five gas exhaust analyzers can assist in the detection of emission and drivability issues. Currently, shop-grade analyzers can monitor as many as five exhaust gases, including HC and CO. Modern exhaust analyzers collect data on HC, CO, CO_2, O_2, and NO_x.

RESULTS AND DISCUSSION

A number of tests were carried out on the experimental setup to evaluate the developed PICI structure. This research explains the effect of load on exhaust gas temperature, HC content, NO_x emissions, specific energy consumption, thermal braking efficiency, and CO_2 and CO emission results. In the case of the PICI diesel-petrol and biodiesel-petrol mode, knocking occurs at full load, for this reason no values are given.

The influence of load on exhaust gas temperature

An outlet manifold thermocouple determines the impact of load on exhaust gas temperature. In all cases, the temperature difference under load is measured. In all instances, the heat of the exhaust gas increased with increasing load. More fuel combustion occurs inside the combustion chamber as the load increases, resulting in faster and more complete combustion. The conventional diesel mode's exhaust gas temperature is greater than the other modes in all load conditions, while the biodiesel-biodiesel mode is lower. Under all load circumstances, the PICI model delivered lower exhaust gas temperatures than the conventional mode. This could be owing to the PICI mode's uniform burning of fuel within the combustion chamber. Exhaust gas temperatures were 275°C for conventional diesel and 252°C for PICI diesel at 3/4 load. The temperatures of exhaust gas in conventional biodiesel and PICI modes were 279°C and 254°C, respectively.

The PICI model produced lower temperatures than the diesel and biodiesel modes. The maximum load temperatures for conventional diesel and biodiesel and PICI are 330°C, 300°C, 273°C, and 265°C, respectively. In PICI mode, the temperature of the exhaust gas fluctuates with increasing load. Using biodiesel or petrol in conjunction with primary or secondary fuels, on the other hand, led to lower exhaust gas temperatures than using diesel, biodiesel, or petrol alone. It led to lower exhaust gas temperatures than the standard model [22, 30].

Fig. 4 depicts the temperature difference of exhaust gas with biodiesel, diesel, and gasoline under PICI mode. For the biodiesel-petrol combination, the PICI mode had the lowest exhaust gas temperature. At 3/4 load, the biodiesel - petrol PICI mode reduced exhaust gas temperature by 266°C. As demonstrated in Fig. 4, the

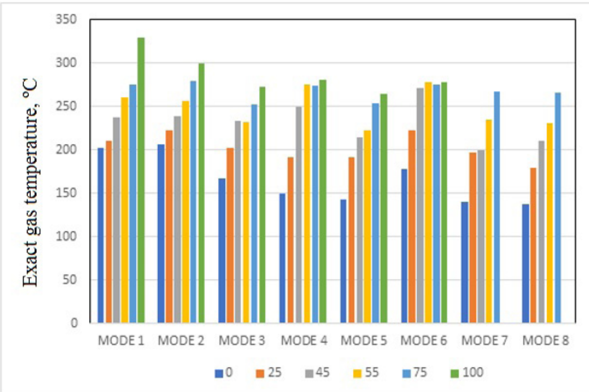

Fig. 4. Exact gas temperature variation vs. load for all modes.

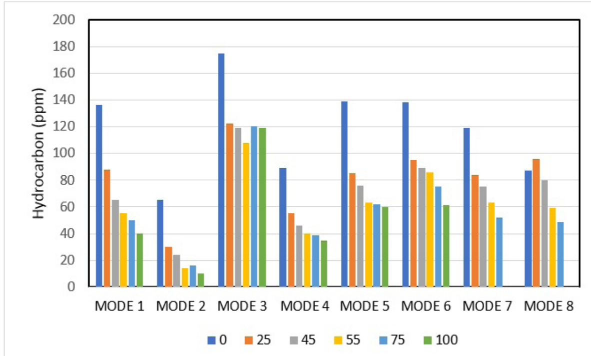

Fig. 5. Variation of hydrocarbon vs. load for all modes.

maximum exhaust gas temperature for all the fuel samples utilized in this study was identical. For biodiesel-biodiesel combinations, the lowest exhaust gas temperature in PICI mode is 265°C, followed by 266°C and 267°C for biodiesel-petrol and diesel-petrol combinations, respectively. Compared to the other fuels, the PICI mode generated the hottest exhaust gas temperature [23, 31]. The highest temperature reached by this sample of fuel was 281°C. Like in PICI mode of operation, when biodiesel is used as the primary fuel and biodiesel, diesel, or gasoline is used as the secondary fuel, the exhaust gas temperature changes [24, 32].

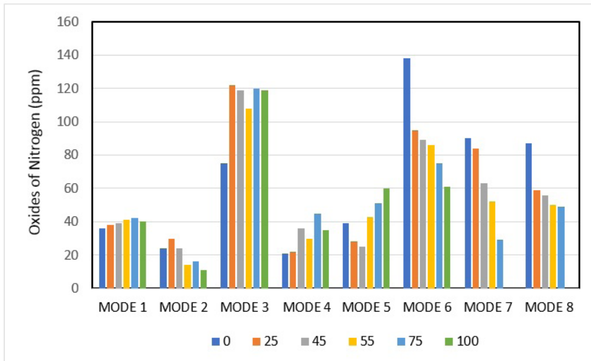

Fig. 6. Variation of NO_x emissions vs. load for all modes.

The effect of load on exhaust gas hydrocarbon

The emission of hydrocarbons in all modes is illustrated under different loads. According to the research, the traditional diesel mode emits most HC, while the PICI mode emits the least. With increasing load, the conventional mode HC emission increased, while the PICI emission decreased. Under all load circumstances, bio-diesel - bio-diesel fuel has lesser HC emissions than diesel - diesel fuel [25, 33]. The HC emissions for diesel and biodiesel in conventional and PICI modes are shown in Fig. 5. According to the study, the conventional mode produced more HC emissions than the PICI mode. The homogeneous mixture of fuel in the combustion chamber may result from incomplete combustion in the PICI mode. The regular diesel and biodiesel, diesel-diesel, and biodiesel-biodiesel modes produce 40, 10, 119, and 60 ppm of HC, respectively. In diesel-diesel PICI mode, whenever the load is raised from 0 % to 100 %, HC emissions decrease from 175 ppm to 119 ppm. For the same load interval, conventional biodiesel emissions reduce from 65 ppm to 10 ppm. In the PICI mode, when utilizing different primary and secondary fuels, the HC emission fluctuates with the load (Fig. 5). In diesel-petrol and biodiesel-petrol modes, the HC emission reduced as the load rose in all PICI cases [26, 34, 35]. Conventional biodiesel produced lower HC emissions than biodiesel-biodiesel among the PICI modes.

The influence of load on NO_x emissions

In this research, NO_x emissions are monitored overall operation modes. Fig. 6 depicts NO_x emissions for conventional mode with diesel, biodiesel, and PICI for both primary and secondary injections. For all load conditions, biodiesel-based operations emit less NO_x than diesel-based operations in the conventional mode. Fewer NO_x emissions were produced by PICI mode operations than by conventional mode operations, possibly due to lower and more uniform combustion chamber temperature and uniform fuel/air mixing. A PICI engine uses a variety of primary and secondary

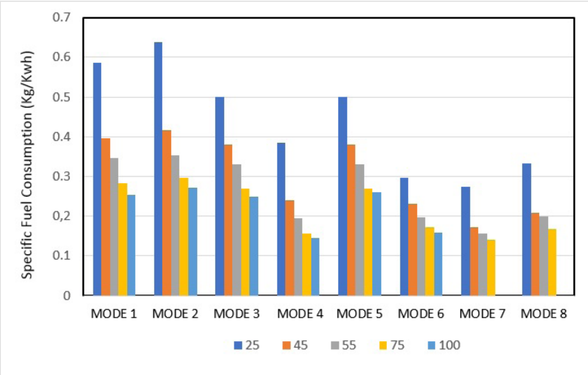

Fig. 7. Variation in specific fuel consumption vs. load for all modes.

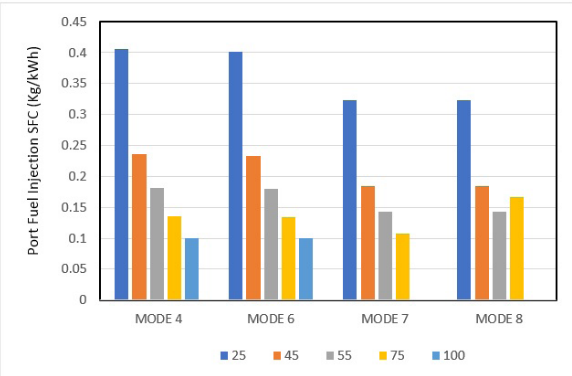

Fig. 8. Variation in specific fuel consumption vs. load for PICI modes.

fuels. In terms of NO_x emissions, biodiesel and diesel-petrol combinations emit significantly less NO_x than other PICI combinations. For all load conditions, the NO_x emissions in these two cases are comparable. When the load is increased from 0 % to 100 %, the NO_x emission rises from 36 to 40 ppm for diesel and 24 to 11 ppm for biodiesel modes, respectively. The variation of NO_x emissions from various fuels is depicted in this figure; NO_x emissions are less variable than HC emissions. There is only a minor difference between conventional diesel, biodiesel, and PICI diesel - diesel - biodiesel. Combinations of biodiesel and diesel emit less NO_x than biodiesel and gasoline [27, 36]. With gasoline as a secondary fuel, the fluctuation in NO_x emissions is lower than with the other combinations.

Implications of load on fuel consumption

The Specific Fuel Consumption (SFC) reduces with load in all operational modes. As demonstrated in Fig. 7, the SFC is lower in the PICI mode than in the conventional mode under all load circumstances. This may be because of the secondary fuel supply in PICI mode as opposed to the primary fuel supply in conventional mode. According to Fig. 7, the conventional mode consumes more specific fuel than the PICI mode. By utilizing various primary and secondary fuels, the PICI mode reduces specific fuel consumption. This could be because the PICI mode burns fuel more uniformly and completely than the conventional mode [28, 37]. Biodiesel is the main fuel and biodiesel, diesel, and gasoline as secondary fuels this indicates that under identical load conditions, biodiesel as a primary or secondary fuel burns more fuel than other modes. The low calorific value of biodiesel, as well as its other physical and chemical properties, may result in increased specific fuel usage.

Fig. 8 shows the change in specific fuel consumption (Port Fuel Injection) with load for all PICI modes. At full load, the port fuel injection is less in the case of PICI modes of diesel-biodiesel and biodiesel-diesel mode [29, 38, 39]. The maximum port fuel injection rate is in the biodiesel-petrol mode.

Brake thermal efficiency

Biodiesel fuel has higher thermal efficiency than diesel fuel. However, diesel and biodiesel are both used for main and secondary injection in a typical diesel engine. Each time the load is increased, it is by a factor of 25 % to determine the brake's thermal efficiency. The thermal efficiency of all brake thermal efficiency modes are increases with load [30, 39]. Whenever the load is increased from 25 % to 100 %, the thermal efficiency of diesel and biodiesel rises from (in %): 14.14 to 32.62 and 12.96 to 30.42, respectively. Leading to a smaller combustion temperature, the PICI mode provided greater thermal efficiency for the same fuels than the conventional mode [31]. In PICI, at 1/4 loading circumstances, diesel and gasoline generated higher brake thermal efficiency than some other modes of operation. Diesel and biodiesel reduced brake thermal efficiency as primary and supplementary fuels. Fig. 9 displays the brake thermal efficiency magnitudes for various load scenarios and mode of operation. The analysis revealed that under all load situations, the PICI modes of operation generated the maximum thermal efficiency. The thermal efficiency of biodiesel conventional and diesel-petrol and biodiesel-petrol PICI modes are lower [32].

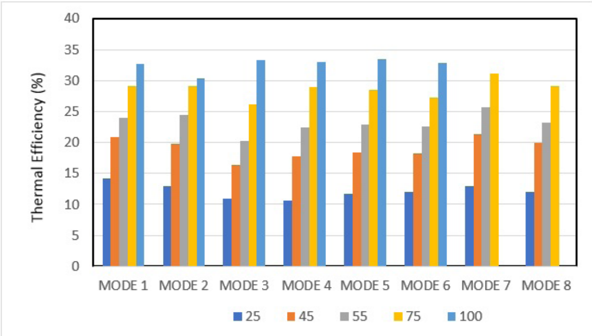

Fig. 9. Brake thermal efficiency vs. load for all modes.

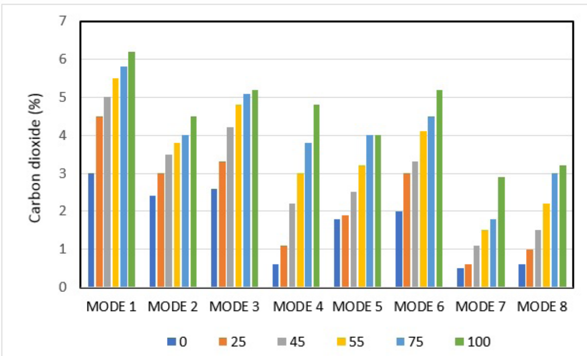

Fig. 10. Variation of carbon dioxide vs. load for all modes.

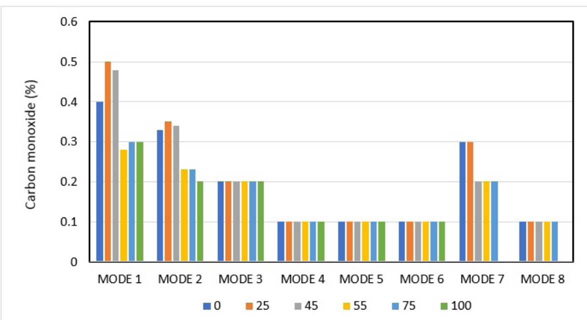

Fig. 11. Comparison of CO emissions vs. load for all mode.

Carbon dioxide emission

Diesel emits more CO_2 than biodiesel in both conventional and PICI modes, according to the study. This could be because diesel and biodiesel have different chemical properties. The CO_2 emissions for diesel and biodiesel increase from, %: 3.0 to 6.2 and 2.4 to 4.5, respectively, once the load increases from 0 % to 100 %. Diesel-diesel PICI mode emits 2.6 - 5.2 % of CO_2 for the same load conditions, whereas biodiesel-biodiesel emits 1.8 - 4 % of CO_2.

Fig. 10 depicts a mixed trend in CO_2 emissions for various fuels in conventional and PICI modes. Diesel produced more CO_2 emissions than other fuels in both conventional and PICI modes. In PICI mode, diesel, gasoline, and other fuels produced lower CO_2 emissions. This could be because biodiesel combustion emits more CO_2 than gasoline and diesel.

Effects of load on CO emissions

Except for the diesel-petrol combination, the study found no variation in CO with increasing load for any of the PICI modes of operation. Increasing load initially increased CO emission in the conventional mode of operation; increasing load decreased CO emission. The bio-diesel either primary or secondary produced the least CO emissions when compared to other PICI modes. Fig. 11 depicts CO emissions at full load in four PICI modes with three fuel combinations. As a primary and secondary fuel, biodiesel emits less CO than gasoline and diesel. According to the study, using biodiesel as fuel produces less CO in PICI modes. Biodiesel-petrol also produces less CO_2. The reason could be that biodiesel contains more O_2 than diesel-petrol.

CONCLUSIONS

The current research setup demonstrates that CO and HC emission levels can be reduced while maintaining the very same output power as a standard diesel engine. In the PICI mode, biodiesel-biodiesel has higher thermal efficiency as primary and secondary fuels than other fuels at full load. Both traditional and PICI modes have the same thermal efficiency at the same load. Diesel and gasoline, as primary and secondary fuels, produced the lowest CO_2 emissions of any PICI mode. Increasing the load has no effect on CO emission in the PICI mode. Utilizing biodiesel resulted in lower CO emissions when compared to alternative solutions.

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