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Influences of Ambient Temperature, Injection Pressure and Spray Characteristics on Ignition Delay and Combustion Process of Palm Oil and Waste Cooking Oil

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Abstract. Alternative fuels have been explored for the substitution of diesel to lessen dependence on fossil fuel and to mitigate environmental pollution. Opted on biodiesel seem like promising due to its availability and regenerability, as well as ability to lower emissions. The objective of this research is to investigate the effects of ambient temperature, injection characteririics and spray characteristics on ignition delay and combustion process of biodiesel blends derived from palm oil and waste cooking oil. The ignition delay and combustion were observed using a rapid compression machine with ambient temperatures ranging from 850 K to 1050 K and injection pressure ranging from 80 MPa to 130 MPa. Palm and waste cooking oil biodiesel blends fuel were produced by blending these oils with Euro5 pure diesel at concentration of 5vol%, 10vol% and 15vol% correspondingly. Higher injection pressure and higher ambient temperature have been found to significantly reduce the ignition delay and influences to the heat recovery of combustion, while the higher biodiesel blending concentration of biodiesel promotes the reduction of CO emissions.

Key Words : Biodiesel, Palm oil, Waste cooking oil, Rapid compression machine, Ignition delay, Emission

INTRODUCTION

Progressive of automobiles, railways, in land and sea transportation resulted in rapid exhaustion of fossil fuels reserves (Oguma, Lee and Goto, 2012; Kalghatgi, 2018; Nursal *et al.*, 2018, Amir et al. (2011,2009). This status quo has accelerated the searching for viable and renewable alternative energy sources globally. Biofuel is one of the available resources and favourable solution since it is alike of fossil fuel with the exception of biological sources derivation (Kim *et al.*, 2012; Khalid *et al.*, 2016).

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For diesel engine, opted on biodiesel as alternate fuel for compression ignition stratagem was a wise decision for several reasons as it is intensely biodegradable, its chemical compound has least toxicity and may reduce the emission elements that harmful to the human and environment, and also has been proven employed well in many different types of diesel engines applications without major modifications or critical performance drop (Karikalan and Chandrasekaran, 2016; Khalid *et al.*, 2018). Since the sources of biodiesel was accessible in Malaysia for decade, the present work envisioned to assess the reliability of biodiesel derived from palm oil and waste cooking oil (Wahab *et al.*, 2017). The sources of palm oil is abundantly available since Malaysia is one of the world largest palm oil producer (Derman *et al.*, 2018), while waste cooking oil is comprehensibly worldwide accessible in addition of their cheaper in price made those oils raise the potential to be favourable feedstocks for biodiesel production (Johari *et al.*, 2015; Nursal *et al.*, 2017). In addition, the rich oxygenated property of biodiesel promotes pleasant emission reduction of hydrocarbon, carbon monoxide and particulate matter with trade-off of oxides of nitrogen (NOx). However, NOx minimization can be prospered by low-temperature combustion (LTC) and exhaust gas recirculation (EGR) approaches (Jung *et al.*, 2019; Marasri *et al.*, 2019).

Despite the benefits and prospective of biodiesel, the use of biodiesel also exposed to certain problem particularly on fuel droplet formation and vaporisation, poor atomisation, higher surface tension and during air-fuel mixing process due to its higher viscosity that may affected the combustion quality, engine performance, and efficiency (Khalid *et al.*, 2017). Many strategy has been implemented to resolve these disruptive such as employed low biodiesel concentration (Serrano *et al.*, 2015), dual fuel strategy (Lee *et al.*, 2017; Kassa and Carrie Hall, 2018), fuel preheating strategy (Khalid *et al.*, 2017) and addition of booster/fuel additive in biodiesel (Nursal, Zali, Jalil, *et al.*, 2017).

Evaluation of ignition delay is a practicable approach to assess the mixture formations, spray atomization and vaporization in which correlate to the physical properties of fuel (Jaat *et al.*, 2019) as well as the premixed combustion which correspond to the complex chemical reaction (Al-Abbad *et al.*, 2017).

This study analyse the ignition delay of biodiesel blends dedicated from the initiation of fuel injection until the end of combustion along with emissions produced using rapid compression machine (RCM). The objective of this research is to investigate ignition delay period, ignition process and combustion process of biodiesel blends derived from palm oil and waste cooking oil. The ignition delay was measured by fuel ignition in a rapid compression machine with ambient temperatures ranging from 850 K to 1050 K and injection pressure ranging from 80 MPa to 130 MPa. Palm and waste cooking oil biodiesel blends fuel were produced by blending these oils with Euro5 pure diesel at concentration of 5vol%, 10vol% and 15vol% correspondingly.

METHODOLOGY

The experimental facilities are separated into five main categories comprises fuel blending apparatus, rapid compression machine (RCM), data acquisition system (DAS), commonrail injection system and gas analyzer apparatus. Palm oil and waste cooking oil independently were blends and stired with neat diesel with Euro5 rating for two hours under 270 rpm rotational speed and 70°C constant heating temperature. The biodiesel used in the experiment was blended into three different ratios of 5vol%, 10vol% and 15vol%. *Figure 1* illustrates the schematic diagram of fuel blending apparatus.

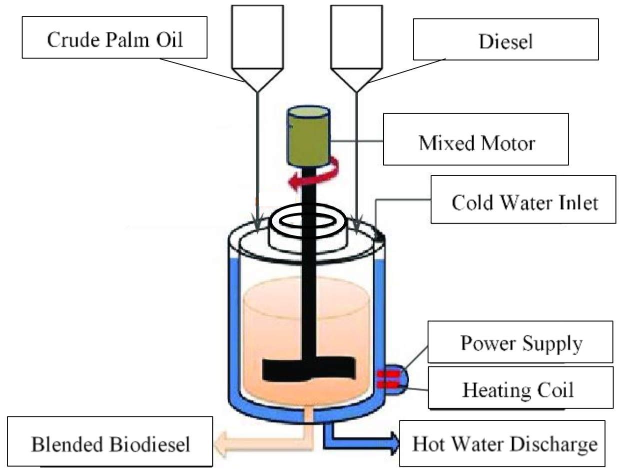

FIGURE 1. Schematic diagram of fuel blending machine.

The density and kinematic viscosity of palm oil-biodiesel blends (PB5, PB10, PB15) and waste cooking oil-biodiesel blends (WB5, WB10, WB15) that has been measured are summarized in *Table 1*.

TABLE 1. Fuel Properties.

Fuel Type	Properties	
	Density (kg/m^3)	Kinematic Viscosity (mm^2/s)
PB5	837.05	2.90
PB10	837.66	3.01
PB15	840.43	3.03
WB5	889.01	3.01
WB10	890.12	3.18
WB15	891.80	3.20

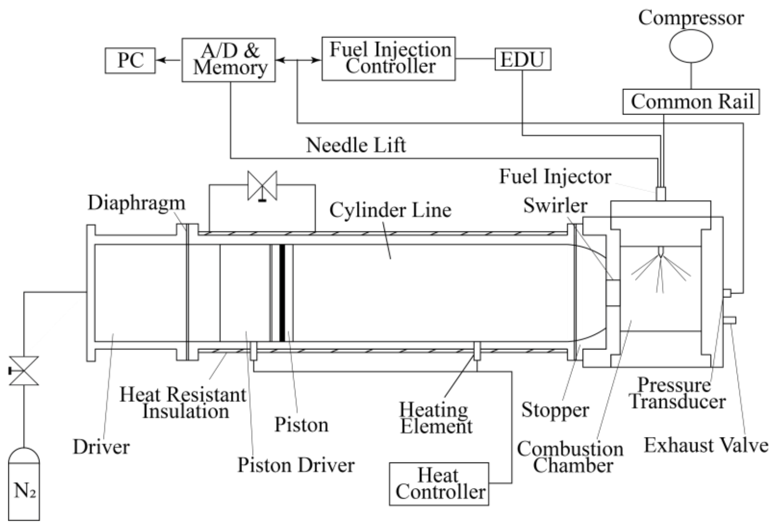

FIGURE 2. Schematic diagram of RCM.

An RCM is used to simulate the autoignition behavior that executed single compression stoke and combustion similar to real sensation in diesel engine. The schematic diagram of RCM with commonrail injection system and other auxiliaries is illustrated in *Figure 2*. A light and freely moving piston is positioned in the main cylinder liner, separated from driver cylinder by mylar diaphragm.

The driver cylinder was filled with non-reactant gas for instance nitrogen (N2) that is used in this study with pressure of 19 bar to instantaneously push the piston rapidly towards a stopper point just before the reaction chamber (RC) at the end of compression stroke. At relatively high pressure and temperature in RC after piston stop, the commonrail was then immediately trigger signal and injecting fuel at specified time and duration. The pressure traces thru the course of experiment will be recorded by DAS. In this work, the injection pressure (IP) was varied at 8 MPa, 90 MPa and 130 MPa in association of ambient temperature (AT) from 750 K to 1050 K. The operation conditions of experiment are presented in Table 2.

TABLE 2. Experimental Conditions.

Fuel	Injector type	6 holes, Ø = 0.16 mm
	Fuel type	PB5, PB10, PB15, WB5, WB10 and WB15
	P_{inj} (MPa)	80, 90 and 130
	q_i (ml)	0.04
Ambient	T_i (K)	750K, 850K, 950K and 1050K
	r_s (m/s)	19
	ρ (kg/m^3)	16.6
	O_2 (vol%)	21

RESULT AND DISCUSSION

Significnce of Blending Concentration on Ignition Delay (ID) and Emission

The significance of blending concentration on behavior of autoignition and emissions was investigated for palm oil-biodiesel blends (PB) as well as waste cooking oil-biodiesel blends (WB) at 5vol%, 10vol% and 15vol% concentration. The fuel quantity of 0.04 ml injected at 130 MPa with ambient temperature of 950 K are fixed for this drive. The initial in-chamber pressure and ambient air density of 0.1 MPa and 16.6 kg/m^3 correspondingly are considered. *Figure 3* represents the autoignition behavior for PB and WB biodiesel blends at 5, 10 and 15vol% under specific experimental conditions. The ID for each biodiesel blends at different concentration was interpreted from this figure. Y-axis demonstrate the in-chamber pressure changes after the end of piston stroke with function of time while X-axis specifies duration until the finishing point of combustion.

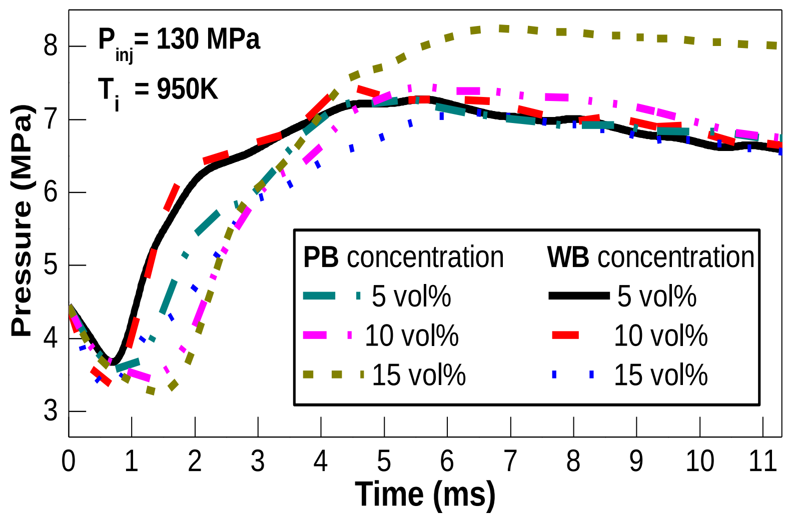

FIGURE 3. Ignition delay of PB and WB at 5%, 10% and 15% blending concentration.

Based on *Figure 3*, PB fuels exhibits longer ID compared to WB for every similar concentration. Additionally, the ID period increases as the blending concentration increased for most fuels by the facts that increased of fuels viscosity. Higher viscosities affect the poor atomization and reduce the efficiency of mixture formation. The figure also demonstrates the shortest ID represent lowest RC peak pressure while the longest ID has highest RC peak pressure. Asides, the earliest SOI was lead by WB at 5vol% while the latest autoignition represented by PB at 15vol% concentration. The breakdown of the high molecular weight of biodiesel through chemical reaction at high temperature is the reason increase in ID for higher concentration fuels.

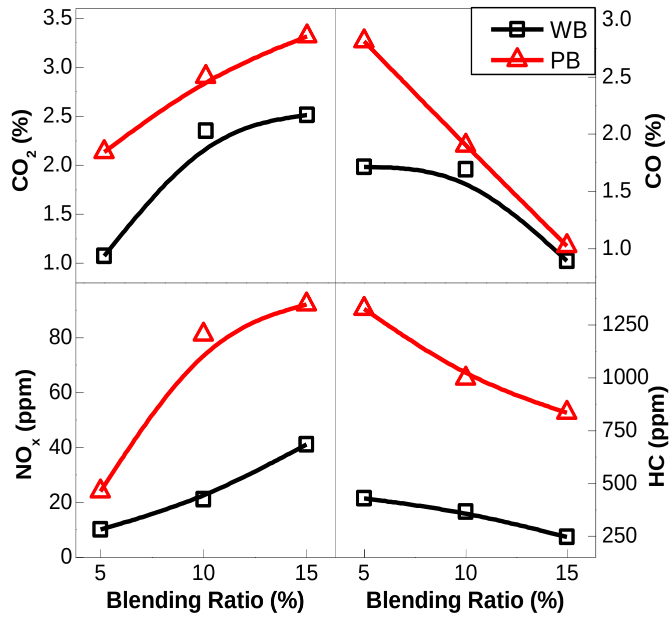

FIGURE 4. Effect of different biodiesel blending ratio on emission.

Separately, the effect of blending concentration on exhaust emission for PB and WB at 5vol%, 10vol% and 15vol% under similar testing conditions was shown in *Figure 4*. Referring to the figure, the hydrocarbon (HC) emission decreased proportional to the increasing of concentration. Higher amount of volatiles particles such as oxygen and organic condensates in high concentration fuels is the reason for that effect. In addition, HC emission promoted by WB was lower than that of PB fuels due to its lower volatility property. Inversely, the percentage of carbon dioxide (CO_2) and oxides of nitrogen (NOx) emissions increase corresponding to the rise of blending concentration due to the facts that more oxygen in greater blending concentration improvise the combustion efficiency resulting complete combustion. However the downside of high oxygen content fuels is it contributes to the increase of NOx emission. In other hands, the emission of carbon monoxide (CO) drop away consistently as blending ratio increased throughout combustion progress which opposed to CO_2 emission. Furthermore, overall emissions exhibited by WB apaarently lower compared to PB in all probability because it has more oxygen molecules in its contain.

Implication of Variation Injection Pressure (IP) on Ignition Delay (ID) and Emission

The autoignition behavior plot specifically the ignition delay of PB and WB fuels for influences of variant IP at 80 MPa, 90 MPa and 130 MPa accompanying with fixed ambient temperature at 950 K is depicted in *Figure 5*.

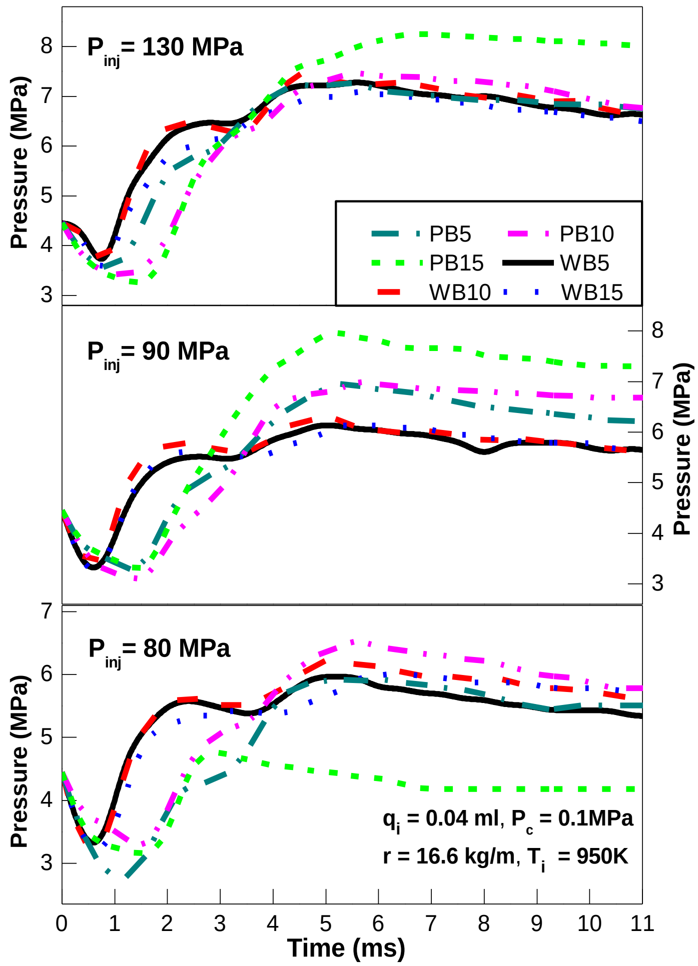

FIGURE 5. Ignition delay of PB and WB under variation injection pressure.

In view of the results obtained, the autoignition of PB5 for 80 MPa occurs at 3.0 ms, become quicker at 2.0 ms for 90 MPa and later as at 1.4 ms under IP of 130 MPa. Similar trends have been observed in in-chamber pressure curves for PB10 and PB15 fuels. The ID was 2.5 ms and 2.6 ms for PB10 and PB15 in turn for 80 MPa and further reduce to 2.0 ms and 2.1 ms at higher IP of 130 MPa. It can be seen that the decrease of ID for most PB fuels as the IP increases is mainly due to higher temperature in RC improve the air-fuel mixture formation, consequent better premixed combustion.

On the other hands, similar trends in WB fuels have been observed where the ID gradually decreases as the injection pressure amplified from 80 MPa to 130 MPa. The ID for WB5 under the injection of 80 MPa recorded as 1.3 ms reduced to 1.1 ms at 90 MPa. This behavior was found to be lower at 0.7 ms for utmost IP of 130 MPa. Furthermore, the ID measured was 1.1 ms and 1.5 ms for WB10 and WB15 in turn at 80 MPa and remain declined to 0.8 ms and 0.9 ms at highest IP of 130 MPa. It is apparent that the ID for most biodiesel blends fuel decreases with increasing IP as well as in-chamber pressure. The higher temperature in RC through high IP condition consequently enhance the air-fuel mixture and resulting better premixed combustion and shorten ID.

Aparts, the implication of variant IP on emission by PB and WB fuels combustion in RCM can be represented by emissions graphs plotted that comprises of CO_2, CO, HC and NOx as displayed in *Figure 6*. The experiment parameters varies at injection pressures of 80 MPa, 90 MPa and 130 MPa whilst ambient temperature was kept unchanged at 950 K.

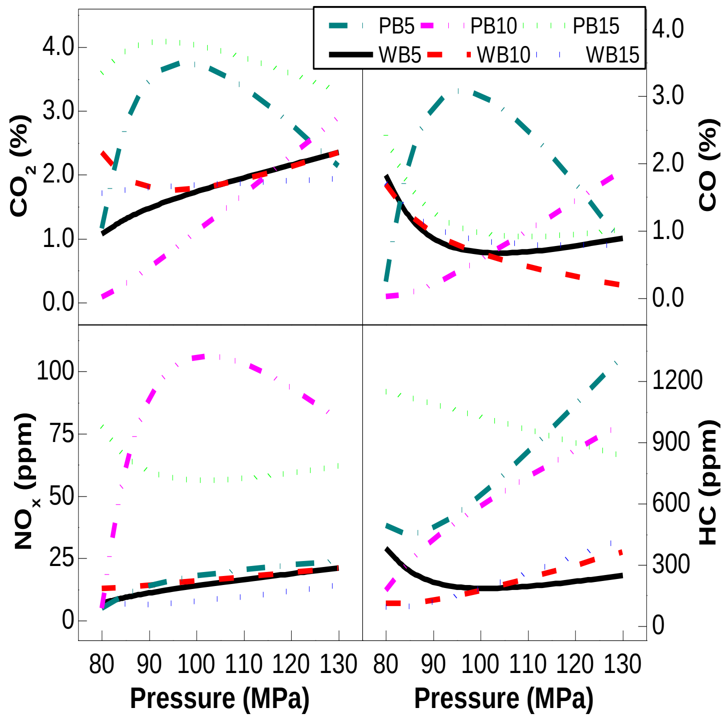

FIGURE 6. Effect of different injection pressure on emission.

It can be seen that the CO and HC emission decreased propotional to the increasing of IP for PB15, supporting that air-fuel mixture progress will be enhanced through higher IP, which bound for complete combustion. However opposing trend is shown by the PB10. Aside, all WB fuels remarked gradually decresed in CO associated with increasingly of HC corresponding to the IP increment. In addition, the CO_2 and NOx emissions is apparent to increase parallel to the increment of IP, which is mainly due to high temperature in RC contributes to combustion process improvement along with promotion of higher percentage of CO_2 productions. Emissions promoted by PB were found to be higher than by WB fuels in overall.

Implication Of Variation Ambient Temperature (At) On Ignition Delay (Id) And Emission

Variant AT for combustion is to be expected influences the autoignition behavior and combustion process of biodiesel fuel. Evidence for this was provided by RCM analysis of PB and WB fuels for AT ranging from 750 K to 1050 K as shown in *Figure 7*. It can be seen on *Figure 7* that the trends showed the decreases of ID with the increment of AT. The ID measured for WB15 was 2.0 ms at lowest AT and later decreases to 1.5 ms at AT of 850 K. The similar trend was observed for AT at 950 K in which ID reduce to 1.3 ms and conclude at 1.1 ms delay period for 1050 K temperature. The ID observed to be shorter with the increasing AT primarily due to the fact that the expansion of the fuel molecular sizes during higher combustion temperature bound for the weaken of C-H bonding and thus lowering the bond dissociation energy that assists to the improvement of fuel reactivity. In conjunction, PB fuels also demos the decreasing trend in ID that comparable to that of WB. The greatest ID for PB was 2.5 ms by PB5 at AT of 750 K. This remarked ID is reduce bit by bit to it lowest of 2.0 ms at AT 1050 K. As discussed, this conditions occurs due to decreases of bond dissociation energy as AT inclined.

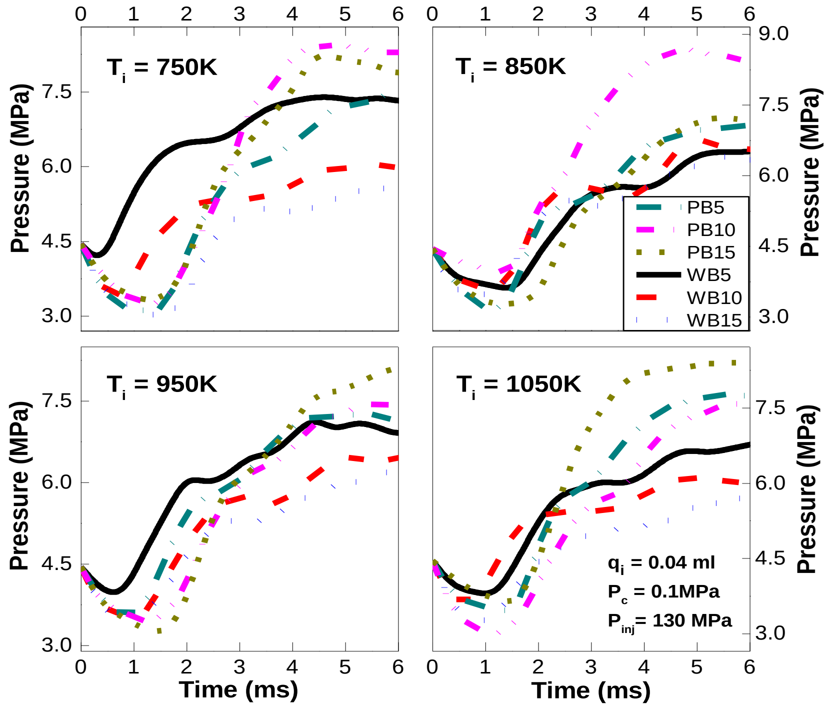

FIGURE 7. Ignition delay of PB and WB under variation ambient temperature.

Figure 8 displays the variation AT influences on emission impacts of the potential reaction mechanisms of PB and WB fuels combustion through a constant injection pressure of 130 MPa. For this purposes, the experiment has been carried out through different AT ranging from 750 K to 1050 K with 100 K temperature increment step.

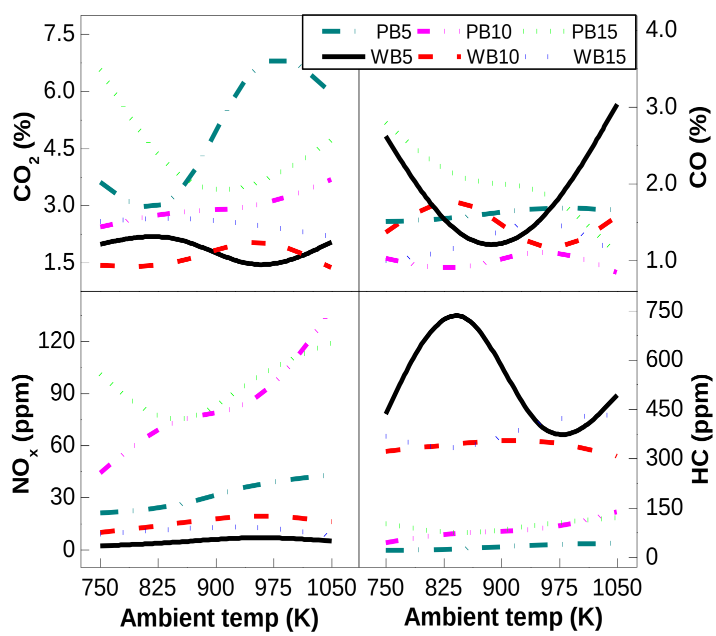

FIGURE 8. Effect of variant ambient temperature on emission.

As can be seen in *Figure 8*, the NOx and CO_2 emission are slightly increases as AT in CVC increased while the CO and HC emissions were decrement at a slight with respect to the AT progressive for all fuels with the exception of WB5. Emission of NOx increased during higher temperature of CVC and RC that primarily affecting the combustion temperature and hence influences the NOx formation. Higher AT directed to better fuel atomization and penetration rate that improvise combustion process and efficiency. Besides, the CO_2 emission for PB5 and PB10 increased parallel to the AT suggests that the particular fuels undergo a good combustion process at high temperature of combustion. In addition, the CO emission produces is decreased with increasing ambient temperature. At the higher AT i.e. 1050 K explored, the CO_2 emission for PB and WB fuels were at the greater compared to that at lower AT. Nevertheless, minor reduction of HC with respect to the increment of AT was remarked which is mainly related to the shorter ID and satisfactory air-fuel mixing progression that aid to complete combustion then reducing HC.

CONCLUSION

This work was devoted to investigate ignition process and combustion process, in detail the ignition delay (ID) period during fuel combustion of biodiesel blends derived from palm oil (PB) and waste cooking oil (WB) blends. The results of ID and emission of PB and WB fuels indicate that several parameters such as blending concentration, injection pressure (IP) and ambient temperature (AT) reflect the autoignition behavior and combustion process. This work concludes that quickest ID of PB and WB fuels vacant by lower concentration, suggesting that the less biodiesel concentration, the better spray atomization and premixing, enhance ignitability and shorten ID. Contradictory to the AT and IP of CVC where the shortest ID of PB and WB fuels offered by higher IP and higher AT. Increasing IP and AT contributes to improve air-fuel mixing, enhance combustion and hasten ID. Aside, WB fuels remarked lower emissions than PB. Overall, the presented results by RCM shows that PB and WB blends at high IP and AT provide better autoignition, while high blending concentration provide better CO emissions.

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