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Chemical Kinetic Investigation: Exploring the Impact of Various Concentrations of HHO Gas with a 40% Biodiesel/Diesel Blend on HCCI Combustion

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***Abstract*-This study uses the Chemkin software program to evaluate the effect of different quantities of oxyhydrogen gas [HHO] added to 40% biodiesel and diesel mix [B40], including B40, B40+5HHO, B40+10HHO, and B40+15HHO, on the HCCI combustion process's efficiency. The information collected includes cylinder pressure, cylinder temperature, accumulated gas phase heat release, heat loss rate, UHC, and mole fractions of O_2, CO, CO_2, diesel [NC_7H_{16}], biodiesel [$C_5H_{10}O_2$], and oxyhydrogen [H_2O]. The finding is that, when compared to a blend of biodiesel and diesel, using oxyhydrogen in the biodiesel/diesel mix boosts the properties of the HCCI engine.**

***Keywords:* biodiesel/diesel blend, HHO gas, HCCI Engine, CHEMKIN-PRO, engine characteristics, CI engine.**

Abbreviations/Nomenclature

CI	Compression engine
HCCI	Homogeneous charge compression engine
D100	Conventional diesel fuel or 100% diesel fuel
B40	40% biodiesel and 60% diesel blend
B40+5HHO	40% biodiesel and 60% diesel blend plus 5 oxyhydrogen gas
B40+10HHO	40% biodiesel and 60% diesel blend plus 10 oxyhydrogen gas
B40+15HHO	40% biodiesel and 60% diesel blend plus 15 oxyhydrogen gas
TDC	Top dead center
°CA	Degree crank angle
°C	Degree Celsius
PPM	Parts per million
TE	Thermal efficiency
BSFC	Brake specific fuel consumption
EGT	Exhaust gas temperature
UHC	Unburned hydrocarbon
CO_2	Carbon dioxide
CO	Carbon monoxide
O_2	Oxygen rate
NOx	Nitrogen oxide
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
T_C	Cylinder temperature

Abbreviations/Nomenclature Cont…

P_C	Cylinder pressure
HRR	Heat release rate
ITE	Indicated thermal efficiency
IMEP	Indicated Mean Effective Pressure
IP	Indicated Pressure
ISFC	Indicated specific fuel consumption

I. INTRODUCTION

The world currently promotes the use of renewable energy resources more and more because of the negative impact that fossil fuels and non-renewable resources have on the environment and human health [1-5]. Concerns about the greenhouse effect and global climate change prompted researchers to seek environmentally friendly resource replacements for fossil fuels [6-11]. Carbon dioxide emissions from fossil fuel extraction and burning grow, exacerbating greenhouse gas consequences including glacier melting, increasing sea levels, and acid rain. Urgent reduction is required to meet environmental and human development issues [12-17]. Diesel engines can be substituted with biodiesel, an environmentally friendly fuel. Biodiesel may be made from a number of ingredients, including edible and non-edible plant-based oils, fats from animals, and reused oil. The production of biodiesel can be achieved using enzymatic, chemical, or mechanical extraction processes. Several methods are employed to produce biodiesel from a variety of feedstocks, including pyrolysis, micro-emulsion, transesterification, and dilution [13-18]. The HCCI engine is a prominent contemporary combustion technology [19]. It is also known as a homogeneous charge compression ignition engine, which Onishi et al. discovered. This engine combines the benefits of both a compression-ignition [CI] diesel engine and a spark- ignition [SI] gasoline engine [20-24], leading to increased efficiency and lower NOx and PM emissions, as well as the ability to obtain a homogeneous mixture without the need for an injector or spark plug to control the combustion process [19, 25-28]. The Chemkin software program is a complex tool for deve

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loping chemical kinetic simulations of difficult processes. Its advanced solutions and powerful functions allow for the speedy and accurate construction of models for specific applications, which have been widely verified [29-34].

The following literature review papers illustrate the impacts of several concentrations of oxyhydrogen gas with a 40% biodiesel and diesel mix using the HCCI engine in the Chemkin software program.

The study examines the effects of hydrogen addition to nitrogen gas in a Chemkin program using the GRI-Mech 3.0 mechanism [29, 35-40]. The study found that higher hydrogen percentages led to a decrease in major reactants, a shorter reaction duration, and a faster reaction rate. However, the mole fractions of H, O, and OH increased over time. The study also found that higher hydrogen percentages can hinder CO and CO_2 production, as H radicals consume other components. Despite this, the addition of H_2 to CH_4 increased combustion rates and decreased emissions [41-45].

The study demonstrated the effects of hydrogen peroxide addition on HCCI engine parameters at different equivalence ratios, applied at different engine speeds [46]. The paper found high values at IMEP, IP, torque, TE, Pmax, and HRR, while NOx and Tmax were low. Compression ratio values increased at 0.1 and 0.2 equivalence ratios [47-52].

A study comparing ignition delay and multi-stage ignition for four blends of 50% dimethyl ether and 50% C1-C4 alkane mixes was conducted using Chemkin software and the NUIG Aramco Mech 3.0 mechanism [53]. Results showed the DME and C_3H_8 mix had the greatest ignition delay, while DME and CH_4 had a smaller delay. The number of primary interactions was high at DME and CH_4 but low at DME and C_3H_8 [54-58].

The study found that adding hydrogen and methane to HCCI engines, with or without exhaust gas recirculation, can result in combustion processes in a single zone model [59-64]. High values of TC, PC, HRR, ITE, and NO were observed, while low values were observed for work, torque, CO, UHC, fuel consumption, and burning time. The methane-hydrogen combination is a promising sustainable fuel for diesel engines, offering economic, energy, and environmental benefits [65-69].

The study simulated the effects of adding a blend of H_2S and NH_3 to acid gases in a Chemkin program using the Claus process model thermal reactor [70-74]. Results showed that the H_2S/NH_3 mix, and air flow rate significantly impacted the reactor's output temperature and gas composition. Proper regulation of the air flow rate is crucial for optimal performance and S_2 generation.

The study explores the effects of biodiesel and diesel blends on HCCI engine parameters in a Chemkin program [75-78]. Results show a rise in Pmax, Tmax, and NHR with incremental equivalence ratios, while parameters drop with high biodiesel and diesel blends. CD declines with increasing equivalence ratios [79, 80].

The study examines the impact of palm oil-based biodiesel and diesel blends on HCCI-DI engine performance and emissions. Performance metrics like engine power, BMEP, BSFC, NOx, UHC, CO_2, and CO were compared [81]. Results showed higher engine power in DI mode than HCCI-DI mode, and decreased engine power and BMEP for all fuels. NOx levels decreased with higher ω levels, while UHC emissions decreased when diesel fuel was combined with PO5, and PO10 showed the best combustion due to increased oxygen content. CO_2 levels dropped in both DI and HCCI-DI modes, with PO5 and PO10 having the highest levels in DI mode [82-84].

The study investigated the performance, combustions, and emissions of HCCI, and neat diesel CI engines fueled with biodiesel Ceiba Pentandra Oil Methyl Ester [85-90]. The results showed a significant reduction in emissions compared to neat diesel CI engine operation, but increased HC and CO levels. The study highlights the need for improved fuel efficiency in HCCI engines.

The study examined the effects of biodiesel and diesel fuels on performance, combustion, and exhaust emissions in biodiesel HCCI and diesel HCCI engines [91-96]. The addition of a biodiesel/diesel blend to the HCCI engine reduced cylinder temperature and oxygen availability, resulting in lower combustion efficiency. However, it also increased ISFC, CO, HC, and smoke opacity while decreasing power output, EGT, PCP, and HRR for all tested fuels.

The study explores the performance, emission, and combustion values of orange oil methyl ester biodiesel/diesel blends (O25 and O50) with and without hydroxyl (HHO) in a diesel engine [97]. The results show that the relationship between BTE and BSFC is inversely proportional, with BTE falling by 6.9% at O25 and 10.06% at O50 and rising by 9.08% at O25 + HHO and 3.54% at O50 + HHO. BSFC growth increases by 3.7% and 7.4% at O25 and O50. When HHO is added to O25 and O50, cylinder pressure and HRR increase while ignition delay decreases. NOx increases when O25 is added to HHO but decreases when HHO is added to biodiesel. The study concludes that adding HHO to a biodiesel/diesel blend increases BTE, cylinder pressure, HRR, and NOx while decreasing BSFC, ignition delay, HC, CO, and smoke emissions [98-101].

The study examined the performance, combustion, and emissions of a CI engine using 20% used cooking oil biodiesel and 80% diesel with hydroxyl additives [102]. The results showed that the addition of HHO to biodiesel/diesel blends increased PCP and HRR but reduced them at the B20 blend due to its low calorific value [103-105]. The combustion duration was shorter for B20 + HHO. The lowest noticeable values of CO, HC, and smoke emissions were observed when HHO additives were added to the biodiesel/diesel blend. The study concluded that adding HHO to a biodiesel/diesel blend increased PCP, HRR, BTE, and NOx values while decreasing ignition delay, combustion duration, BSFC, CO, HC, and smoke emissions [106, 107].

The study analyzed the impact of hydrogen hydride [HHO] on M. oleifera biodiesel and diesel blends on CI engine performance, combustion, and emission characteristics [108]. Results showed that BTE increased with B20H to 80% engine load but decreased with BSFC. Cylinder pressure and EGT increased with B20H, while CO, CO_2, and HC decreased. HHO can customize engine performance and reduce environmental pollution, but NOx emissions increased with increased engine load.

The aim of this research is to study the effects of various concentrations of oxyhydrogen gas to biodiesel and diesel blend on HCCI engine characteristics through a software program called Chemkin.

II. THE EXPERIMENTAL METHODOLOGY AND PROCEDURE

The “CHEMKIN-PRO” chemical kinetics software was selected for simulations, with the “n-Heptane, Detailed Mechanism, Version 3.1” mechanism [109] chosen for data processing to analyze the reaction of diesel fuel [NC_7H_{16}], biodiesel [$C_5H_{10}O_2$] and oxyhydrogen [H_2O] at various percentage blends. Additionally, "ic_engine__hcci_heat_loss_woschni" was a model project that included “the closed internal combustion engine simulator” model component, which operated the simulator on it, as shown in the figure [1]. The table [1] shows the specification of engine including, initial pressure, initial temperature, equivalence ratio, used Fuel/blend, engine crank angle, compression ratio, clearance volume, engine connecting rod to crank radius ratio, engine speed, start crank angle or ATDC, heat transfer correlation, Prandtl number, Woschni correlation of average cylinder gas velocity, gas reaction rate multiplier.

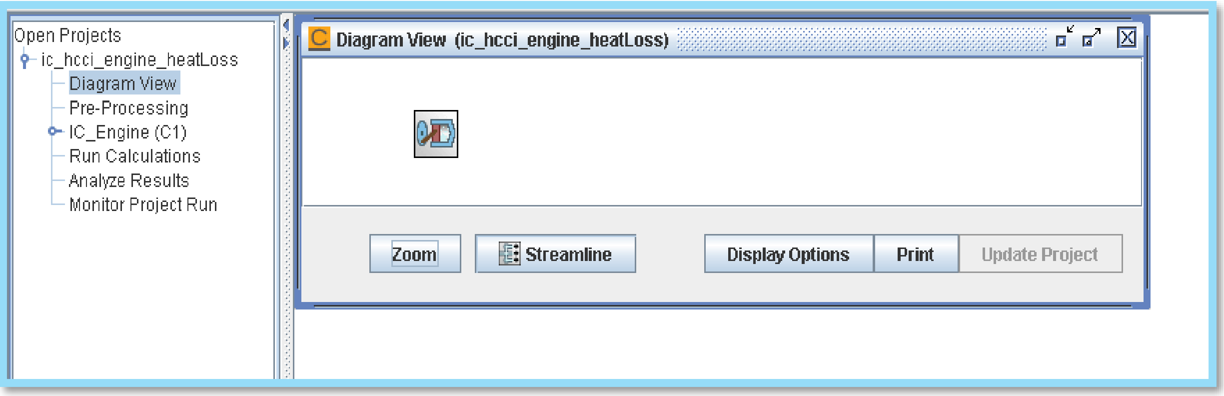

Figure 1. The model of project

Table 1. Engine specifications

Engine specifications	
Initial pressure	0.95 atm
Initial temperature	343 K
Equivalence ratio	0.3
Used Fuel/blend	Diesel [NC_7H_{16}], Biodiesel [$C_5H_{10}O_2$] and oxyhydrogen [H_2O]
Engine crank angle	280 °CA
Compression ratio	16.5
Clearance volume	103.3 cm^3
Engine connecting rod to crank radius ratio	3.714286
Engine speed	1500 rpm
Start crank angle or ATDC	-140 °CA

Table 2. Cont…

Heat transfer correlation	Coefficient a	0.035
	Coefficient b	0.71
	Coefficient c	0.0
	Chamber bore diameter	12.065 cm
Heat transfer correlation	Wall temperature	400 K
Prandtl number	0.7	
Woschni correlation of average cylinder gas velocity	Coefficient C11	2.28

Table 3. Cont…

Woschni correlation of average cylinder gas velocity	Coefficient C12	0.308
	Coefficient C2	3.24
	Ratio of swirl velocity to mean piston speed	0.0
Gas reaction rate multiplier	1.0	

Simulating the HCCI outputs at different values of oxyhydrogen gas to biodiesel/diesel blend to study the impact of it on the HCCI engine combustion process, in addition to the following three steps that demonstrate how the model output results and curves.

A. Step 1

In the beginning, open the Chemkin software program, then choose the open button from the file menu.

B. Step 2

After going to the "open" window, choose the "Home" file. After that, click on the file “sample 45” then choose the file on which the simulation will be performed. In this paper, the file on which the simulation was performed is known as “ic_engine__hcci_heat_loss_methane.ckprj”, then click on file “ic_engine__hcci_heat_loss_woschni”.

C. Step 3

When the file "ic_engine__hcci_heat_loss_woschni" opens, there is a tree below the opened file that contains six stages to outcome results, including diagram view, pre-processing, ic_engine (C1), run calculations, analyze results, and monitor project run.

C.1. Diagram view stage

This stage contains the model components that the project is working on, known as “the closed internal combustion engine simulator”.

C.2. Pre-processing stage

Following the diagram view stage, the pre-processing stage is responsible for defining and running the chemistry set or combustion mechanism in the model of the simulation. There are two elements of the pre-processing section: the chemistry set and mechanism parameters. The chemistry set is a vital part that uploads the project mechanism to obtain the summary, gas-phase kinetics output, gas-transport output, and batch job output. The instructions below illustrate how to run the mechanism files on the model. Firstly, open the pre-processing option from the project tree. Secondly, select the chemistry set button and then click the edit chemistry set button to load the working mechanism files, which include gas-phase kinetics files, thermodynamics data file, and gas transport data file, and afterwards click on save/save as button. Thirdly, after clicking on the run pre-processor button to execute the mechanism files on the model used, the message "successful run" will appear in the program's message box, which indicates that the mechanism files have been uploaded. Finally, the view results button displays summary, gas-phase kinetics output, gas transport output, and batch job output. At this time, close the pre-processing window and go for the next option, which is called ic_engine (C1).

C.3. IC_Engine (C1) Stage

The ic_engine (c1) stage follows the pre-processing stage, which consists of four parts: the c1_ic engine, solver, output control, and continuous. The most significant component is the c1_ic engine, which is divided into two parts: reactor physical properties and reactant species, which are responsible for information about the specifications of the engine and fuels/blends used whose inputs are provided by the user, respectively.

The methods below demonstrate how to input the engine and utilize fuel/blend characteristics in the model. Firstly, open the ic_engine (c1) option from the open project tree. Secondly, choose reactor physical properties button to input the engine characteristic, there is an input parameters used in this research as, engine crank angle [280 °CA], compression ratio [16.5], clearance volume [103.3 cm^3], engine connecting rod to crank radius ratio [3.714286], engine speed [1500], start crank angle or ATDC [-140 °CA], initial pressure [0.95 atm], initial temperature [343 K], heat transfer correlation [coefficient a [0.035], coefficient b [0.71], coefficient c [0.0], chamber bore diameter [12.065 cm], and wall temperature[400 K]], Prandtl number[0.7], Woschni correlation of average cylinder gas velocity [coefficient C11 [2.28], coefficient C12 [0.308], coefficient C2 [3.24], and ratio of swirl velocity to mean piston speed [0.0]], and gas reaction rate multiplier [1.0].

Thirdly, choose the reactant species button to input used fuels/blends characteristics, divided into five parts that need parameters such as equivalence ratio, fuel mixture, oxidizer mixture, complete-combustion products, and added species. This study of the impact of various concentrations of HHO gas [5, 10, 15] with blend of biodiesel and diesel [B40] on HCCI combustion with used fuels are diesel fuel [n-heptane NC_7H_{16}], biodiesel fuel [$C_5H_{10}O_2$] and oxyhydrogen gas [H_2O], and equivalence ratio [0.3], as well the percentages of biodiesel/diesel blend with HHO are 40 % biodiesel and 60% diesel fuel [B40], 40 % biodiesel and 60% diesel fuel plus 5 HHO [B40+5HHO], 40 % biodiesel and 60% diesel fuel plus 10 HHO [B40+10HHO], and 40 % biodiesel and 60% diesel fuel plus 15 HHO [B40+15HHO]. Additionally, there is another fixed input parameters used to include oxidizer mixture with two values of N_2 [0.77] and O_2 [0.23], and complete-combustion products with three inputs of

CO_2, H_2O, and N_2. At this time, close the ic_engine (c1) windows and go to the next option, which is called run calculations.

C.4. Run Calculations stage

This stage operates after the ic_engine (C1) stage, which is responsible for identifying the type of model the user has selected to produce as results. It comprises three parts: model, parameter study, and uncertainty.

C.5. Analyze Results stage

The analyze results stage, positioned next to the run calculations stage, determines which solutions to analyze via the parameter study, and methods analyze techniques as plot results and analyze reaction paths that are selected by the user.

C.6. Monitor Project Run stage

This stage is the last section, adjacent to the analyze results stage, which is responsible for the steps of running the model to output the results using two options: either curves or data numbers in an Excel sheet.

III. RESULTS AND DISCUSSION

The impact of various percentages of oxyhydrogen gas [HHO] with 40% biodiesel/diesel blend on HCCI combustion:

At a constant initial combustion pressure and temperature of 0.95 atm and 343 K, respectively, with an equivalence ratio of 0.3. The study uses two fuels: n-heptane diesel fuel [NC7H16] and biodiesel [C5H10O2] which are added with oxyhydrogen gas [H_2O]. The study illustrates the effectiveness of 40% biodiesel/diesel blend with different concentrations of HHO gas [B40 [40% biodiesel and 60% diesel], B40+5HHO [40% biodiesel+60% diesel+5HHO], B40+10HHO [40% biodiesel+60% diesel+10HHO], and B40+15HHO [40% biodiesel+60% diesel+15HHO]] for HCCI combustion.

1. Cylinder pressure

Figure [2] shows the cylinder pressure vs. crank rotation angle plot of different blends in the HCCI combustion process. As the proportions of HHO addition to the B40 blend grow, the cylinder pressure readings significantly decline. Furthermore, B40 has a higher cylinder pressure than the three concentrations of HHO gas with B40; therefore, the greatest cylinder pressure point is at B40 with a crank rotation angle of 0.72 °CA and a cylinder pressure of 39.61 atm. [≈ 40.13 bar], while the smallest point is at B40+15HHO with a crank rotation angle of -20 °CA and a cylinder pressure of 19.89 atm. [≈ 20.15 bar].

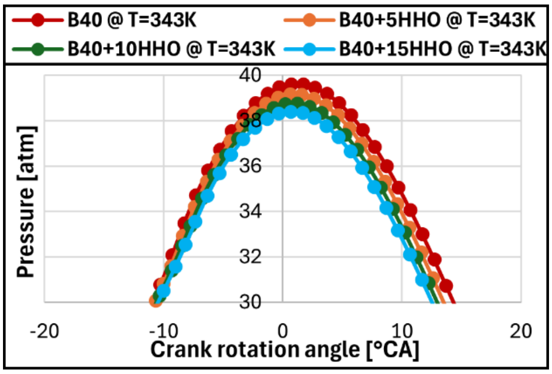

Figure 2. Cylinder pressure vs. crank rotation angle

2. Cylinder temperature

Figure [3] shows the cylinder temperature vs. crank rotation angle plot of different blends in the HCCI combustion process. As the proportions of HHO addition to the B40 blend grow, the cylinder temperature readings significantly decline. Furthermore, B40 has a higher cylinder temperature than the three concentrations of HHO gas with B40; therefore, the greatest cylinder temperature point is at B40 with a crank rotation angle of 6.72 °CA and a cylinder temperature of 951.57 K. [≈ 678.42 °C], while the smallest point is at B40+15HHO with a crank rotation angle of -20 °CA and a cylinder temperature of 754.79 K [≈ 481.64 °C].

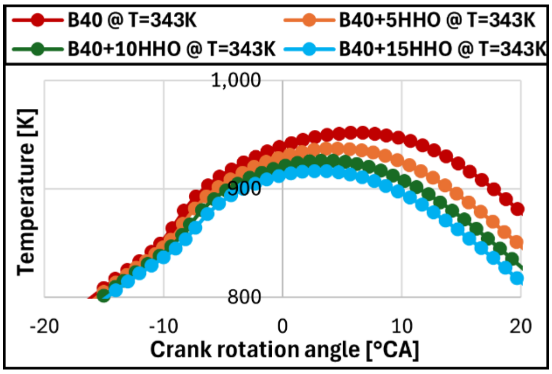

Figure 3. Cylinder temperature vs. crank rotation angle

3. Accumulated gas phase heat release

Figure [4] shows the accumulated gas phase heat release vs. crank rotation angle plot of different blends in the HCCI combustion process. As the proportions of HHO addition to the B40 blend grow, the accumulated gas phase heat release readings significantly decline. Furthermore, B40 has a higher accumulated gas phase heat release than the three concentrations of HHO gas with B40; therefore, the greatest accumulated gas phase heat release point is at B40 with a crank rotation angle of 20 °CA and an accumulated gas phase heat release of 1899052000 erg, while the smallest point is at B40+15HHO with a crank rotation angle of -

20 °CA and an accumulated gas phase heat release of 43.01 erg.

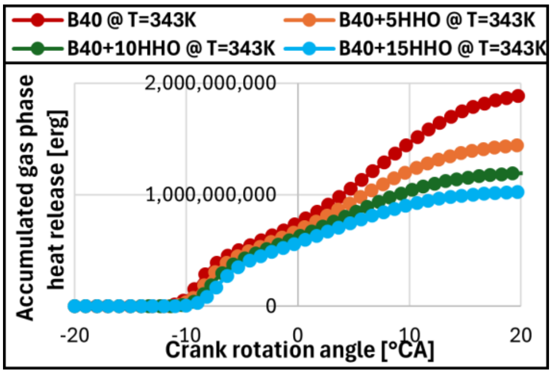

Figure 4. Accumulated gas phase heat release vs. crank rotation angle

4. *Heat loss rate*

Figure [5] shows the heat loss rate vs. crank rotation angle plot of different blends in the HCCI combustion process. As the proportions of HHO addition to B40 blend grow, the heat loss rate readings become significantly unsteady, rising between -16 °CA and -20 °CA, then dropping from -16 °CA to 20 °CA. Furthermore, B40 has a higher heat loss rate than the three concentrations of HHO gas with B40; therefore, the greatest heat loss rate point is at B40 with a crank rotation angle of 12.72 °CA and a heat loss rate of 1176.12 cal/sec, while the smallest point is at B40+5HHO with a crank rotation angle of -17 °CA and a heat loss rate of 12.74 cal/sec.

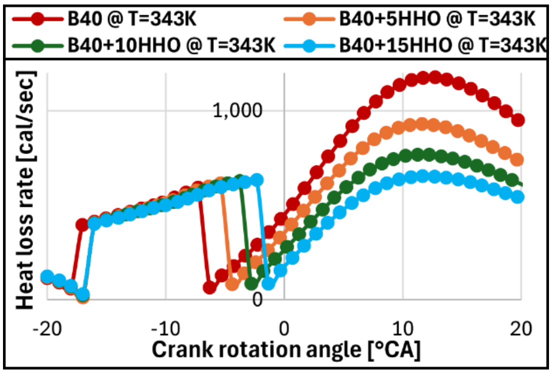

Figure 5. Heat loss rate vs. crank rotation angle

5. *Mole fraction O_2*

Figure [6] shows the mole fraction O_2 vs. crank rotation angle plot of different blends in the HCCI combustion process. As the proportions of HHO addition to the B40 blend grow, the mole fraction O_2 readings significantly decline. Furthermore, B40 has a higher mole fraction O_2 than the three concentrations of HHO gas with B40; therefore, the greatest mole fraction O_2 point is at B40 with a crank rotation angle of -20 °CA and a mole fraction O_2 of 0.228, while the smallest point is at B40+15HHO with a crank rotation angle of 20 °CA and a mole fraction O_2 of 0.197.

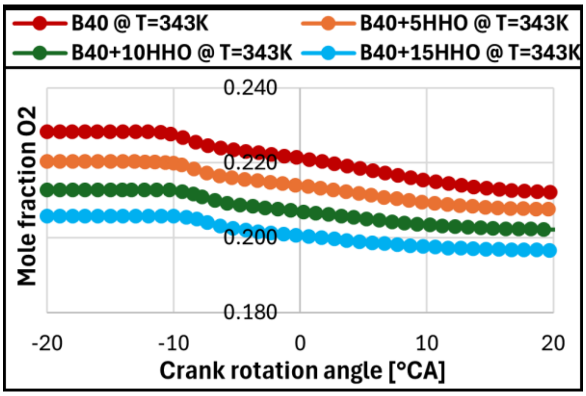

Figure 6. Mole fraction O_2 vs. crank rotation angle

6. *Mole fraction CO*

Figure [7] shows the mole fraction CO vs. crank rotation angle plot of different blends in the HCCI combustion process. As the proportions of HHO addition to the B40 blend grow, the mole fraction CO readings significantly decline. Furthermore, B40 has a higher mole fraction CO than the three concentrations of HHO gas with B40; therefore, the greatest mole fraction CO point is at B40 with a crank rotation angle of 20 °CA and a mole fraction CO of 0.006, while the smallest point is at B40+15HHO with a crank rotation angle of -20 °CA and a mole fraction CO of 0.000,000,000,0298.

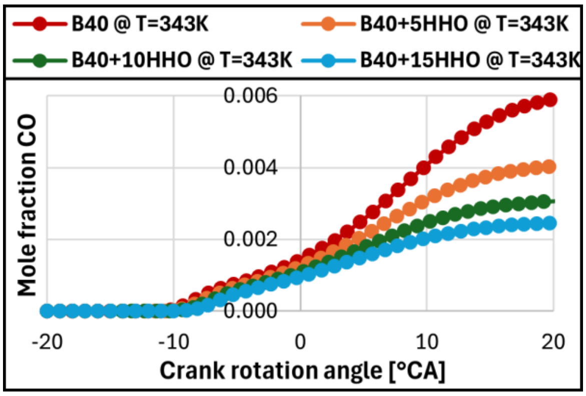

Figure 7. Mole fraction CO vs. crank rotation angle

7. *Mole fraction CO_2*

Figure [8] shows the mole fraction CO_2 vs. crank rotation angle plot of different blends in the HCCI combustion process. As the proportions of HHO addition to the B40 blend grow, the mole fraction CO_2 readings significantly decline. Furthermore, B40 has a higher mole fraction CO_2 than the three concentrations of HHO gas with B40;

therefore, the greatest mole fraction CO_2 point is at B40 with a crank rotation angle of 20 °CA and a mole fraction CO_2 of 0.00036, while the smallest point is at B40+15HHO with a crank rotation angle of -20 °CA and a mole fraction CO_2 of 0.000,000,000,000,000162.

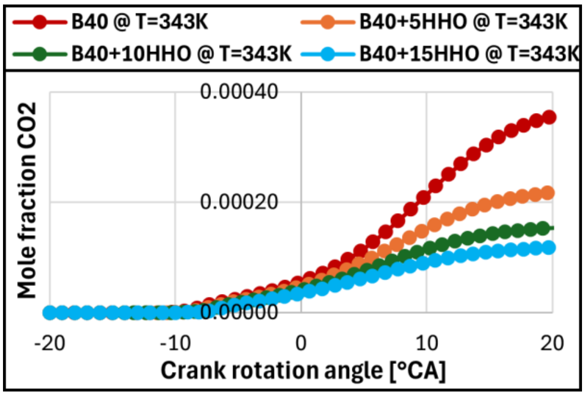

Figure 8. Mole fraction CO_2 vs. crank rotation angle

8. *UHC*

Figure [9] shows the UHC vs. crank rotation angle plot of different blends in the HCCI combustion process. As the proportions of HHO addition to B40 blend grow, the UHC readings become significantly unsteady, dropping between -20 °CA and -8 °CA, then rising from -8 °CA to -6 °CA, after that decremental till 6 °CA following that incremental to 20 °CA. Furthermore, the greatest UHC point is at B40 with a crank rotation angle of -20 °CA and an UHC of 30605.13 PPM, while the smallest point is at B40 with a crank rotation angle of 20 °CA and an UHC of 13661.58 PPM.

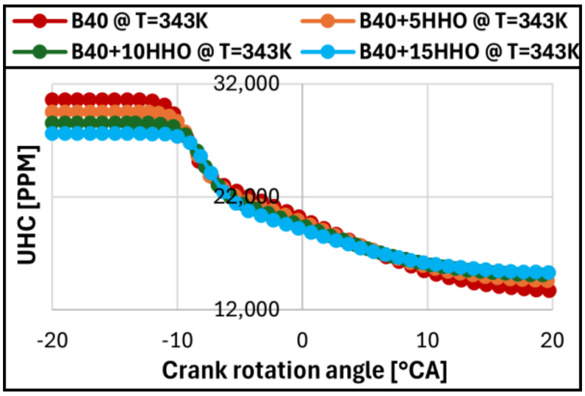

Figure 9. UHC vs. crank rotation angle

9. *Mole fraction NC_7H_{16}*

Figure [10] shows the mole fraction NC_7H_{16} vs. crank rotation angle plot of different blends in the HCCI combustion process. As the proportions of HHO addition to the B40 blend grow, the mole fraction NC_7H_{16} readings become significantly unsteady, dropping between -20 °CA and -10 °CA; therefore, B40 has a higher mole fraction NC_7H_{16} than the three concentrations of HHO gas with B40, after that rising from -10 °CA to 20 °CA which causes lower values of B40 compared to other blends. Furthermore, the greatest mole fraction NC_7H_{16} point is at B40 with a crank rotation angle of -20 °CA and a mole fraction NC_7H_{16} of 0.0044, while the smallest point is at B40 with a crank rotation angle of 20 °CA and a mole fraction NC_7H_{16} of 0.00024.

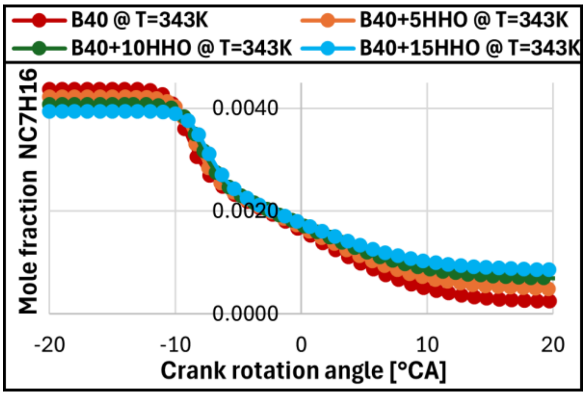

Figure 10. Mole fraction NC_7H_{16} vs. crank rotation angle

10. *Mole fraction $C_5H_{10}O_2$*

Figure [11] shows the mole fraction $C_5H_{10}O_2$ vs. crank rotation angle plot of different blends in the HCCI combustion process. As the proportions of HHO addition to the B40 blend grow, the mole fraction $C_5H_{10}O_2$ readings become significantly unsteady, dropping between -20 °CA and 5 °CA; therefore, B40 has a higher mole fraction $C_5H_{10}O_2$ than the three concentrations of HHO gas with B40, after that rising from 5 °CA to 20 °CA which causes lower values of B40 compared to other blends. Furthermore, the greatest mole fraction $C_5H_{10}O_2$ point is at B40 with a crank rotation angle of -20 °CA and a mole fraction $C_5H_{10}O_2$ of 0.0029, while the smallest point is at B40 with a crank rotation angle of 20 °CA and a mole fraction $C_5H_{10}O_2$ of 0.0013.

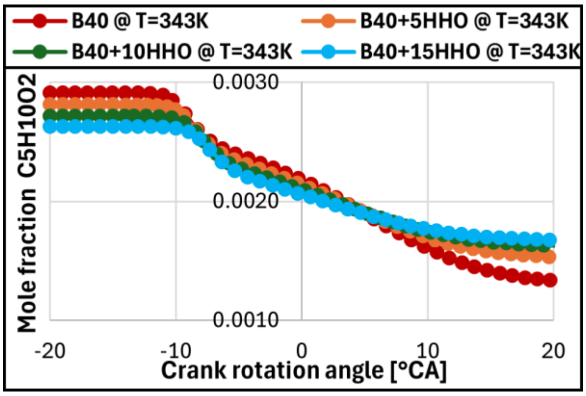

Figure 11. Mole fraction $C_5H_{10}O_2$ vs. crank rotation angle

11. *Mole fraction H_2O*

Figure [12] shows the mole fraction H_2O vs. crank rotation angle plot of different blends in the HCCI combustion process. As the proportions of HHO addition to the B40 blend grow, the mole fraction H_2O readings significantly climb. Furthermore, B40 has a lower mole fraction H_2O than the three concentrations of HHO gas with B40; therefore, the greatest mole fraction H_2O point is at B40+15HHO with a crank rotation angle of 20 °CA and a mole fraction $H_2O$of 0.104, while the smallest point is at B40 with a crank rotation angle of -20 °CA and a mole fraction H2O of 0.000,000,0009.

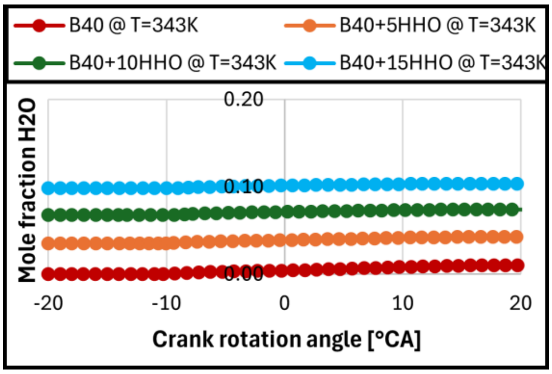

Figure 12. Mole fraction H_2O vs. crank rotation angle

IV. CONCLUSION

This paper explains the influence of the various concentrations of HHO with a 40% biodiesel and diesel mix at constant initial temperatures [343 K], initial pressure [0.95 atm], and equivalence ratios [0.3] in the engine of HCCI by using the Chemkin software program. The below points illustrate the conclusion of this research:

- When three concentrations of HHO are added to B40, which causes a reduction in cylinder pressure, cylinder temperature, accumulated gas phase heat release, and mole fractions of O_2, CO and CO_2. Furthermore, the B40 blend achieved the highest values as compared to the other blends.
- However, there are remarkable unsteady outputs of heat loss rate, UHC, and the mole fractions of NC_7H_{16}, $C_5H_{10}O_2$, and H_2O as a result of the addition of three concentrations of HHO to B40. Moreover, B40 has a higher outcome than the three concentrations of HHO with B40, except for the for the mole fraction of H_2O, for which HHO concentrations are more than B40.
- Finally, adding oxyhydrogen to a blend of biodiesel and diesel can improve the output characteristics of an HCCI engine.

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