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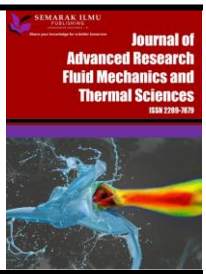

Study on the Effect of Intake Air Temperature towards RCCI Mode Engine of Performance and Emission

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ABSTRACT

Significant progress has been made in the field of research pertaining to combustion engines to lower emissions such as nitrogen oxide (NOx) and carbon monoxide (CO). In recent years, the relative control compression ignition (RCCI) engine has been created to minimize emissions of nitrogen oxides (NOx). This research examines the influence of the intake air temperature has on RCCI-mode engines' performance and emissions. A modified single-cylinder diesel engine was used to investigate the effects of changing intake air temperature and Primary Reference Fuel (PRF) over a spectrum of engine loads. The result shows that a higher air intake temperature for the RCCI strategy improved the performance of the RCCI engine, especially on fuel mixtures of B0 and PRF40, without comparing to a single fuel strategy, and reduced the amount of NOx emissions in the trade-off between UHC and CO compared to a single fuel strategy. In the not-too-distant future, one of our goals is to do more research on the influence that fuel octane has on port injection rate while maintaining the same values and parameters.

1. Introduction

In an Internal Combustion Engine (ICE), the ignition and combustion of the fuel occurs within the engine itself. The engine then partially converts the energy from the combustion to work. Over the last several years, internal combustion engines have proven to be the most beneficial resources for use in the transportation industry [1]. However, the growth of internal combustion engine technology and engine production worldwide has trade-off effects with the environment. Contribution towards emissions of numerous greenhouse gases from ICE has affected the world's climate. The major causes of air pollution are fossil fuel combustion processes, which occur in automobiles and power plants and produce toxic chemical compounds such Carbon Monoxide (CO), Sulphur Dioxide (SO_2), Nitrogen Oxide (NOx), unburned hydrocarbons (HC), and particulate matter (PM). These substances have negative effects on both the environment and human respiratory

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systems, contributing to acid rain, stratospheric ozone depletion, photochemical smog, and the greenhouse effect [2].

Compression-ignition (CI) and spark-ignition (SI) engines are the major kinds. Thermal efficiency is different for both kinds. Diesel engines, which use compression to ignite fuel, have a high compression ratio (CR). More heat is kept and utilized to create power, increasing thermal efficiency. The problem with SI engines is that they aren't very effective at small throttle openings because to the substantial turbulence and frictional (head) loss that occurs when the intake air tries to battle its way around the virtually closed throttle (pump loss). Since the compression ratio of a compression ignition engine is typically higher than that of a spark ignition engine, the compression ignition engine is typically the more efficient of the two types of engines.

Nowadays, different types of combustion engines are developed to follow the emission regulation in reducing urban pollutants such as soot, Particulate Matter (PM), Nitrogen Oxides (NOx), unburned hydrocarbons (HC) and Carbon Monoxide (CO). Spark-ignited (SI) engines with three-way catalysts have traditionally been successful at reducing the number of urban pollutants, whereas diesel engines have traditionally been effective at reducing the amount of CO_2 produced [3]. Incorrect fuel-to-air ratios may lead to soot formation in an engine's combustion chamber, which is a by-product of the incomplete combustion of hydrocarbons. Soot may develop when there is not enough oxygen to fully combust the fuel. Similarly, if the fuel contains solid particles that do not entirely burn, particulate matter (PM) may be produced in the combustion chamber. They may then be released into the air as particulate matter. NOx is an abbreviation for the two air-polluting nitrogen oxides—nitrogen monoxide (NO) and nitrogen dioxide (NO_2)—that are produced when fuels are burned. High exhaust temperatures are conducive to NO production; hence the NO_2/NOx ratio tends to increase as temperature rises [2].

The concern of emission of urban pollutant from transportation has led us towards the Low Temperature Combustion (LTC) approach. Significantly higher thermal efficiency combustion engines with reduced amount of soot and NOx produced can be achieved by using LTC strategy. The engine's operating temperature is lowered in LTC mode by increasing the Exhaust Gas Recirculation (EGR) or running the engine with an excess air ratio (λ) of much more than 1 [4]. Higher soot emissions occur from conventional diesel combustion's (CDC) stoichiometric state, in which fuel is oxidised with air at high temperature, resulting in greater NOx forms [5,6]. When compared to other LTC concepts, RCCI offers several advantages, particularly in terms of fuel dependability and the ability to regulate the timing of combustion. Dual-fuel, partly premixed combustion is achieved using RCCI. A low-reactivity fuel (LRF) like iso-octane is premixed in port fuel injection (PFI), whereas a high-reactivity fuel like n-heptane is direct-injected (DI) during the compression stroke. RCCI approach is connected to double-fuel HCCI, and one-fuel PPC techniques. It was shown that premixed combustion methods produce low Nitrogen Oxide (NOx) and soot emissions while simultaneously generating high thermal efficiency which demand the use of fuels that have various reactivities profile. Combustion flexibility is clearly a strength of dual fuel RCCI operation, and this was a pleasant side advantage for LTC mode to obtain optimum thermal efficiency and low pollutant combustion.

A sort of combustion process known as low temperature combustion (LTC) is one in which the temperature of the combustion itself is maintained at a level that is relatively low and described as a thermodynamic method to optimising the efficiency of internal combustion engines that use reciprocating pistons [7]. Through the auto-ignition of diluted air-fuel mixtures, Low Temperature Combustion aims to keep in-cylinder temperatures low rather than allow flame propagation. Given that LTC is predicated on autoignition, how it is achieved is in turn reliant on the auto-ignition properties of the fuel. Since different fuels have varied physical and auto-ignition properties, several methods must be used to create and regulate LTC. Low temperature combustion (LTC) engines may dramatically cut emissions of pollutants because one of the potential innovative in-cylinder combustion technologies is low temperature combustion (LTC), which reduces oxides of nitrogen and particulate matter emissions while also improving specific fuel consumption. Research conducted by Pachiannan *et al.,* [8] found that controlling the flame temperature and the local equivalence ratio may simultaneously lead to a decrease in NOx and soot emissions. This is possible because the NOx and soot emissions are substantially controlled by the flame temperature and equivalence ratio (λ). Regarding the findings by Li *et al.,* [9], RCCI is a dual fuel engine combustion technology that utilizes in-cylinder fuel blending with at least two fuels of different reactivities, and then uses a multiple injection strategy and a relevant EGR rate to control the in-cylinder reactivity to optimize the phasing, duration, and magnitude of the combustion process, resulting in high thermal efficiency and low NOx and soot emissions. The PFI (port fuel injector) may be found in the intake manifold. Gasoline, a low reactivity fuel (LRF), is injected by port fuel injection (PFI) and premixed with air in the cylinder before the intake stroke begins. During the compression stroke, diesel high reactivity fuel (HRF) is delivered into the cylinder through the DI (direct injector) using a single, double, or triple injection method. The squish area is the intended target of the HRF injected early, whereas the HRF injected later serves as an ignition source [10]. In addition, one of the critical factors that determines how well an engine works is the compression ratio of the cylinders in the engine. On a study conducted by Wang *et al.,* [11], for a particular sustained workload, the RCCI engine with a compression ratio of 11.70 was fine-tuned.

Intake temperature has been demonstrated to have a significant impact on the phasing of combustion and the emissions produced by RCCI engines, according to several research. Splitter *et al.,* [12] have conducted research on a wide variety of RCCI engine intake pressures and temperatures, as well as a variety of premixed ratios. They found that E85, which is a mixture of 85% ethanol and 15% gasoline by volume, worked well as a fuel with a low level of reactivity. In situations when the premixed ratio is equal to 0.66, the newly found speed load-phasing contour reveals that losses have been cut down significantly. RCCI can achieve high thermal efficiency of up to 56% while simultaneously lowering emissions of NOx and PM without relying on after-treatment strategies such as EGR [13]. The operation of the engine at a ratio of air to fuel that is close to or approaching stoichiometric results in better thermal efficiency when using the dual fuel mode. Another significant advantage of dual fuelling that has been noted is a reduction in emissions of both nitrogen oxides and particulate matter (PM). This advantage comes on top of the high engine efficiency that can be achieved when dual fuel mode is used in conjunction with high loads. When using natural gas as part of a dual fuel system, the NOx and PM emissions from a diesel engine are reduced, according to Mustafi *et al.,* [14], while Krishnan *et al.,* [15] find that brake specific NOx is between 0.07 and 0.8 g/kWh, significantly lower than the 8.5 g/kWh found in conventional diesel. Low brake thermal efficiency and high hydrocarbon (HC) and carbon monoxide (CO) emissions are some of the drawbacks of operating a diesel engine in dual fuel mode, despite the benefits of increased thermal efficiency at full engine load and reduced emissions of nitrogen oxide (NOx) and smoke [16,17]. Theoretical and practical studies on a dual-fuel diesel engine (6.7 kW at 3000 rpm) using natural gas were conducted by Papagiannakis *et al.,* [18]. The engine's performance was noted to be poor across all loads, with excessive HC and CO emissions. Increases in the percentage of energy supplied by natural gas result in a lower air-fuel ratio, which in turn reduces heat production during the pre-mixed combustion phase of the engine at all loads. The ignitability and combustion velocity of a fuel are quantified by its global reactivity. The octane or cetane number, as well as the fuel's chemical composition and physical qualities, are what decide this. To put it simply, fuels having a greater global reactivity will ignite more readily and burn more rapidly than those with a lower global reactivity. When it comes to internal combustion engines, global reactivity is a major factor in establishing combustion parameters including combustion rate, combustion pressure, and heat release rate. Injecting a combination of gasoline and diesel fuel into the engine at various stages in the compression stroke creates the reactivity gradient. Having the fuel ignited at various periods enables for a cleaner, more efficient combustion process while also lowering pollutants. Based on Imtenan *et al.,* [19], this kind of combustion is referred to as reactivity-controlled compression ignition (RCCI) combustion, and its name comes from the fact that the phasing of the in-cylinder combustion is mostly determined by the fuel's reactivity.

This research studies the influence that the intake air temperature has on RCCI-mode engines in both their performance and emissions. This investigation make use of a modified single-cylinder diesel engine by changing the intake air temperature and the desired Primary Reference Fuel (PRF) over a spectrum of engine loads. The projected findings will demonstrate the effect that the intake air temperature has on the overall performance of the engine as well as the emissions it produces, and they will shed light on the parameters under which RCCI mode engines function most effectively under certain loads.

2. Material and Method

2.1 Flow Chart

The experiment's functioning is shown in Figure 1. The experiment begins with a review of prior research published in journals linked to the RCCI Engine. The desired mixture of fuel is then decided upon for use in this study. PRF40 is the main option for Primary Reference Fuel (PRF) that is employed. Uses iso-octane in PRF as well as n-heptane for mixing gasoline. It denotes 40% iso-octane and 60% n-heptane for PRF40. Due to its high cetane rating, diesel was used for this experiment. Engine starting and combustion roughness are influenced by the ease with which diesel fuel ignites. The duration between the fuel entering the combustion chamber and it starting to burn is reduced in proportion to the cetane rating. To explore the performance and emissions of the RCCI Engine for dedicated PRF value, various engine speeds at 900, 1500, and 2100 rpm and varied engine loads at 0%, 20%, 40%, 60%, and 80% are employed. Air intake temperature is one of the main parameters that will be manipulated for this experiment, which are 40 °C and 50 °C. Until the required results are reached, the experiment is carried out step by step. All outcomes will be kept on file and converted to graphs.

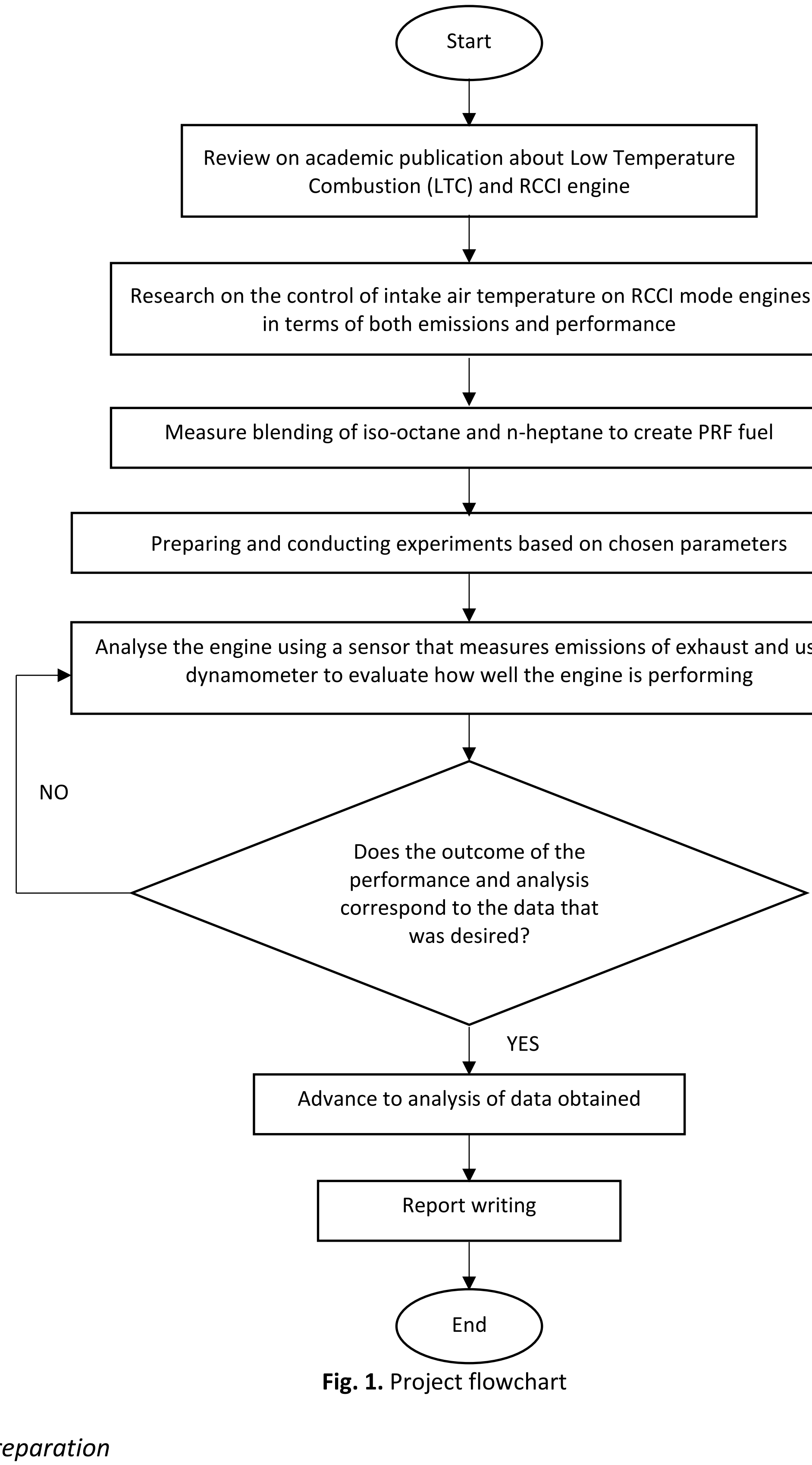

Fig. 1. Project flowchart

2.2 Fuel Preparation

Low Reactivity Fuel (LRF) and High Reactivity Fuel (HRF) are the two fuel types used by the RCCI engine mode. In this experiment, primary reference fuel (PRF40), which were injected using a port injection technique, served as the low reactivity fuel whereas pure diesel (B0), which was injected via direct injection, served as the high reactivity fuel (HRF). Additionally, since the direct injection system receives pure diesel, no mixing is necessary. In Table 1 below, the volume of each n-heptane and isooctane utilised in this experiment is listed.

Table 1
Fuel Matrix

Fuel mixture (500ml each blend)		
Primary Reference Fuel	n-heptane	Isooctane
PRF40	60%	40%

The chemical compound heptane, sometimes referred to as n-heptane, has the formula

$$H_3C(CH_2)5CH_3 \quad (1)$$

or

$$C_7H_{16} \text{ (petrol)} \quad (2)$$

and is a vital part of petrol. A gasoline that is 100% heptane corresponds to the zero point on the octane rating scale when it is used as a test fuel component in anti-knock test engines. The octane number, which is related to the antiknock properties of a comparable combination of heptane and isooctane, is shown on petrol (petrol) pumps all around the world. Table 2 lists the characteristics of N-heptane. As seen in Table 3, isooctane is an alkane made up of pentane with two methyl substituents at position 2 and one methyl substituent at position 4. It functions as a nonpolar solvent, a fuel additive, and a nephrotoxin.

Table 2
n-heptane properties

N-heptane Properties	
Item	Description
IUPAC Name	Heptane @ Dipropylmethane
Molecular formula	C_7H_{16}
Molecular Weight	100.2
Physical properties	Clear & colourless liquid Petroleum odour Flash point 25°F Insoluble in water Less dense than water Vapours heavier than air
Boiling Point	98.5°C – 90.6°C
Melting Point	285°C
Experimental properties	Lighter component in gasoline that burns more explosively causing engine pre-ignition (knocking)in its pure form, as opposed to octane isomers, which burn more slowly and give less knocking

Table 3
Iso-octane properties

Iso-octane Properties	
Item	Description
IUPAC Name	2,2,4-trimethylpentane
Molecular formula	C_8H_{18}
Molecular Weight	114.23
Physical properties	Clear & colourless liquid Petroleum odour Flash point 25°F Insoluble in water Less dense than water Vapours heavier than air
Boiling Point	99.2°C – 107.3°C
Melting Point	418°C
Experimental properties	Antiknock octane number 100; dipole moment: 0 2,2,4-Trimethylpentane is used in determining octane numbers of fuels, in spectrophotometric analysis, as a solvent and thinner, and in organic syntheses.

2.3 Experimental Procedure

Firstly, the fuel blending procedure was implemented. Mix the iso-octane and n-heptane in a ratio of 40:60 for PRF40. Mix the mixture by using a mechanical stirrer at a speed of 735 rpm for 10–15 minutes. Beginning with diesel in normal engine mode, the experiment will run at speeds of 900, 1500, and 2100 rpm with varying engine loads at 0%, 20%, 40%, 60% and 80% with air intake temperature of 40°C. The experiment will then go on using a PRF40 running in RCCI engine mode. PRF40 and diesel will be poured into two beakers respectively. Both beakers are used as gasoline tanks in this experiment. Pure diesel is utilised in direct injection systems, whereas low reactivity fuel (PRF) is used in port injection systems. The two gasoline tanks will be set up on different weighing scales so that the weight losses, which represent fuel use, can be calculated. To start the engine power, the engine switch will be switched on. If the engine has been running for 15 minutes, measure the engine performance first to make sure the engine has reached the proper operating temperature. Torque, power, and efficiency are the chosen engine performance metrics to be measured temperature and power of exhaust gases. In order to gather data, it is also required to make sure that all machines are turned on and that all software is linked to them. Repeating the experiment at three different rpms—900, 1500, and 2100 rpm—with five distinct phases of load—0%, 20%, 40%, 60% and 80% at TPS 15% and air intake temperature of 50°C—will provide various data of PRF40. All information is verified and documented.

To run the engine in dual fuel injection, the engine was changed. At the port and dynamometer, the injection system is modified. The diesel engine must be converted from single fuel injection to dual fuel injection, which comprises direct injection and port injection, in order to establish the RCCI engine mode as shown in Figure 2. Pure diesel is utilised as high reactivity fuel in direct injection whereas low reactivity fuel, which is the varying PRF values in this research, is used at port injection. Table 4 provides more information on the engine specifications utilised in this study.

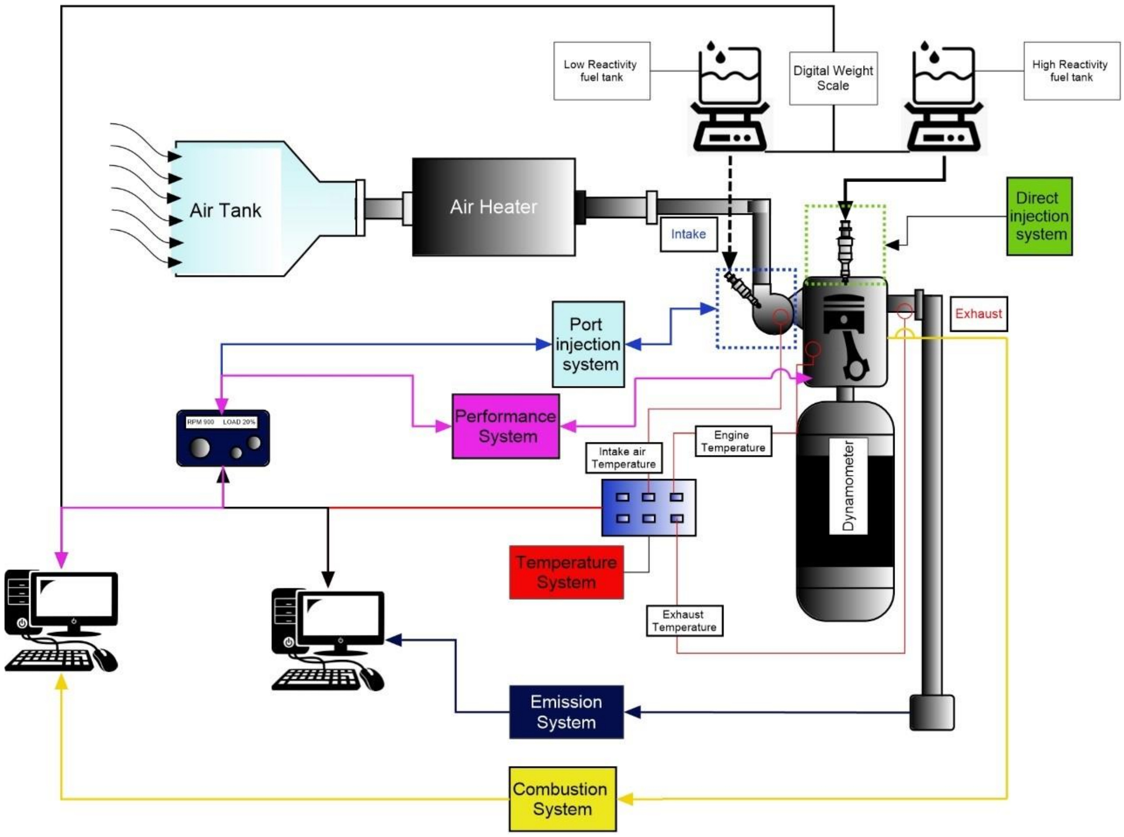

Fig. 2. Schematic diagram

Table 4
Specifications of Engine

Model	YANMAR TF120M
Type	Horizontal single-cylinder 4 stroke diesel engine
Bore (mm)	92
Stroke (mm)	96
Displace volume (cm^3)	638
Compression ratio	17.7:1
Fuel injection type	Direct Injection (DI)
Maximum power	7.7 kW @ 2400 rpm
Maximum torque	161 Nm @ 4500 rpm
Maximum rating output	12.0 HP @ 2400 rpm

2.4 Experimental Software

DynoMon V4 is a computer software that is used for testing on a dynamometer, which is a sort of apparatus that is used to measure force, torque, or power which related to engine performance. A software for monitoring, recording, and evaluating the operation of engines, electric motors, or other mechanical systems. Tuner MS Studio Lite is a tuning software that was involved in this research. Tuner Studio's data filtering capabilities allow for the modification of standard parameters like as RPM, coolant temperature, load, MAP, and MAF to conform to a user's particular setup or desire. The controller's calibration settings will need to be changed as a result. Runtime information may be captured and stored in a data log with its help. Offline tuning, load and save capabilities for Tune Files, and basic data logging are the features that are included in this product. Readings of the emission may be seen in "real time" with the help of the programme known as KANE LIVE and Kane Autoplus Gas Analyser device. UHC, CO, CO2, NOx, and NO were the gases that were emitted as gas.

Because all the data can be seen either digitally or as a graph, it is simple to monitor the parameters over time and see how they evolve. The live data may be saved and kept on your own computer in the form of a.CSV file, which is the standard format used when importing and exporting data. The data gathering software suite known as Picolog 6 can handle a broad variety of tasks. It provides users with a graphical user interface that is intuitive to use, allowing them to easily set up basic or complicated data acquisitions, record, display, and analyse data. During this experiment, this piece of software was used to get temperature readings from the engine system. The intake temperature, the temperature of the engine oil, and the exhaust temperature were the temperatures that were measured.

3. Results and Discussion

The purpose of this experiment is to determine how air intake temperature affects torque, power, exhaust gas temperature (EGT), and gas emissions when Diesel-PRF40 is blended in RCCI engine mode. Under the predetermined operating circumstances, the experiment was carried out. The engine results for the throttle positioning sensor (TPS) 15% are explained in this chapter.

Figure 3 to Figure 7 presented the relationship of Torque (Nm) and Load (%) handled by the engine tested with Pure Diesel (B0) and PRF40 at air intake temperature of 40°C and 50 °C at various speed which are 900, 1500 and 2100 RPM with 15% throttle position. Observation made from the figures above show that Torque (Nm) is directly proportional towards Load (%) as the increment of torque was influenced by the load even though the engine utilised different types of fuel. In addition, torque is decreasing when engine speed increase. Based on the figures and observation, PRF40 at 40°C produce the lowest torque at most loads but at 50°C, it shows a significant improvement on torque and slightly lower than Pure Diesel (B0) at 50°C. This is happening because of other variables that can significantly affect the kinetics of combustion include the energy content of the fuel, variations in heat capacity, and the impact of residual gas [20]. Furthermore, to keep the engine running at each rpm, more air and diesel were introduced. This increased the amount of chemical energy that was burned and converted into kinetic energy, which increased the torque the engine produced. By utilising pure diesel as engine fuel, it is still reliable since it can produce a decent amount of torque compared to other fuel mixtures.

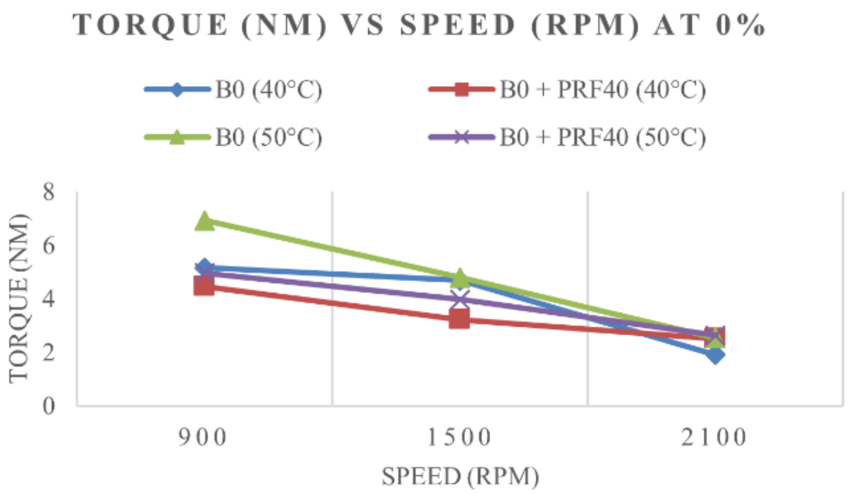

Fig. 3. Torque at 0% load

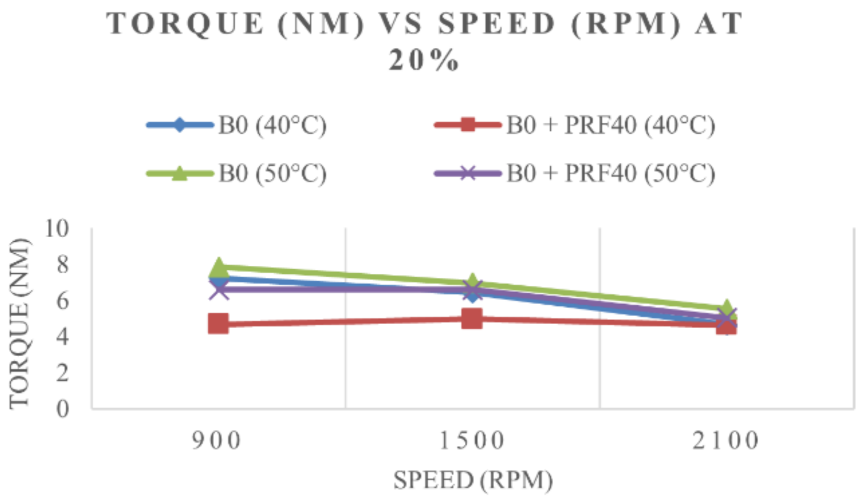

Fig. 4. Torque at 20% load

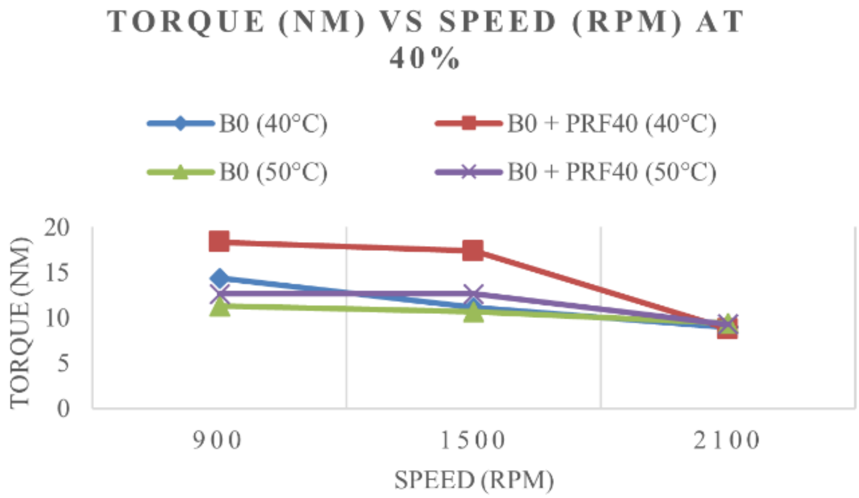

Fig. 5. Torque at 40% load

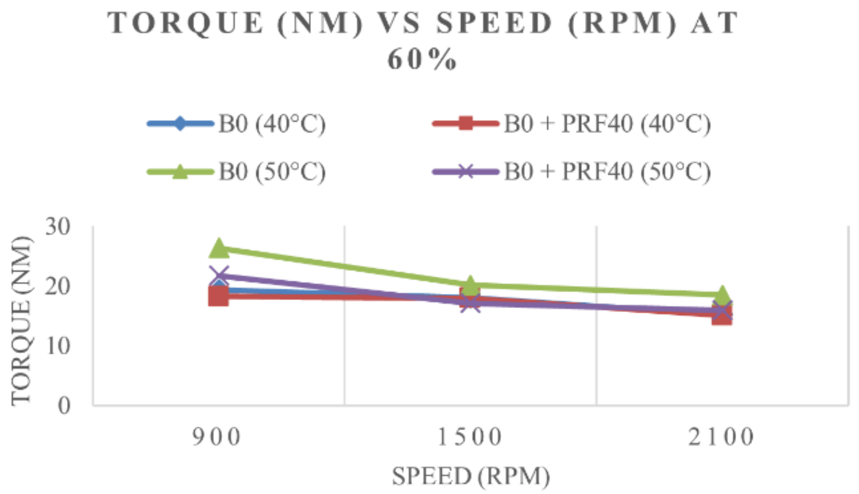

Fig. 6. Torque at 60% load

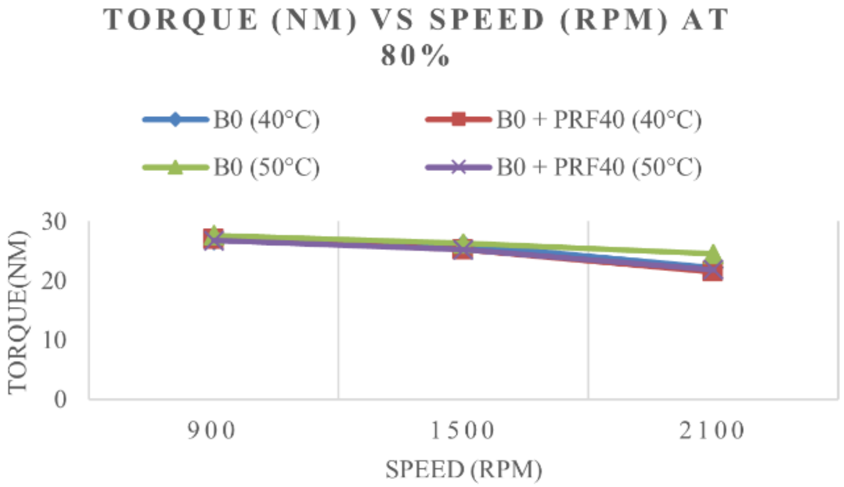

Fig. 7. Torque at 80% load

Figure 8 to Figure 12 illustrate the Power output (W) against the speed (RPM) for both type of single and dual-fuel strategy at air intake temperature of 40°C and 50°C at 900, 1500, and 2100 RPM with throttle position of 15%. From observation, the power is increasing as the load and engine speed increase. As shown on the figure, B0 at air intake temperature of 50°C and 80% load has recorded the highest power which is 5012.34 W. In addition, B0 at air intake temperature of 50°C excel in term of power delivery which show increment about 3.8% compared to B0 (40°C) and 4.3% compared to B0 + PRF40 (50°C). This happen because higher intake temperature promotes the condition which affect the activation energy of dedicated fuel. Also, the objective of using LTC strategies is to reduce emission trade-off with mechanical performance. An observation on dual fuel strategy shows that the power output is likely the same with single fuel strategy which support the idea of LTC. Power output depends on the torque deliver by the engine. Elevation in the amount of air and fuel mixture into the combustion chamber cause an increment of energy released through combustion process and influence the amount of power delivered.

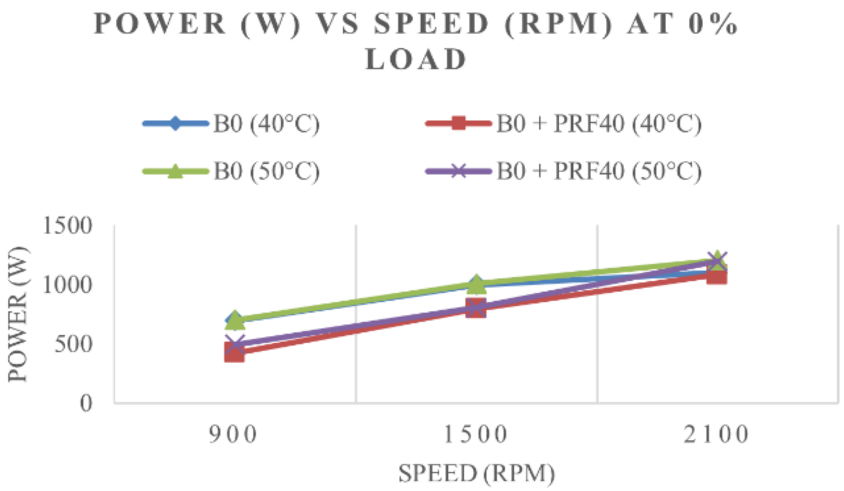

Fig. 8. Power at 0% load

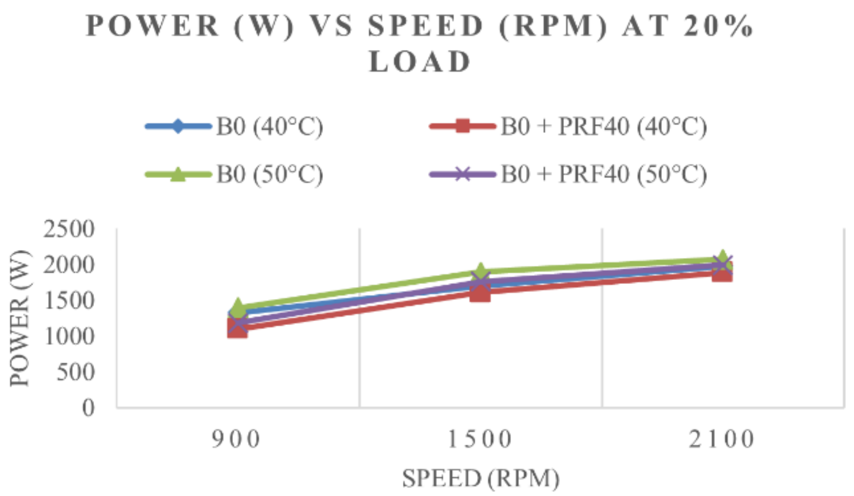

Fig. 9. Power at 20% load

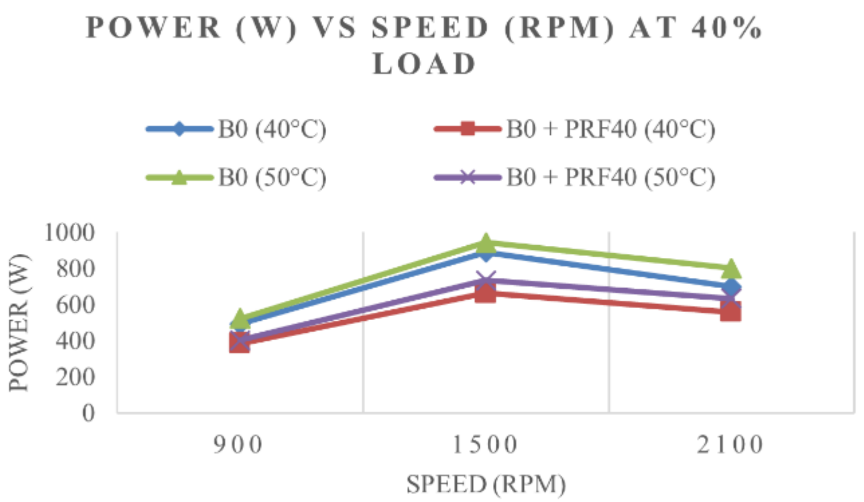

Fig. 10. Power at 40% load

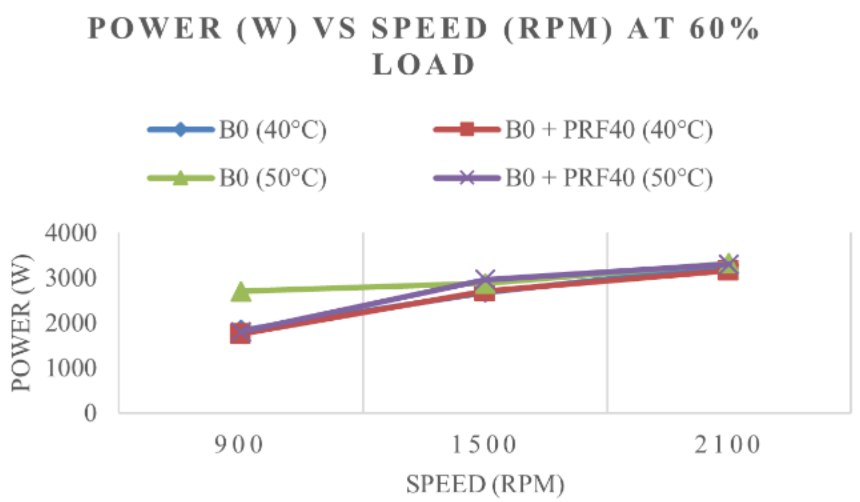

Fig. 11. Power at 60% load

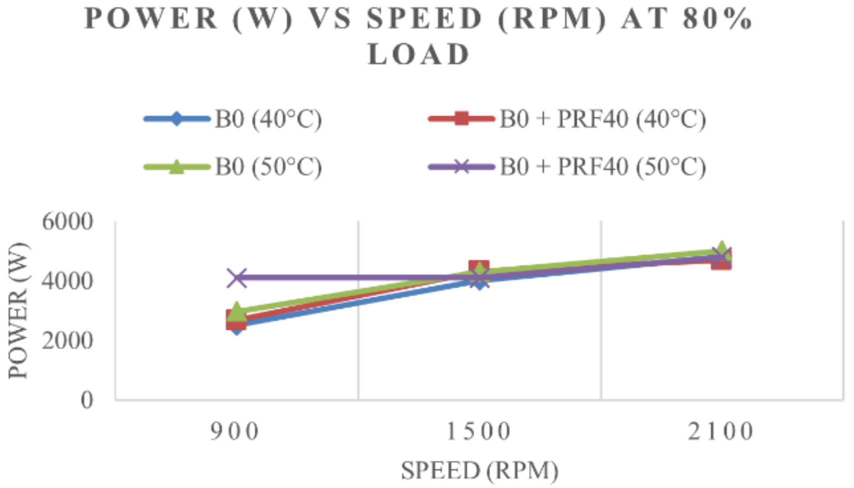

Fig. 12. Power at 80% load

Figure 13 to Figure 17 show the information on Exhaust Gas Temperature (EGT) against speed (RPM) on different loads. Based on observation, EGT will increase when the load and speed increase. This is due to the fact that torque rises as load does. As engine speed slows, pressure and temperature both rise because of the increased torque. As a result, the load will cause the EGT to rise. EGT increase because more air and fuel are injected into the combustion chamber which resulted in increase of energy from combustion process that also promotes higher combustion temperature. Air intake temperature also plays a role in EGT. As example, at 2100 RPM of 80% load, B0 + PRF40 (50°C) shows an EGT increment of 2% compared to B0 + PRF40 (40°C).

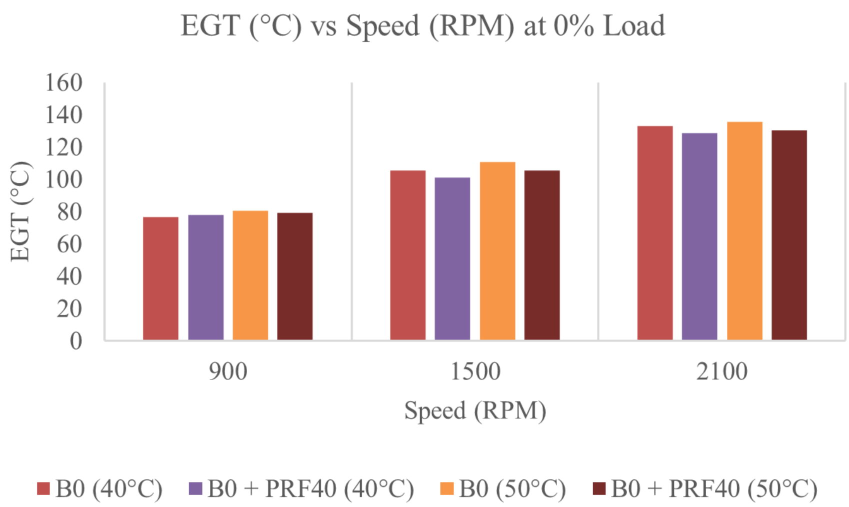

Fig. 13. EGT at 0% load

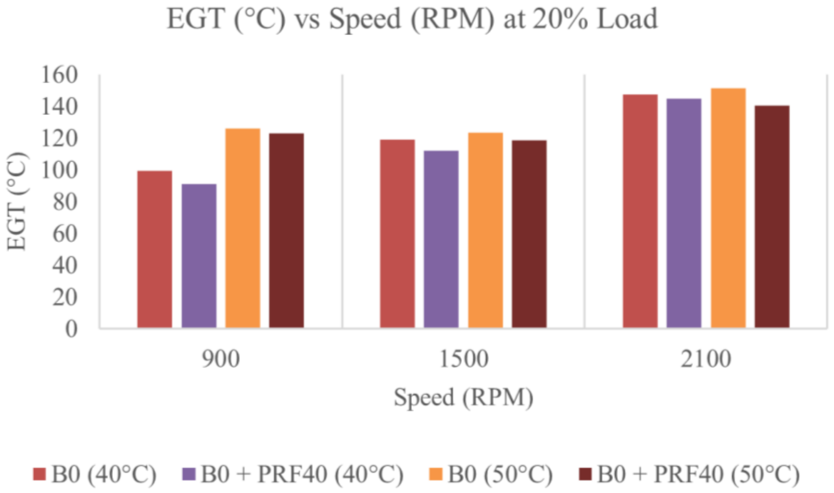

Fig. 14. EGT at 20% load

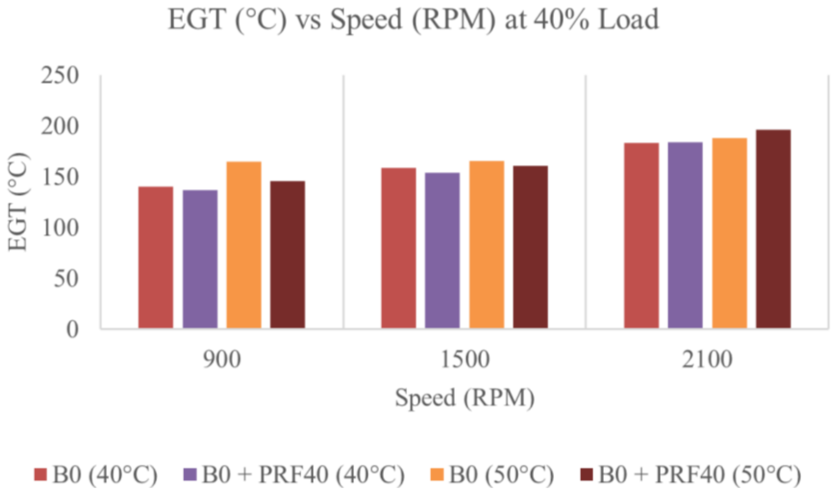

Fig. 15. EGT at 40% load

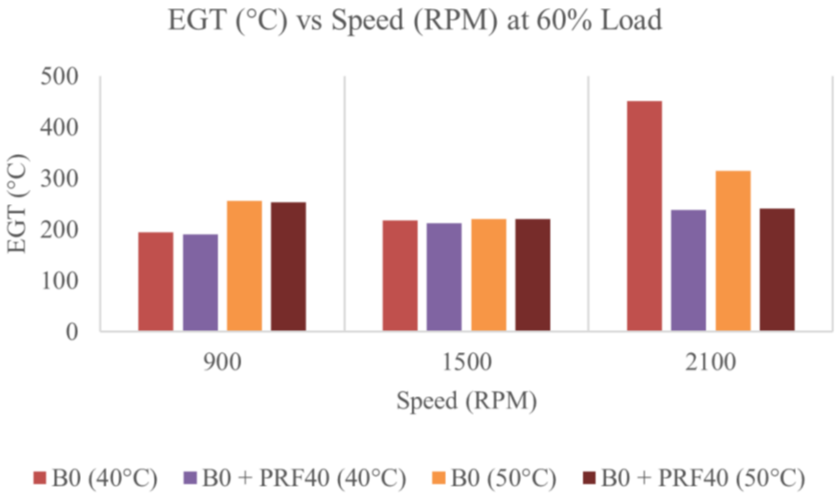

Fig. 16. EGT at 60% load

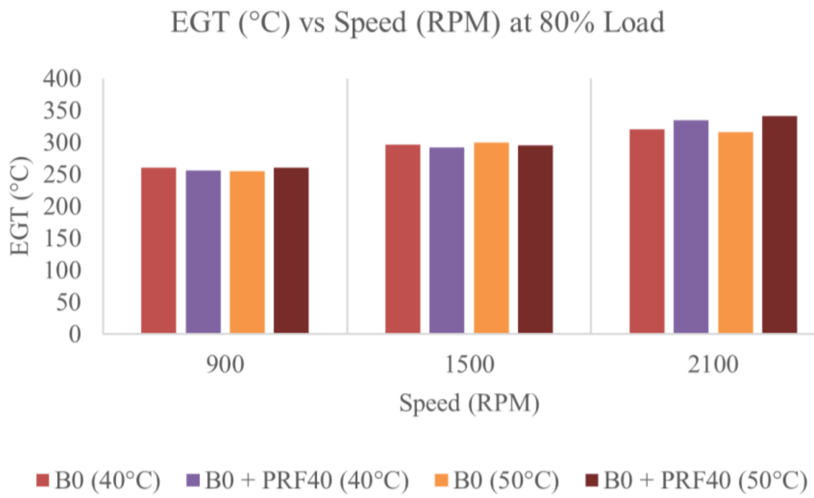

Fig. 17. EGT at 80% load

The amount of carbon monoxide emitted by utilising both Pure diesel and PRF 40 across all loads at air intake temperature of 40°C and 50°C with speed of 900, 1500, 2100 RPM were presented in Figure 18 to Figure 22. For PRF 40, the decreasing trend for carbon monoxide emitted across all loads and speed can be observe clearly on both air intake temperature. Moreover, carbon monoxide emissions are the highest by using B0 and PRF40 fuel mixture at air intake temperature of 50°C with engine speed of 900RPM which is 0.8 % at 0% load. Insufficient oxygen during the combustion process results in the formation of carbon monoxide. Complete combustion is difficult to achieve in diesel engines because of issues with the way the fuel and air are mixed, how the fuel is distributed inside the combustion chamber, and the circumstances that surround combustion. Because of these circumstances, fuel-rich regions may have pockets where complete combustion does not take place, which can result in the production of carbon monoxide [21]. Moreover, the relationship between carbon monoxide emission and loads is inversely proportional since higher loads need more power for combustion, which increases the combustion temperature and promotes a complete combustion process cycle [22].

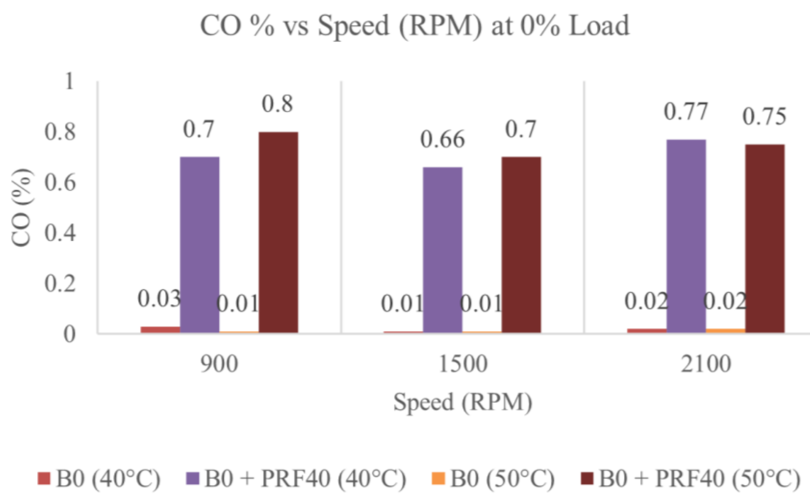

Fig. 18. CO at 0% load

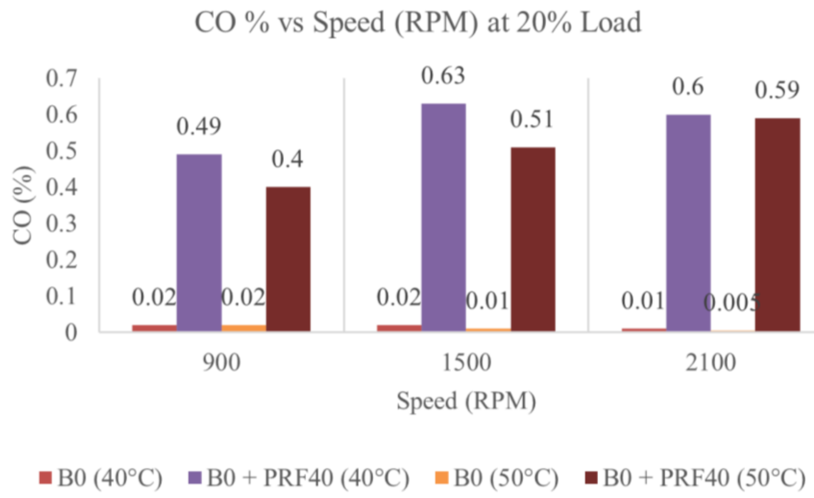

Fig. 19. CO at 20% load

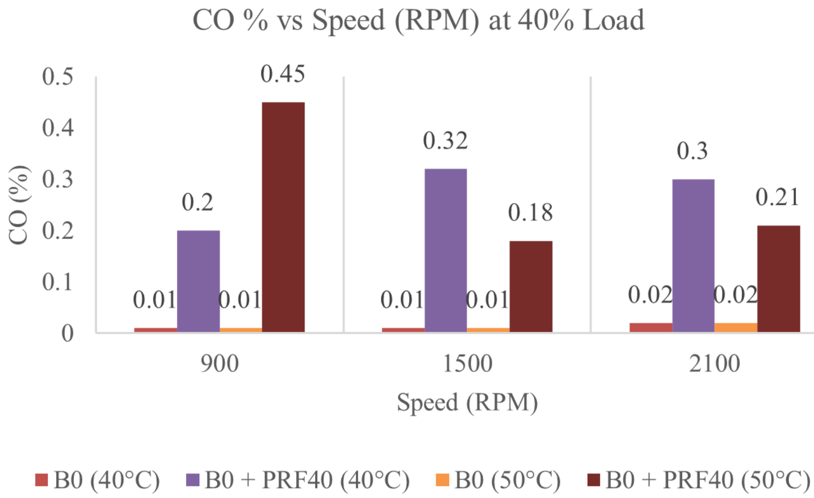

Fig. 20. CO at 40% load

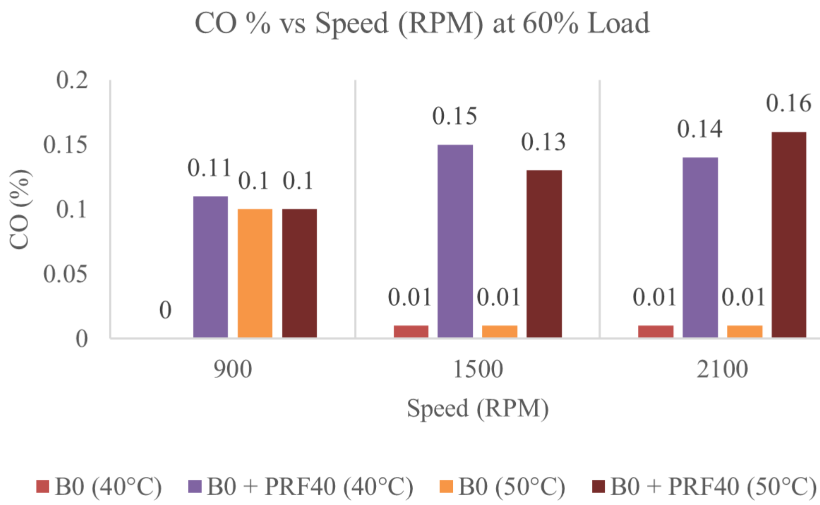

Fig. 21. EGT at 60% load

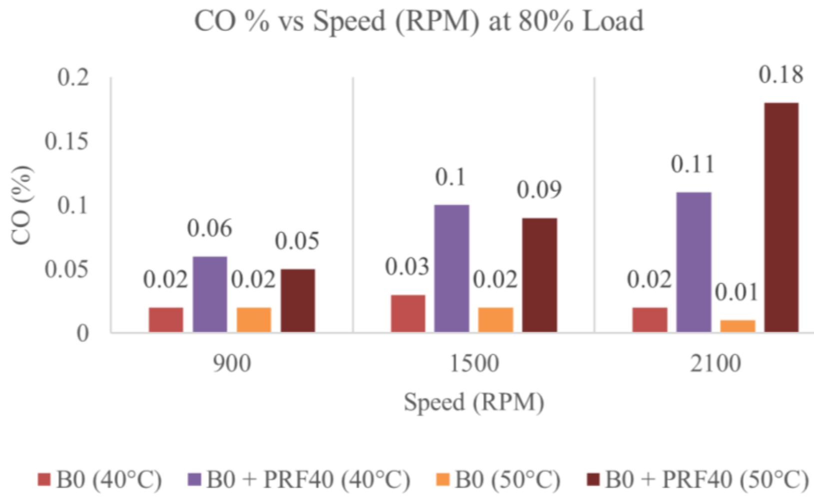

Fig. 22. CO at 80% load

Carbon Dioxide emissions for Pure Diesel and PRF40 across all loads for both air intake temperature of 40°C and 50°C at 900,1500 and 2100 RPM is presented in Figure 23 to Figure 27. From observation, the percentage of CO_2 emission is directly proportional with the engine's loads. Moreover, the highest percentage for carbon dioxide emission was recorded at 80% load by PRF40 at air intake temperature of 50°C which is 6.6%. In addition, data shows that PRF40 emits less CO_2 compared to pure diesel (B0) at lower loads but significantly increases on the way up at higher loads for both air intake temperature. These findings show that increasing engine loads will promote more complete cycle of combustion since it indicates that the engine is undergoing complete combustion. Finally, this pattern indicates that more fuel is burnt entirely through the hydrocarbon chain, producing CO_2 instead of CO [23].

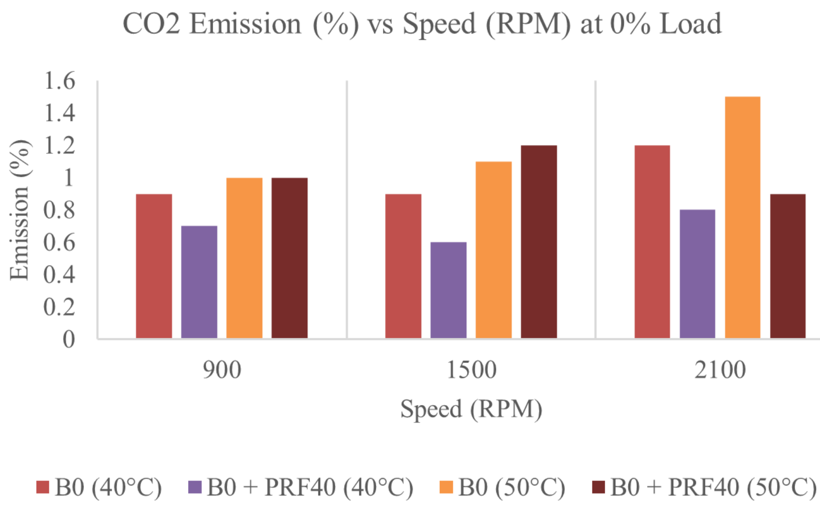

Fig. 23. CO_2 at 0% load

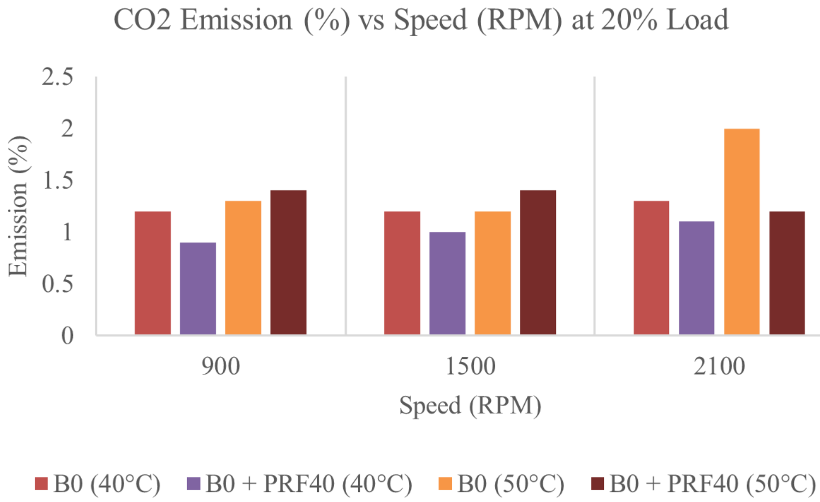

Fig. 24. CO_2 at 20% load

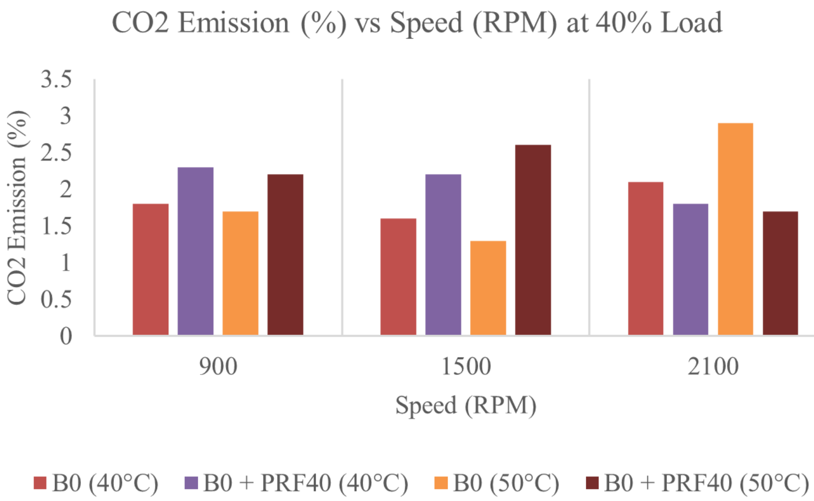

Fig. 25. CO_2 at 40% load

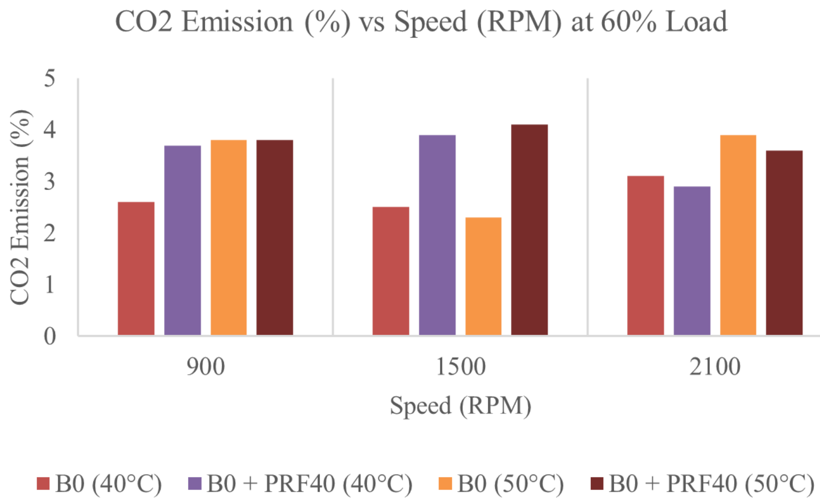

Fig. 26. CO_2 at 60% load

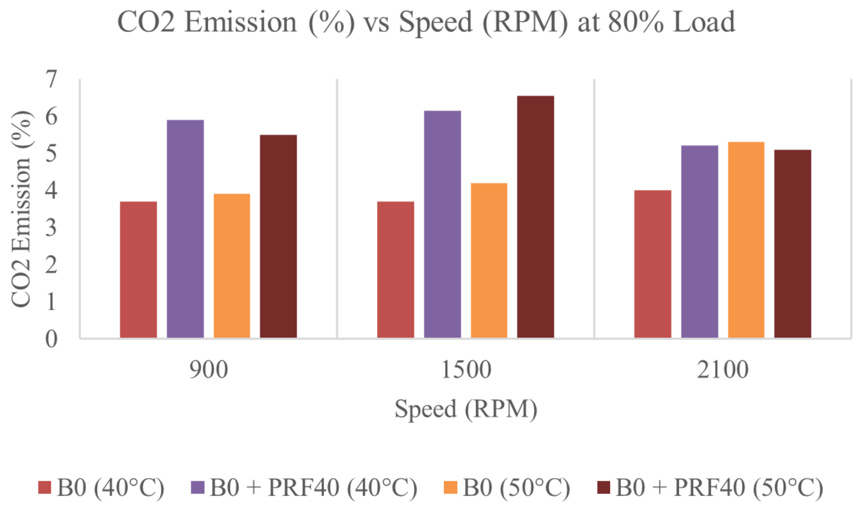

Fig. 27. CO_2 at 80% load

Unburned Hydrocarbon (UHC) for both single and dual fuel strategy at air intake temperature of 40°C and 50°C and 900, 1500 and 2100 RPM with 15% throttle position is presented in Figure 28 to Figure 32. One of the clear observations is that the amount of UHC emitted when utilising only pure diesel (B0) as engine fuel produces almost zero emissions across all loads. In fact, the highest recorded emission of UHC from pure diesel is at 40°C of air intake temperature, which is 13 ppm. For PRF40, UHC is significantly higher across all loads compared to pure diesel, but the amount of UHC decline as the loads increase. These things happen because the cetane value, which gauges the fuel's ability to ignite, is greater for diesel fuel. A higher cetane value indicates that the diesel will burn more reliably and efficiently in CI engines under compression which resulting lower UHC compared to other fuel mixture [24].

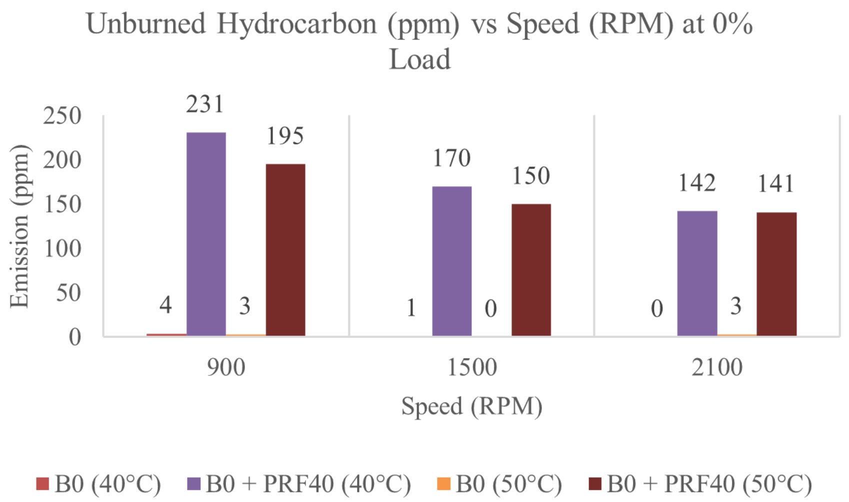

Fig. 28. UHC at 0% load

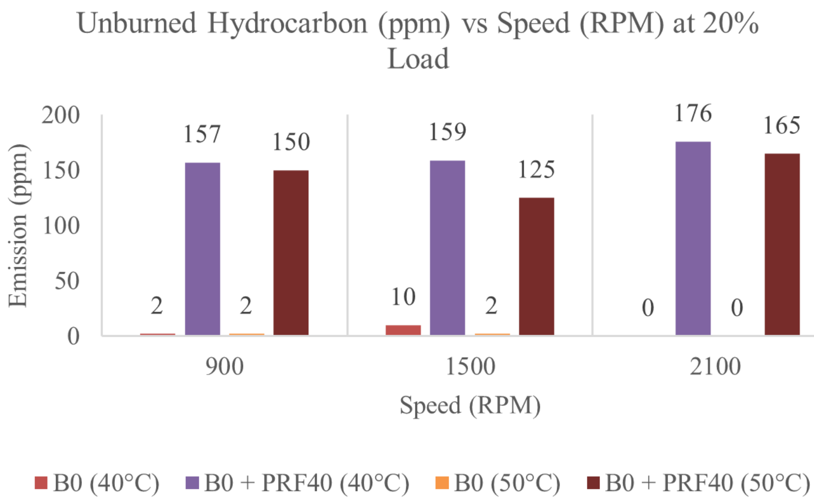

Fig. 29. UHC at 20% load

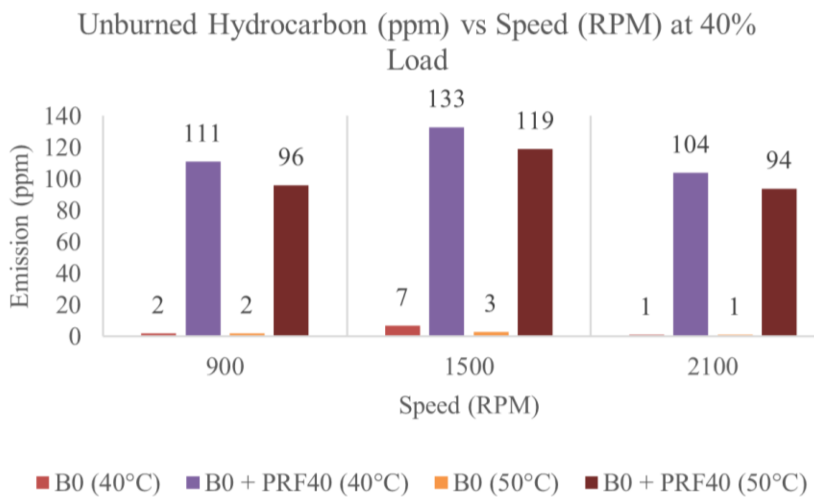

Fig. 30. UHC at 40% load

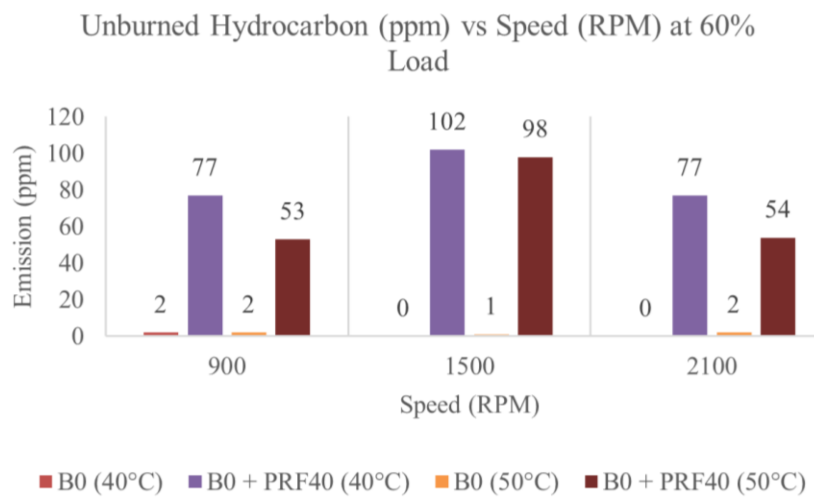

Fig. 31. UHC at 60% load

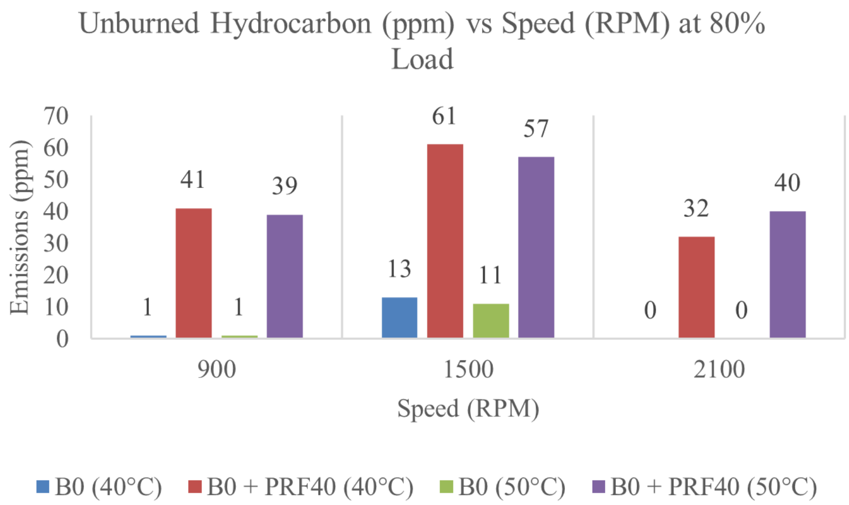

Fig. 32. UHC at 80% load

The emission of Nitrogen Oxide, NOx for both Pure Diesel (B0) and dual fuel (PRF40) at air intake temperature of 40°C and 50°C at 900, 1500 and 2100 RPM were presented in Figure 33 to Figure 37. The trend in NOx emissions can be seen clearly across all loads, which is inclining when the engines are working at higher loads. NOx emission increase as the engine load increases and decreases as the engine speed increase. In details, NOx emission is the highest at B0 with an air intake temperature of 50°C at 80% engine load at 900RPM, which is 823 ppm, the lowest emission of NOx at an air intake temperature of 50°C with 0% engine load, which is 87 ppm. At higher and lower loads, dual-fuel strategy (B0 + PRF40) performs better in terms of NOx emissions compared to diesel at both air intake temperatures. Thermal NO production is largely influenced by temperature, time spent at high temperatures, and oxygen concentration. When the mixture becomes lean, the temperature in the cylinder drops, which is bad for NOx formation and so lowers NOx emissions [25].

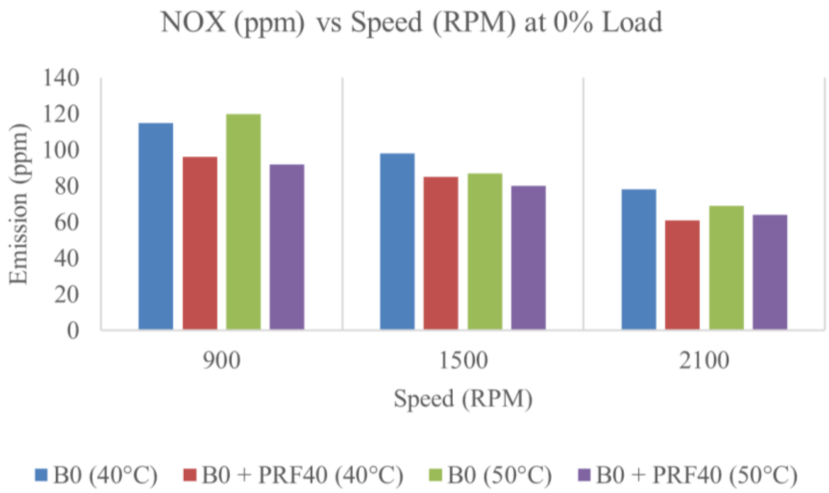

Fig. 33. NOx at 0% load

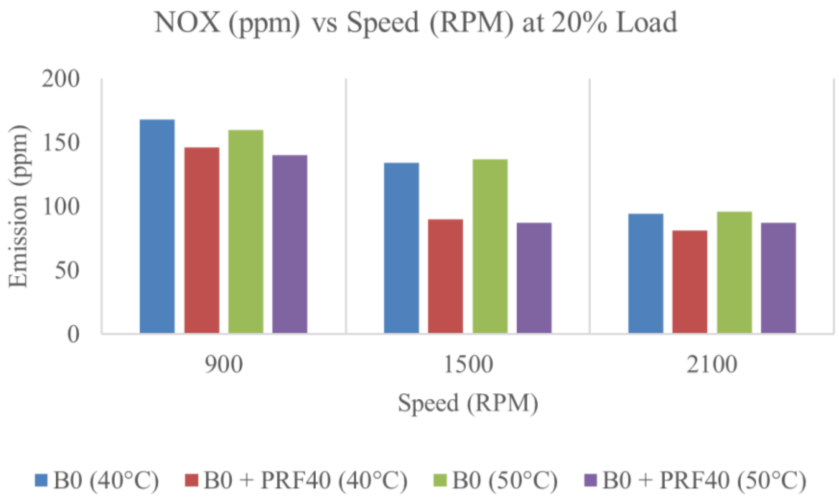

Fig. 34. NOx at 20% load

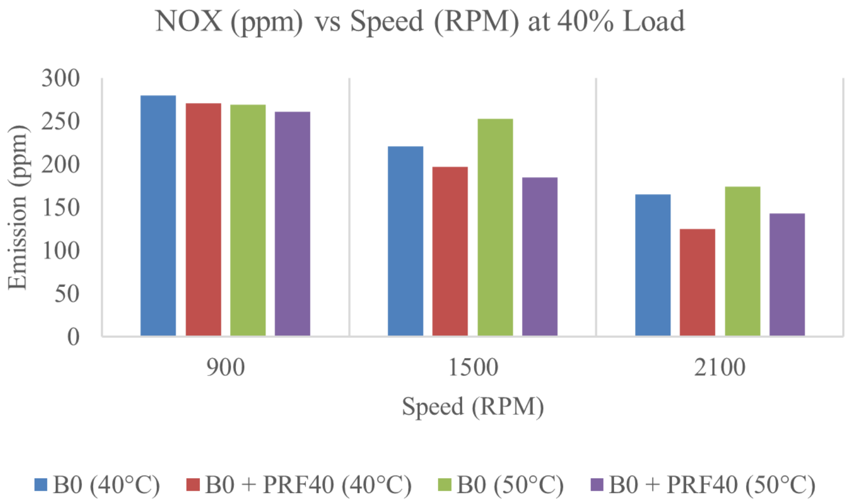

Fig. 35. NOx at 40% load

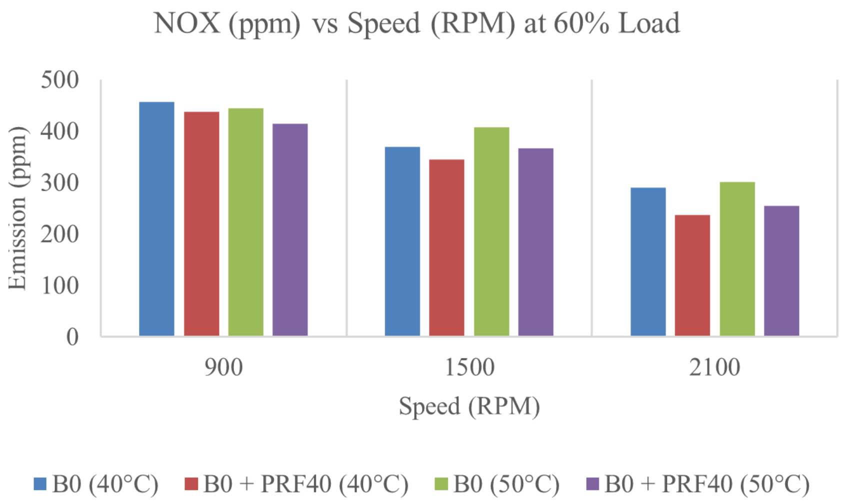

Fig. 36. NOx at 60% load

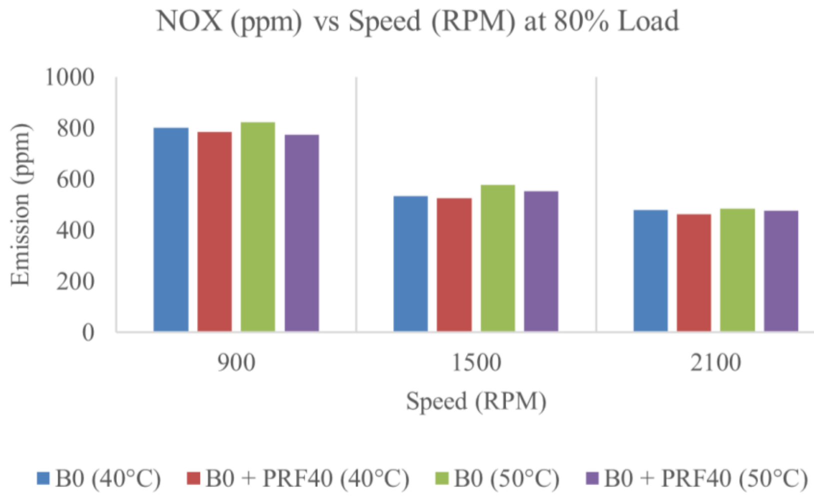

Fig. 37. NOx at 80% load

4. Conclusions

By manipulating the air intake temperature for both single (B0) and dual fuel (B0 + PRF40) type combustion, this research had achieved its objectives in order to study the characteristics and outcomes of engine performance and emissions. The goal of this experiment is to study the engine performance manipulated by air intake temperature which resulting in analysis of Torque (Nm), Power Output (W) and Exhaust Gas Temperature.

The findings on engine performance show that air intake temperature influences the torque from using single and dual fuel strategy. Torque is higher on combustion that uses higher air intake temperature, across all loads on both single and dual fuel strategy (RCCI) but decrease as the engine speed decreases. The power delivered is increasing as the load and engine speed increase which is influenced by the torque. The result also showed that using single fuel strategy with Pure Diesel (B0) on both air intake temperature performs better than dual fuel strategy (RCCI) since the engine was designed solely for B0 to operate at optimum condition. For EGT, it will increase when the load and speed increase.

The next objective of this experiment for engine's emission, the result was analysed through the emission of NOx, CO, CO_2 and UHC from combustion of single and dual fuel strategy. Using RCCI strategy, the amount of CO emitted is always higher than single fuel strategy (B0). In addition, CO emitted by RCCI decreases when the loads and engine speed increase without comparing to single fuel combustion. Next, CO_2 emissions are increasing as the speed and engine load increase influenced by air intake temperature since it supports the trend of CO emission which more complete combustion process occur. For UHC, when using just pure diesel (B0) as engine fuel, all loads create nearly no UHC emissions compared to RCCI strategy which produced significantly higher amount of UHC emission. Lastly, the focus of this experiment is to study the rate of NOx emission between single and dual-fuel strategy (RCCI). As expected, the amount of NOx emitted from RCCI strategy shows that it has relatively lower NOx emissions compared to single fuel strategy (B0). In addition, increasing air intake temperature on RCCI strategy helps to lower the amount of NOx produced. These findings support the concept of RCCI strategy which produces lower NOx trade-off with UHC and CO.

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