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EXPERIMENTAL INVESTIGATION OF THE EFFECT OF THE INJECTION PRESSURE CHANGE ON DIESEL ENGINE EMISSIONS USING WASTE VEGETABLE OILS

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Abstract

Diesel engines are one of the most common reciprocating engines for use in many applications that convert the chemical energy in the fuel into kinetic energy. Vegetable oils are viewed as an alternative fuel or sustainable fuel and are utilized straightforwardly in diesel engines. Since these oils are sustainable and ecological amicable. The injection pressure of diesel engines can be altered to help ensure that the viscosity of the vegetable oils is low enough to allow proper atomization of the fuel. Waste vegetable oils can also be blended with diesel fuel for use under a wide range of conditions. The injection pressure is one of the important variables affecting the emissions of the engine. In this experimental study: the effect of changing the injection pressure 170, 185 and 200 bars on the emissions of a diesel engine by using different types of blends of waste vegetable oils with diesel fuel was studied. The important results are that with an increase in injection pressure it leads to reduce carbon monoxide in a range of percentages from 5% to 35%, as well as reducing carbon dioxide emissions in a range of percentages from 2% to 12% compared to the 170 bar injection pressure at different loads. Carbon dioxide is one of the main pollutants that cause an increase in global warming, and the use of these oils with a change in injection pressure has led to a further decrease in carbon dioxide emissions, and thus a decrease in global warming.

Keywords

Injection Pressure, Diesel Engine, Diesel Fuel, Waste Vegetable oil, Renewable Fuel and Exhaust Gas Emissions.

1. Introduction

Waste vegetable oils can be used as an alternative fuel in diesel engines. When waste vegetable oils is used directly as a fuel in a diesel engine, the injection pressure of diesel engines can be altered to help ensure that the viscosity of the vegetable oil is low enough to allow proper atomization of the fuel. Waste vegetable oils can also be blended with conventional diesel for use under a wide range of conditions. These oils are environmentally friendly and help reducing the global warming, where carbon dioxide constituted about 79-81 % of all greenhouse gas emissions in world from human activities in 2020 [1,2] as it is the main gas responsible for the increase in global warming.

The effect of injection pressure on the performance of a diesel engine using different types of fuel is the focus of many researchers. The used different fuels, hone biodiesel with injection pressure 180 to 240 bars [3], Neem oil methyl ester and castor oil methyl ester [4], DF with injection pressure from 100 to 250 bars [5], fuels at different cetin numbers with injection pressure 100 to 250 bars [6], Fresh Corn oil and palm oil with injection pressure 120 to 210 bars [7], lemon grass methyl ester with injection pressure 210 to 240 bars [8], fatty acid methyl ester with injection pressure 125 to 135 bars [9], waste cooking oil at 160 bar injection pressure [10], algae oil methyl ester with injection pressure 240 to 260 bars [11], polanga oil and thyme oil with injection pressure 180 to 220 bars [12], honge-rice bran biodiesel with injection pressure 180 to 220 bars [13], syzygium cumini oil biodiesel with injection pressure 200 to 260 bars [14], jatropha oil with injection pressure 400 to 600 bars [15], waste cooking oil biodiesel with injection pressure 170 to 220 bars [16], third generation Azolla biodiesel with injection pressure 300 to 900 bars [17], hydrogen fuel with injection pressure 50 and 70 bars [18] and biodiesel-butanol blends at different injection pressures [19]. Other researchers have studied the effect of biodiesel blended with diesel fuel on diesel engine emissions without change of injection pressure, such as, biodiesel from sunflower and soybean [20, 21], Biodiesel from Pithecellobium dulce seed oil [22, 23], Biodiesel from jatropha oil [24], Biodiesel from algae [25], Biodiesel from acetone [26], Nano sized silver and hydrogen peroxide used as nanoparticles additive in diesel/biodiesel fuel blends [27, 28] and Biodiesel from waste cooking oil and cyclohexane [29, 30]. Biodiesel is produced from many types of vegetable oils by transesterification—a process that converts fats and oils into biodiesel and glycerin.

From previous studies: the focus is on emissions of CO, CO_2 , HC and NO_X, where carbon dioxide constituted about 79% of all greenhouse gas emissions in the United States from human activities in 2020 [2] as it is the main gas responsible for the increase in global warming. Therefore, waste vegetable oils were used in this research because they are environmentally friendly.

The objective of the research is to use other types of oils as a fuel for the diesel engine which is waste palm kernel oil and waste sunflower oil. This study is to implement practical experiment on a diesel engine using different types of fuels, investigation the effect of injection pressure and engine load on engine emissions at constant engine speed. The aim of using these oils with a change in injection pressure is to reduce the proportion of harmful emissions, including carbon dioxide, which leads to a decrease in global warming.

2. Experimental Set-up and Test Procedure

The plan designed for the experimental study of the emissions of diesel engine using different species of fuels, DF, and three types of blends (by volume) of waste palm kernel oil with DF i.e. blends of 20% WPKO with 80% DF (B20-WPKO), likewise, B30-WPKOB40-WPKO, and also three types of blends (by volume) of waste sunflower oil with DF i.e. blends of 20% WSFO with 80% DF (B20-WSFO) likewise, B30-WSFO and B40-WSFO; were studied at injection pressure change and engine load at constant engine speed. Injection pressures used are 170, 185 and 200 bars as are the percentages of 20%, 40% and 60% of the engine loads are used in the study at a constant engine speed.

Fuel used main characteristics are shown in table 1. As shown in this table: pure diesel has the highest gross calorific value, lowest viscosity, lowest density and highest Cetane number. When diesel fuel mixed with waste vegetable oils to make blends; it is found that the more percentage of waste vegetable oils in the blends, the higher density, the higher viscosity, the lower gross calorific value and lower Cetane number. Pure WVO has the lowest gross calorific value, the highest viscosity and density.

Table 1. Properties of Fuel

	DF	Pure WPKO	Pure WSFO
Calorific value (kJ/kg)	42700	37200	37000
Viscosity (mm2/s) at 35 oC	5	69.6	67.7
Density (ρ) (kg/m3)	780	835	845
Cetane No.(CN)	48	36.5	37
Chemical Formula	$C_{10.8}H_{18.7}$ [31]	-	$C_{57}H_{103}O_6$ [32]

In the current experimental study a diesel engine was used with the specifications shown in table No. 2. Schematic diagram and a photographing plate of the experimental set-up are shown in Fig.1.

Table 2. Specification of the used diesel engine

Model	Deutz-F1L511
Type	4 stroke, direct injection
No. of cylinder	1
Compression ratio	17
Bore	100 mm
Stroke	105 mm
Power	5.7 Kw
Type of cooling	Air cooling

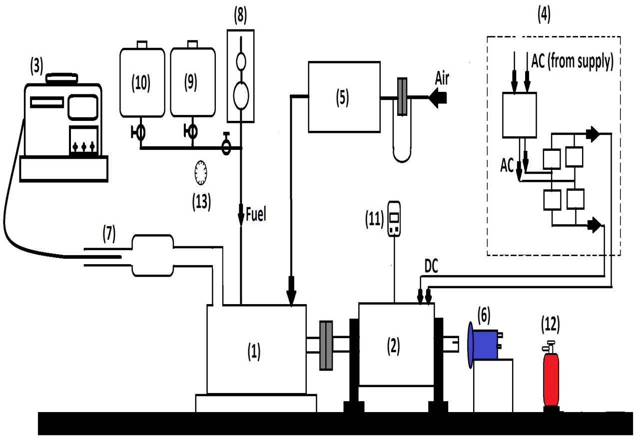


Figure 1(a) Schematic Diagram of the Experimental Setup

Figure 1 (b) A photographing Plate of the Experimental Set-up

(1) Diesel Engine; (2) Electrical Dynamometer; (3) Exhaust Gas Analyzer; (4) Voltage Regulator;(5) Air Box; (6) The Optical Tachometer; (7) Exhaust Gases Pipes;(8) Fuel Consumption Rate Device; (9) Biofuel Tank; (10) Diesel Fuel Tank;(11) The Digital Weight; (12) Fire Extinguisher and (13) Stop Watch

Figure 1. Schematic Diagram and a Photographing Plate of the Experimental Set-up

The excitation voltage field is adjusted to control the engine output by controlling the current entering an electrical dynamometer Therefore, the engine is adjusted at a certain load during test. The accuracy of the optical tachometer is ±0.01% used to measure engine speed. Table No. 3 illustrates during the test: the accuracies of the sensors used to measure the exhaust gas entering the measuring device of gases.

Table 3. Measurement accuracy of exhaust gases

CO	CO2	HC	NOX
±0.01%	±0.2%	±0.2%	±10 ppm

3. Experimental Results and Discussion

3.1. Carbon monoxide emissions for different fuels

The variation of CO emission for the diesel engine using WVO blends and DF with engine loads at different injection pressures are shown in Figures 2-A , 2-B, 2-C, 2-D, 2-E, 2-F and 2-G. From these figures we noticed that, the concentration of carbon monoxide increases with the increase in the load. CO emissions for WVO blends were higher than diesel fuel and it is increased with the increase in blend ratio. CO emission increase was due to higher carbon and C/H ratio content in WVO blends compared with DF. And on the other hand, with the increase in the injection pressure the concentration of carbon emissions decreases due to the improvement of the combustion process of different blends of WVO. This may be due to reduced viscosity of WVO blends which contributes to better atomization and combustion (5, 14, 16 and 17).

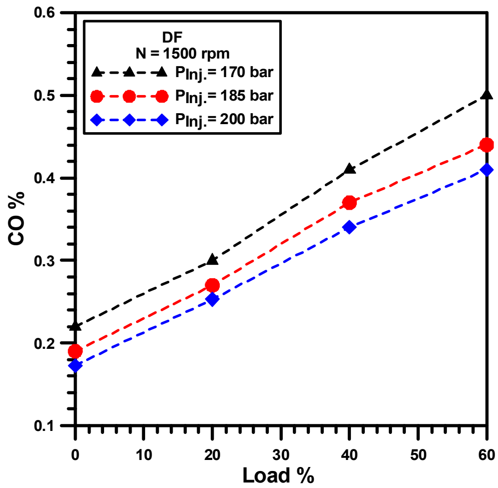


Figure (2-A) Effect of injection pressure on CO emission for Diesel Fuel

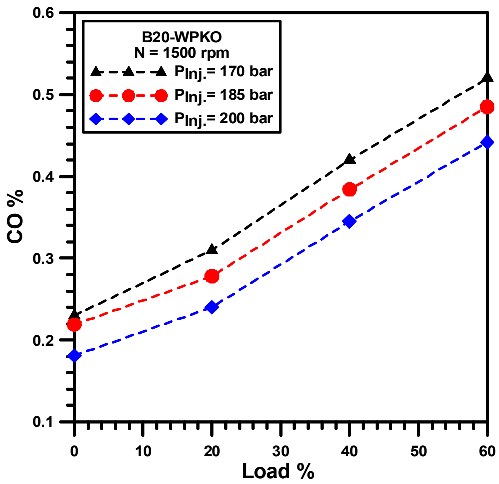


Figure (2-B) Effect of injection pressure on CO emission for B20-WPKO

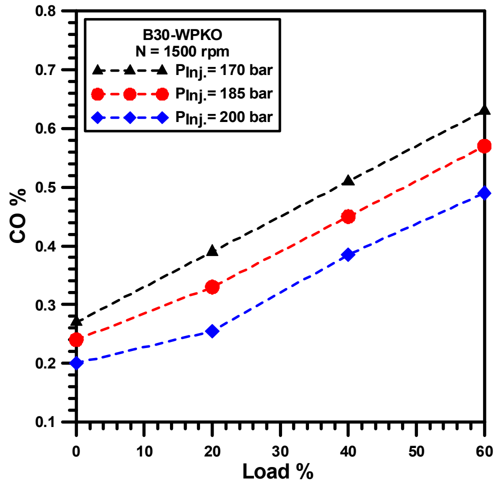


Figure (2-C) Effect of injection pressure on CO emission for B30-WPKO

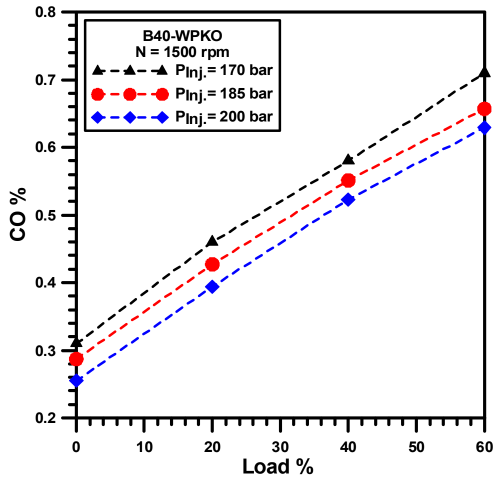


Figure (2-D) Effect of injection pressure on CO emission for B40-WPKO

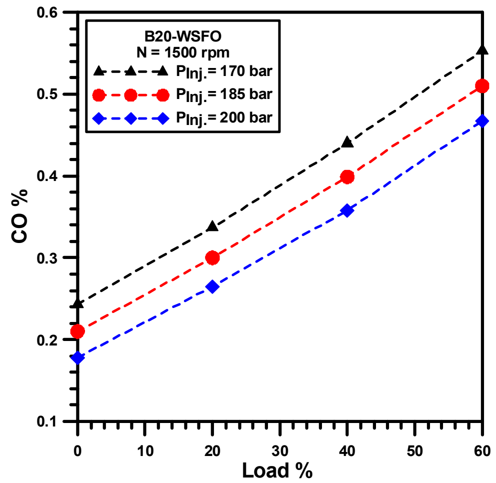


Figure (2-E) Effect of injection pressure on CO emission for B20-WSFO

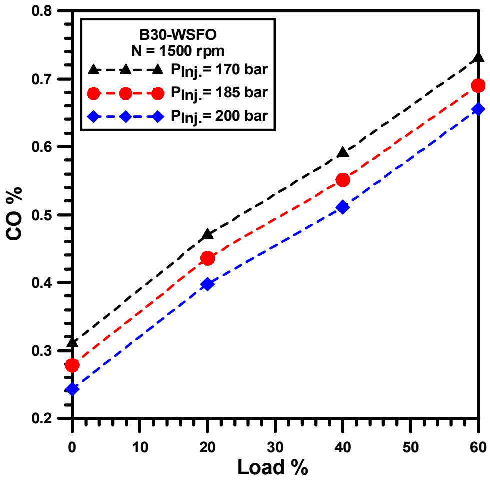


Figure (2-F) Effect of injection pressure on CO emission for B30-WSFO

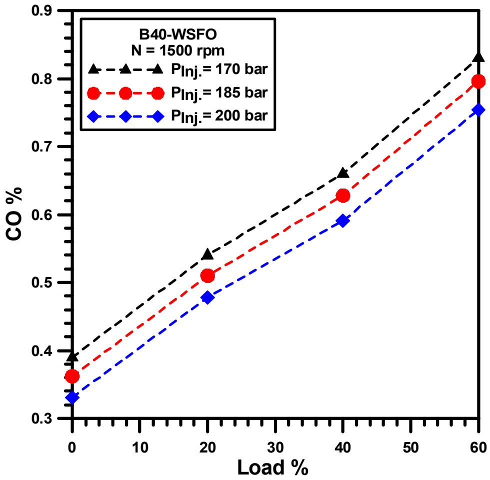


Figure (2-G) Effect of injection pressure on CO emission for B40-WSFO

Figure (2) The injection pressure effect on CO emissions for different fuels

3.2. Carbon dioxide emissions for different fuels

Figures 3-A, 3-B, 3-C, 3-D, 3-E, 3-F and 3-G illustrated the variation of CO_2 for different fuel used versus engine loads and different injection pressure at constant engine speed.

The emissions of Carbon Dioxide increase with increasing load compared with DF for B20-WPKO and B20-WSFO at injection pressure equal 170 bars. Then, CO_2 emissions decrease with increasing load and WVO blends compared with DF for B30 and B40 for fuel used at constant injection pressure. On the other hand, CO_2 emissions for WVO blends decrease with increase of WVO volume percentage due to increase in oxygen content in WVO blend compared with DF at constant injection pressure. As the injection pressure increases; it reduces the percentage of CO_2 emissions emitted from all the fuel used and this is due to decrease in the viscosity of the fuel used as a result of the better atomization which leads to improved combustion process (5).

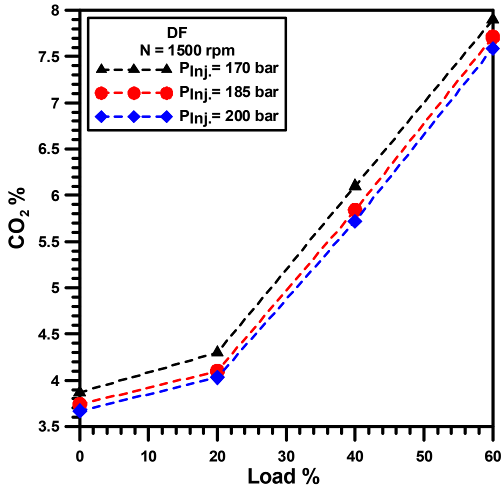


Figure (3-A) Effect of injection pressure on CO_2 emission for Diesel Fuel

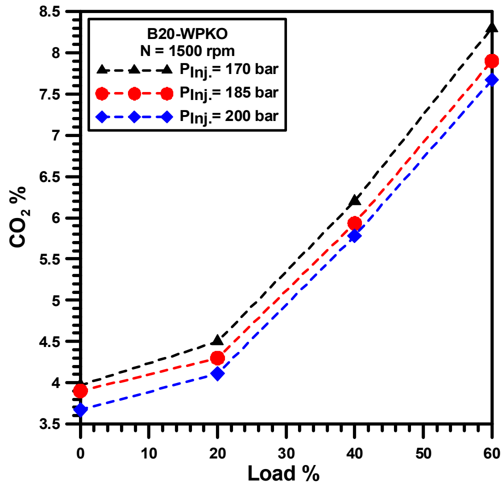


Fig. (3-B) Effect of injection pressure on CO2 emission for B20-WPKO

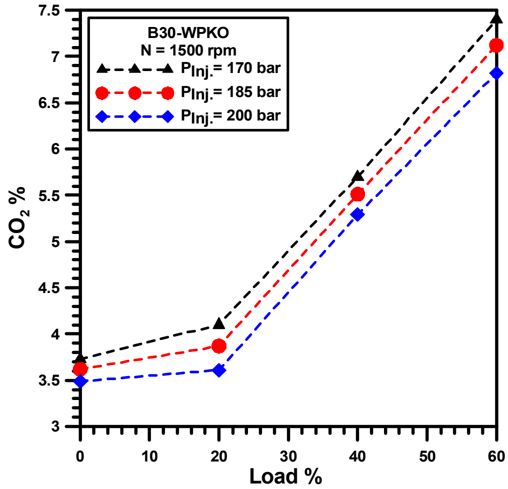


Figure (3-C) Effect of injection pressure on CO_2 emission for B30-WPKO

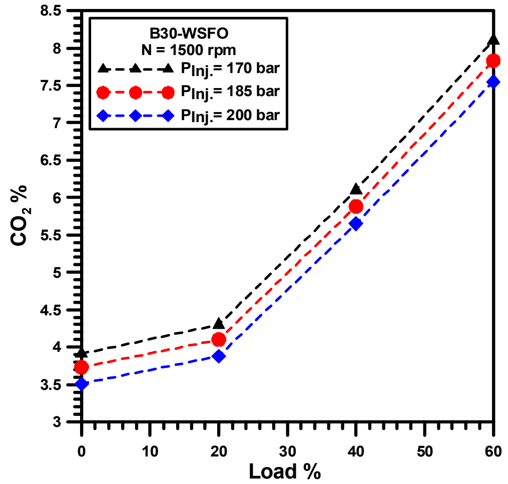


Figure (3-F) Effect of injection pressure on CO_2 emission for B30-WSFO

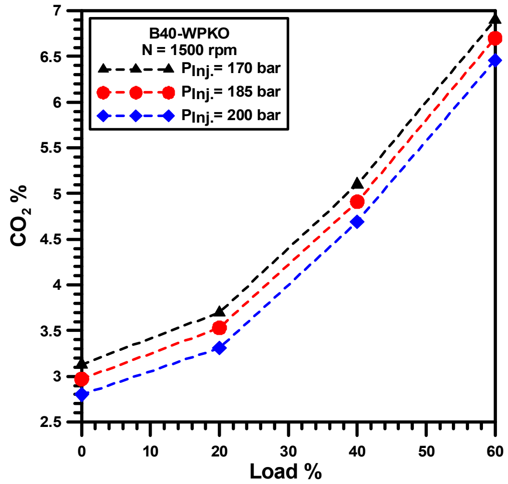


Figure (3-D) Effect of injection pressure on CO_2 emission for B40-WPKO

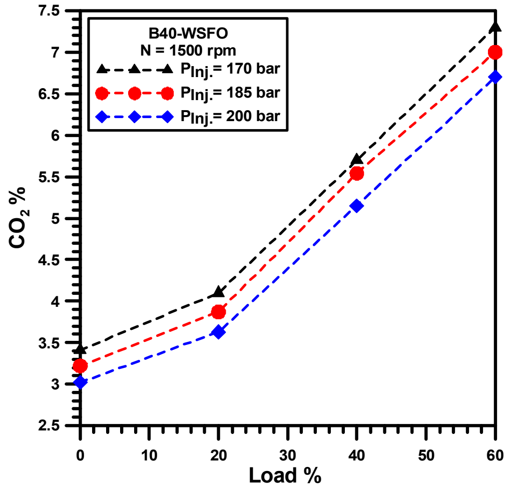


Figure (3-G) Effect of injection pressure on CO_2 emission for B40-WSFO

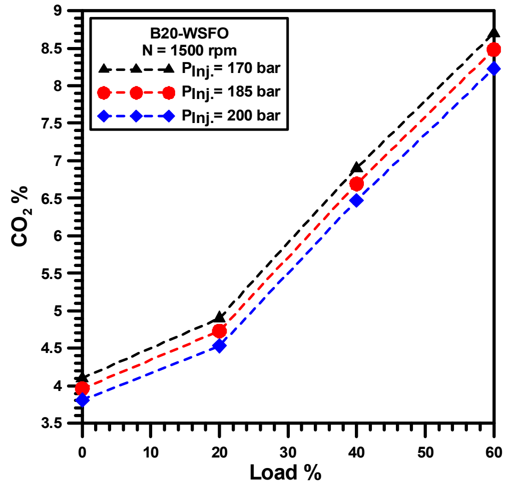


Figure (3-E) Effect of injection pressure on CO_2 emission for B20-WSFO

Figure (3) The injection pressure effect on CO_2 emissions for different fuels

3.3 HC emissions for different fuels

The variation of HC emissions for the diesel engine using different fuels with engine loads at different injection pressures are presented in Figures 4-A , 4-B, 4-C, 4-D, 4-E, 4-F and 4-G.

The HC emissions are minimal at no load and increase with increase of engine load at constant injection pressure. With the increase in the injection pressure the HC emissions of all types of fuels increased due to the increase in the ratio of carbon to hydrogen in the fuel and high density (14).

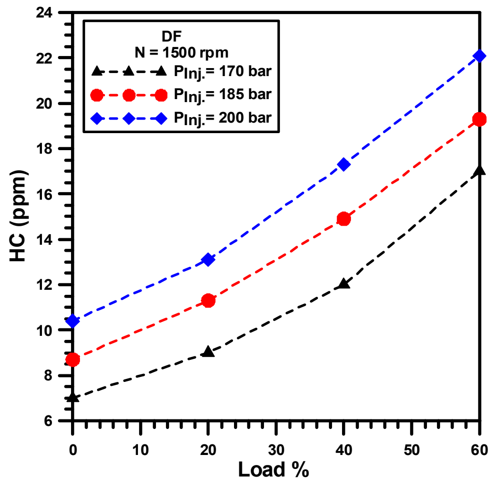


Figure (4-A) Effect of injection pressure on HC emission for Diesel Fuel

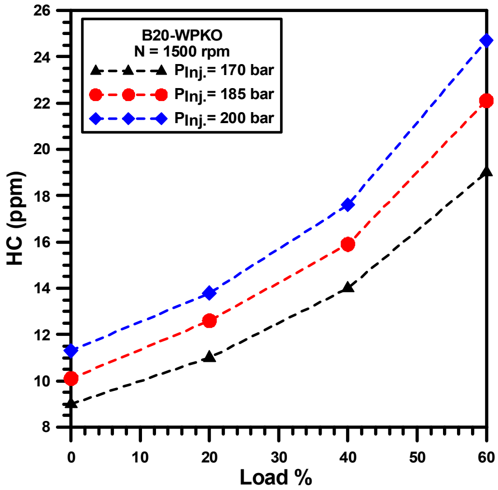


Figure (4-B) Effect of injection pressure on HC emission for B20-WPKO

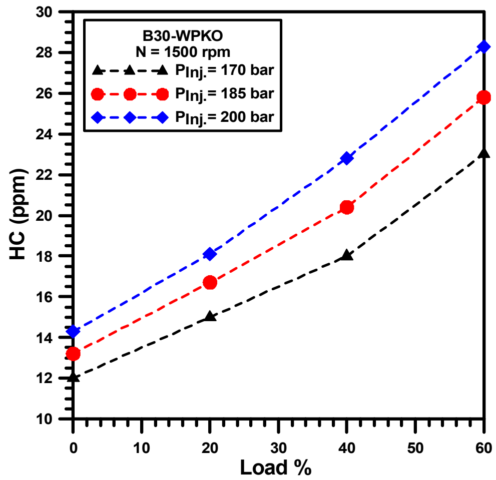


Figure (4-C) Effect of injection pressure on HC emission for B30-WPKO

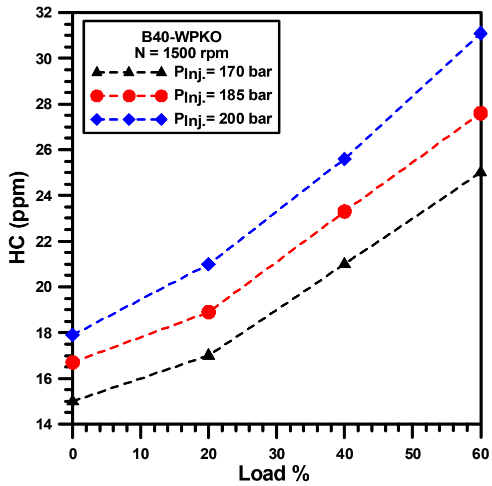


Figure (4-D) Effect of injection pressure on HC emission for B40-WPKO

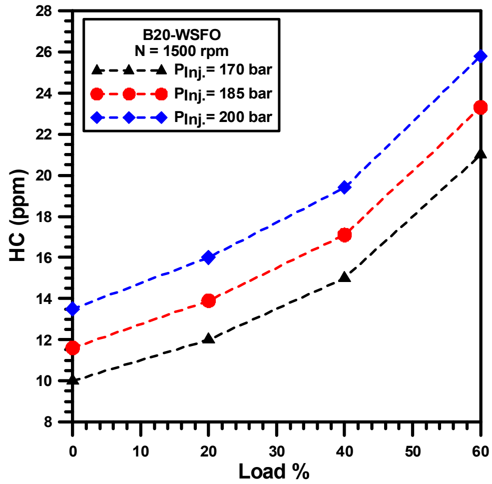


Figure (4-E) Effect of injection pressure on HC emission for B20-WSFO

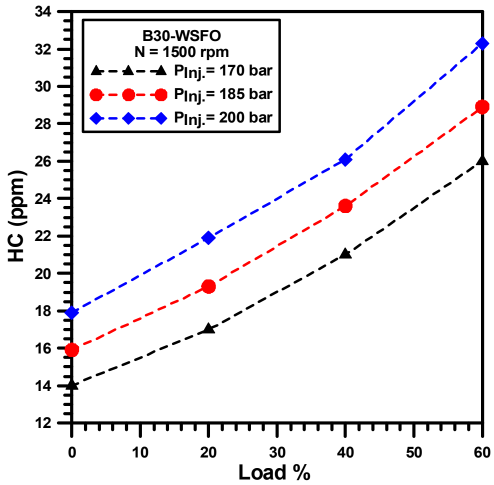


Figure (7-F) Effect of injection pressure on HC emission for B30-WSFO

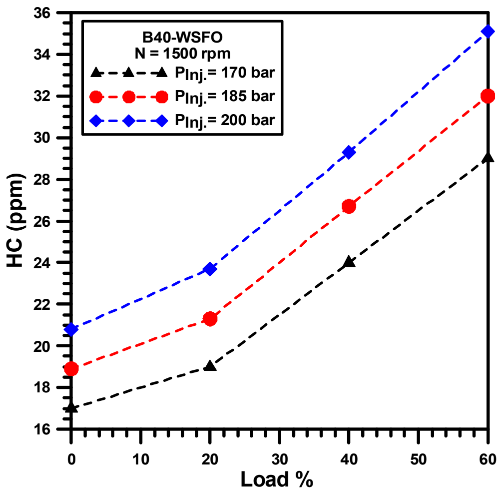


Figure (4-G) Effect of injection pressure on HC emission for B40-WSFO

Figure (4) The injection pressure effect on HC emissions for different fuels

3.4. Nitrogen oxides emissions for different fuels

Figures 5-A, 5-B, 5-C, 5-D, 5-E, 5-F and 5-G show the variation of NO_X for different fuel used versus engine loads and different injection pressure.

The NO_X emissions are minimal when there is no load. The percentage of NO_X emissions increases with increasing injection pressure versus engine load. This increase in NOx emissions for all fuel types due to the improvement of the combustion process resulting from better decomposition by reducing the viscosity of the fuel used.

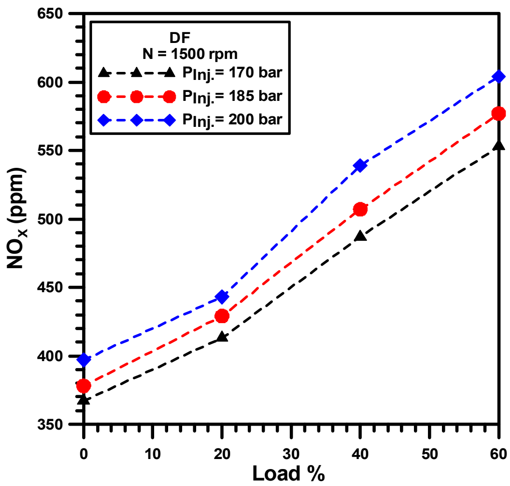


Figure (5-A) Effect of injection pressure on NO_X emission for Diesel Fuel

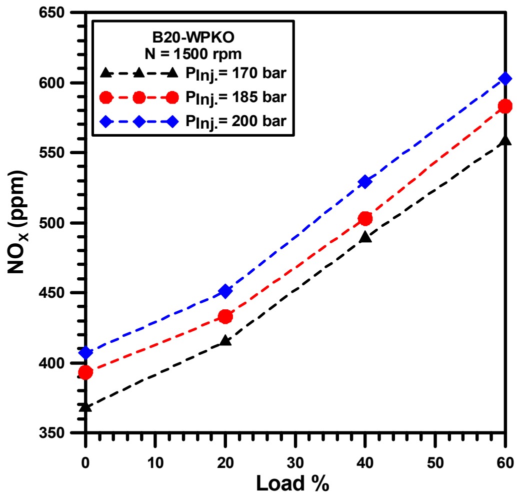


Figure (5-B) Effect of injection pressure on NO_X emission for B20-WPKO

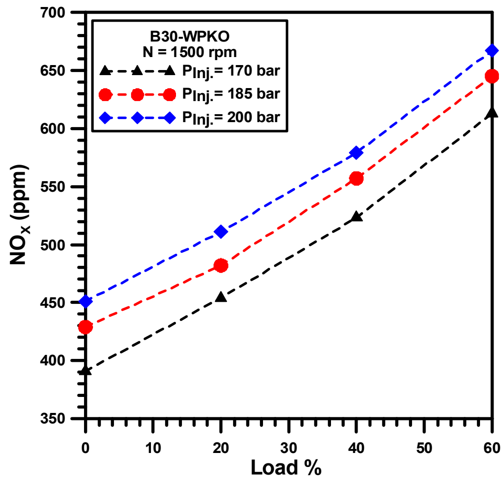


Figure (5-C) Effect of injection pressure on NO_X emission for B30-WPKO

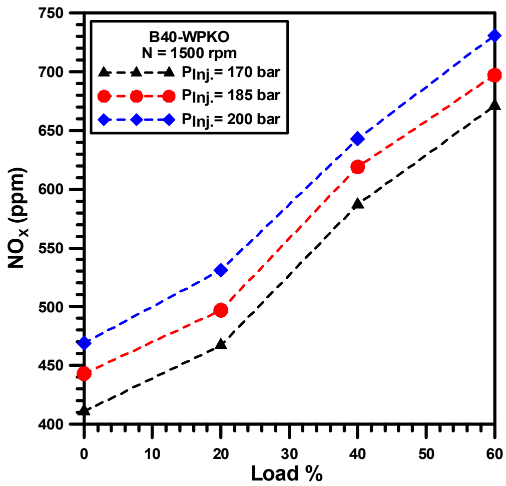


Figure (5-D) Effect of injection pressure on NO_X emission for B40-WPKO

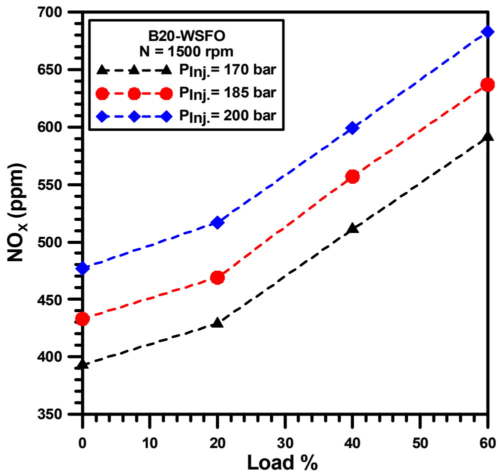


Figure (5-E) Effect of injection pressure on NO_X emission for B20-WSFO

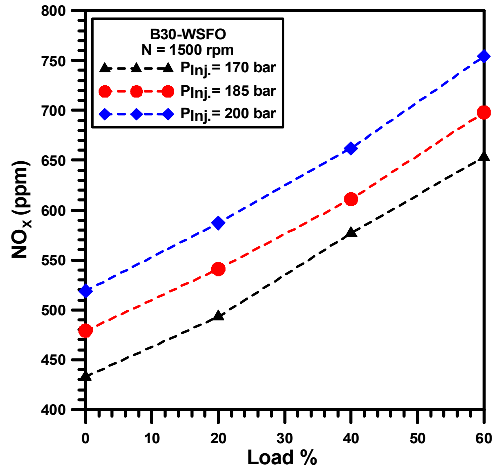


Figure (5-F) Effect of injection pressure on NO_X emission for B30-WSFO

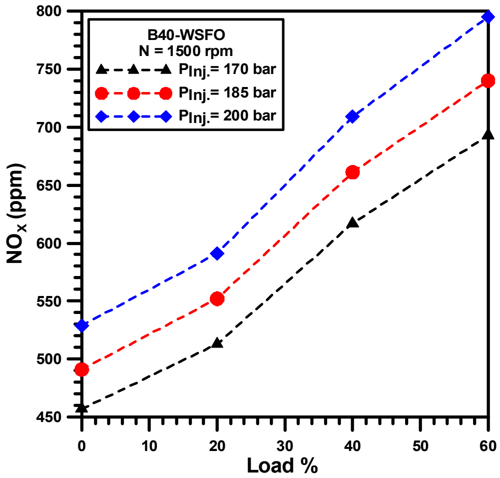


Figure (5-G) Effect of injection pressure on NO_X emission for B40-WSFO

Figure (5) The injection pressure effect on NO_X emissions for different fuels

4. Conclusions

An experimental fulfillment of the exhaust gas emissions of a diesel engine using different fuels at various injection pressures (170, 185 and 200 bars) were investigated. The percentages of increase or decrease in CO, CO_2, NO_X and HC that have been carried out are calculated compared to the results of these emissions at an injection pressure of 170 bars. The following conclusions were obtained:

- The emissions of carbon monoxide decrease with increasing of injection pressure at all different loads. The percentages of decrease in CO emissions a range of percentages from 5% to 35% at 185 and 200 bars compared to that CO emission at 170 bars are shown the figures in Annex (A) for each fuel used.
- The emissions of carbon dioxide decrease with increasing of injection pressure at all different loads. The percentages of decrease in CO_2 emissions a range of percentages from 2% to 12% at 185 and 200 bars compared to that CO_2 emission at 170 bars are shown the figures in Annex (B) for each fuel used.
- The emissions of Nitrogen Oxides increase with increasing of injection pressure at all different loads. The percentages of increase in NO_X emissions a range of percentages from 1% to 22% at 185 and 200 bars compared to that NO_X emission at 170 bars are shown the figures in Annex (C) for each fuel used.
- The emissions of Unburned Hydrocarbons increase with increasing of injection pressure at all different loads. The percentages of increase in HC emissions a range of percentages from 8% to 50% at 185 and 200 bars compared to that HC emission at 170 bars are shown the figures in Annex (D) for each fuel used.

References

Kelvin O. Yoro and Michael O. Daramola, "CO2 emission sources, greenhouse gases, and the global warming effect", Advances in Carbon Capture, 2020.

https://www.epa.gov/ghgemissions/overview-greenhouse-gases.

S.V.Channapattana, Abhay A.Pawar and, Prashant G.Kamble, " Effect of Injection Pressure on the Performance and Emission Characteristics of VCR engine using Honne Biodiesel as a Fuel", Materials today proceedings, Volume 2, Issues 4–5, 2015, Pages 1316-1325. https://doi.org/10.1016/j.matpr.2015.07.049

Nurun Nabi Phd, Mhia Md. Zaglul Shahadat, Md. Shamimur Rahman and Mohd. Rafiqul Alam Beg, "Behavior of Diesel Combustion and Exhaust Emission with Neat Diesel Fuel and Diesel-Biodiesel Blends", SAE, 2004-01-3034. DOI:10.4271/2004-01-3034

İsmet Çelıkten "An experimental investigation of the effect of the injection pressure on engine performance and exhaust emission in indirect injection diesel engines", Applied Thermal Engineering, Volume 23, Issue 16, November 2003, Pages 2051-2060. https://doi.org/10.1016/S1359-4311(03)00171-6

Yakup İçıngür and Duran Altiparmak, "Effect of fuel cetane number and injection pressure on a DI Diesel engine performance and emissions", Energy Conversion and Management, Volume 44, Issue 3, February 2003, Pages 389-397. https://doi.org/10.1016/S0196-8904(02)00063-8

Ghassan M. Tashtoush, Mohamad .Al-Widyan and Aiman M.Albatayneh, "Factorial analysis of diesel engine performance using different types of biofuels", Journal of Environmental Management, Volume 84, Issue 4, September 2007, Pages 401-411. https://doi.org/10.1016/j.jenvman.2006.06.017

Dr. R. Velappan, R. Panchamoorthy, Dr. M.L. Sundararajan, "Influences Of Fuel Injection Pressure On CI Engine Performance And Emission Of Lemon Grass Methyl Ester As Fuel", INTERNATIONAL JOURNAL OF SCIENTIFIC & TECHNOLOGY RESEARCH VOLUME 9, ISSUE 03, March 2020.

Andi F. Sudarma, Hadi Pranoto, Amiruddin Aziz and Mardani A. Sera; "Analysis of Fuel Injection Pressure Effect on Diesel Engine Combustion Opacity Value"; International Journal of Advanced Technology in Mechanical, Mechatronics and Materials (IJATEC) , Vol. 01, No. 1 (2020) 1-5. DOI:10.37869/ijatec.v1i1.6

Syed Sameer Hussain, Syed Abbas Ali and Sunil Thaned, "Influence of Injection Pressure on The Performance of C.I Engine Using Waste Cooking Oil As A Fuel", International Journal of Mechanical And Production Engineering, ISSN: 2320-2092, Volume- 5, Issue-11, Nov.-2017.

Basavaras B. Patil, S. N. Topannavar, K. M. Akkolia, M. M. Shivashimpi and Sunilkumar S. Kattimani; "Experimental investigation to optimize nozzle geometry and compression ratio along with injection pressure on single cylinder DI diesel engine operated with AOME biodiesel"; Energy, Volume 254, Part A, 1 September 2022, 124185. https://doi.org/10.1016/j.energy.2022.124185

J. Senthil kumar, B. R. Ramesh, Bapub S. Ganesan, S. Mahalingam, Hamilton V. De Paul and G. Venkadesh Prasad; "Experimental investigation on 4-Stroke DI diesel engine using methyl esters of Polanga oil and Thyme oil at varying injection pressures"; materials-today-proceedings, Available online 17 May 2021. https://doi.org/10.1016/j.matpr.2021.04.524

K. V. Suresh, Peter Fernandes and K. Rajub; "Effect of injection pressure on performance and emission of diesel engine with blends of Honge-Rice bran bio diesel"; materials-today-proceedings, Volume 35, Part 3, 2021, Pages 489-493. https://doi.org/10.1016/j.matpr.2020.03.071

S. V. Karthic, M. Senthil Kumar, G. Nataraj and P. Pradeep; "An assessment on injection pressure and timing to reduce emissions on diesel engine powered by renewable fuel"; Journal of Cleaner Production, Volume 255, 10 May 2020, 120186. https://doi.org/10.1016/j.jclepro.2020.120186

Athmakuri Ashok, S. K. Gugulothu, Ragireddy Venkat Reddy and Bhasker Burra, "Influence of 1-pentanol as the renewable fuel blended with jatropha oil on the reactivity controlled compression ignition engine characteristics and trade-off study with variable fuel injection pressure"; Sustainable Energy Technologies and Assessments, Volume 52, Part C, August 2022, 102215. https://doi.org/10.1016/j.seta.2022.102215

Murat Kadir Yesilyurt; "The effects of the fuel injection pressure on the performance and emission characteristics of a diesel engine fuelled with waste cooking oil biodiesel-diesel blends"; Renewable Energy, Volume 132, March 2019, Pages 649-666. https://doi.org/10.1016/j.renene.2018.08.024

S. Thiruvenkatachari, C. G. Saravanan, Vallinayagam Raman, M. Vikneswaran, J. S. Femilda Josephin and Edwin Geo Varuvel ; "An experimental study of the effects of fuel injection pressure on the characteristics of a diesel engine fueled by the third generation Azolla biodiesel"; Chemosphere, Volume 308, Part 1, December 2022, 136049. https://doi.org/10.1016/j.chemosphere.2022.136049

Cheolwoong Park, Yongrae Kim, Sechul Oh, Junho Oh, Young Choi, Hongkil Baek, Seung Woo Lee and Kyeonghyeon Lee; "Effect of fuel injection timing and injection pressure on performance in a hydrogen direct injection engine", International Journal of Hydrogen Energy, Volume 47, Issue 50, 12 June 2022, Pages 21552-21564. https://doi.org/10.1016/j.ijhydene.2022.04.274

Qiankun Zhang, Jin Xia, Jianping Wang, Zhuoyao He, Wenbin Zhao, Yong Qian, Liang Zheng, Rui Liu and Xingcai Lu; "Experimental study on ignition and combustion characteristics of biodiesel-butanol blends at different injection pressures"; Renewable and Sustainable Energy Reviews, Volume 160, May 2022, 112289. https://doi.org/10.1016/j.rser.2022.112289

Medhat Elkelawy, Hagar Alm-Eldin Bastawissi, Khaled Khodary Esmaeil, Ahmed Mohamed Radwan, Hitesh Panchal, Kishor Kumar Sadasivuni, Deepalekshmi Ponnamma and Rashmi Walvekar, "Experimental studies on the biodiesel production parameters optimization of sunflower and soybean oil mixture and DI engine combustion, performance, and emission analysis fueled with diesel/biodiesel blends", Fuel, Volume 255, 1 November 2019, 115791. https://doi.org/10.1016/j.fuel.2019.115791

Medhat Elkelawy, Hagar Alm-Eldin Bastawissi, Khaled Khodary Esmaeil, Ahmed Mohamed Radwan, Hitesh Panchal, Kishor KumarSadasivuni, Muthusamy Suresh and Mohammad Israr, "Maximization of biodiesel production from sunflower and soybean oils and prediction of diesel engine performance and emission characteristics through response surface methodology", Fuel, Volume 266, 15 April 2020, 117072. https://doi.org/10.1016/j.fuel.2020.117072

S. Chandra Sekhar, K. Karuppasamy, N. Vedaraman, A. E. Kabeel, Ravishankar Sathyamurthy, Medhat Elkelawy, Hagar Alm ElDin Bastawissi, "Biodiesel production process optimization from Pithecellobium dulce seed oil: Performance, combustion, and emission analysis on compression ignition engine fuelled with diesel/biodiesel blends", Energy Conversion and Management, Volume 161, 1 April 2018, Pages 141-154. https://doi.org/10.1016/j.enconman.2018.01.074

Sriharikota Chandra Sekhar, Karuppasamy Karuppasamy, Ravishankar Sathyamurthy, Medhat Elkelawy, Hagar Alm El Din Bastawissi, Paulraj Paramasivan, Karuppiah Sathiyamoorthy and Pandian Edison, "Emission analysis on compression ignition engine fueled with lower concentrations of Pithecellobium dulce biodiesel-diesel blends", Heat Transfer—Asian Research, Volume 48, Issue 1, p. 254-269. https://doi.org/10.1002/htj.21381

Aparna Singh, Shailendra Sinha, Akhilesh Kumar Choudhary, Hitesh Panchal, Medhat Elkelawy, Kishor Kumar Sadasivuni, "Optimization of performance and emission characteristics of CI engine fueled with Jatropha biodiesel produced using a heterogeneous catalyst (CaO)", Fuel, Volume 280, 15 November 2020, 118611. https://doi.org/10.1016/j.fuel.2020.118611

Medhat Elkelawy, Hagar Alm-Eldin Bastawissi, E. A. El Shenawy, Mohammed Taha, Hitesh Panchal and Kishor Kumar Sadasivuni, "Study of performance, combustion, and emissions parameters of DI-diesel engine fueled with algae biodiesel/diesel/n-pentane blends", Energy Conversion and Management: X, Volume 10, June 2021, 100058. https://doi.org/10.1016/j.ecmx.2020.100058

Medhat Elkelawy, Abd Elnaby Kabeel, E. A. El Shenawy, Hitesh Panchal, Ahmed Elbanna, Hagar Alm-Eldin Bastawissi and Kishor KumarSadasivuni, "Experimental investigation on the influences of acetone organic compound additives into the diesel/biodiesel mixture in CI engine", Sustainable Energy Technologies and Assessments, Volume 37, February 2020, 100614. https://doi.org/10.1016/j.seta.2019.100614

Medhat Elkelawy, Safaa El-din H. Etaiw, Mohamed I. Ayad, Hassan Marie, Mohamed Dawood, Hitesh Panchal and Hagar Alm-Eldin Bastawissi, "An enhancement in the diesel engine performance, combustion, and emission attributes fueled by diesel-biodiesel and 3D silver thiocyanate nanoparticles additive fuel blends", Journal of the Taiwan Institute of Chemical Engineers, Volume 124, July 2021, Pages 369-380. https://doi.org/10.1016/j.jtice.2021.02.019

Medhat Elkelawy, Safaa El-din H. Etaiw, Hagar Alm-Eldin Bastawissi, Mohamed I. Ayad, Ahmed Mohamed Radwan andMohamed M. Dawood, "Diesel/ biodiesel /silver thiocyanate nanoparticles/hydrogen peroxide blends as new fuel for enhancement of performance, combustion, and Emission characteristics of a diesel engine", Energy, volume 216, 1 February 2021, 119284. https://doi.org/10.1016/j.energy.2020.119284

Medhat Elkelawy, Safaa El-din H. Etaiw, Hagar Alm-Eldin Bastawissi, Hassan Marie, Ahmed Mohamed Radwan, Mohamed M. Dawood and Hitesh Panchal, "WCO biodiesel production by heterogeneous catalyst and using cadmium (II)-based supramolecular coordination polymer additives to improve diesel/biodiesel fueled engine performance and emissions", Journal of Thermal Analysis and Calorimetry volume 147, pages6375–6391 (2022). https://link.springer.com/article/10.1007/s10973-021-10920-1

Medhat Elkelawy, E. A. El Shenawy Salma khalaf Abd Almonem, M. H. Nasef, Hitesh Panchal, Hagar Alm-Eldin Bastawissi, Kishor Kumar Sadasivuni, Akhilesh Kumar Choudhary, Deepak Sharma and Mohammad Khalid, "Experimental study on combustion, performance, and emission behaviours of diesel /WCO biodiesel/Cyclohexane blends in DI-CI engine", Process Safety and Environmental Protection, Volume 149, May 2021, Pages 684-697. https://doi.org/10.1016/j.psep.2021.03.028

John B. Heywood, "Internal combustion engine fundamentals", McGraw-Hill, 1989.

Recep Altın, Selim Çetinkaya Hüseyin and Serdar Yücesu, "The potential of using vegetable oil fuels as fuel for diesel engines", Energy Conversion and Management, Volume 42, Issue 5, March 2001, Pages 529-538. https://doi.org/10.1016/S0196-8904(00)00080-7

Nomenclatures and Symbols

CO	Carbon Monoxide	
CO_2	Carbon Dioxide	
DF	Diesel Fuel	
HC	Unburned Hydrocarbons	
NO_X	Nitrogen oxides	
P_{inj}	Injection Pressure	bar
ppm	Parts per million	
rpm	Revelation per minute	
WPKO	Waste Palm Kernel Oil	
WSFO	Waste Sunflower Oil	
WVO	Waste Vegetable Oils	

Annex (A)

$$\%\text{age. decrease in CO}_j = \frac{CO_{i,j} - CO_{170bar\,,j}}{CO_{170bar\,,j}}$$

At the same load

Where,

$i = 185 \text{ or } 200 \text{ bar}$

$j = DF, B20-WPKO, B30-WPKO, B40-WPKO,$

$B20-WSFO, B30-WSFO \text{ and } B40-WSFO$

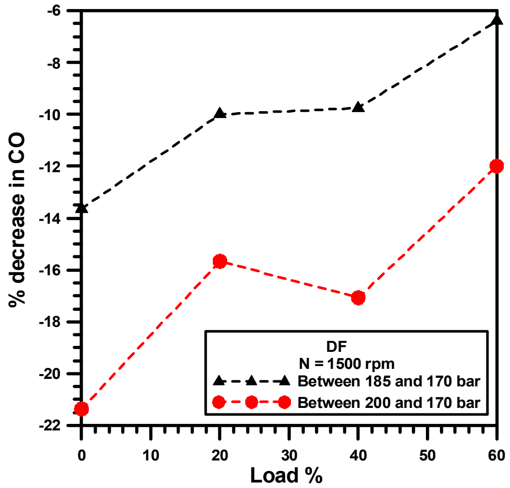


Figure (A.1) %age. decrease in CO for DF

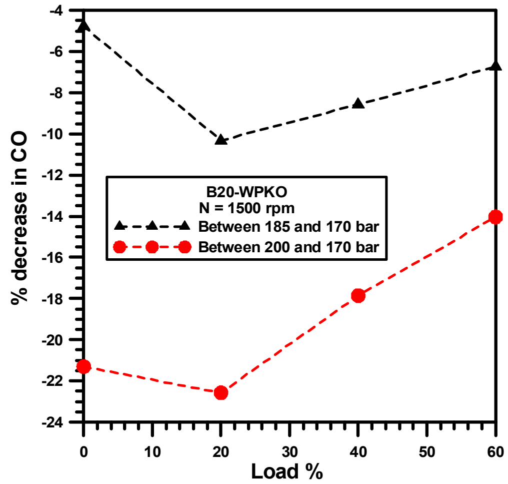


Figure (A.2) %age. decrease in CO for B20-WPKO

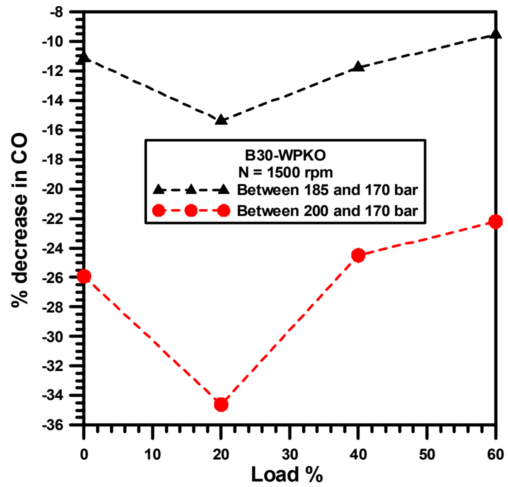
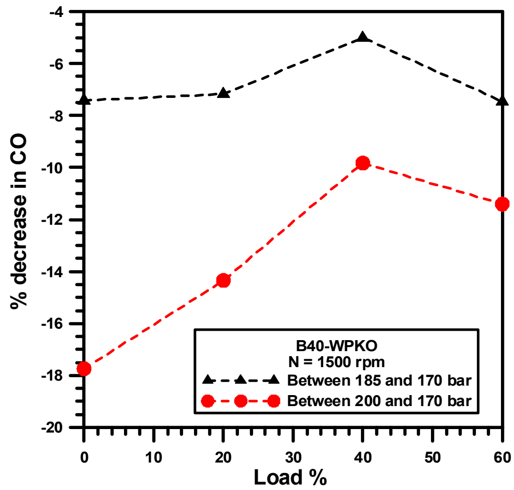


Figure (A.3) %age. decrease in CO for B30-WPKO



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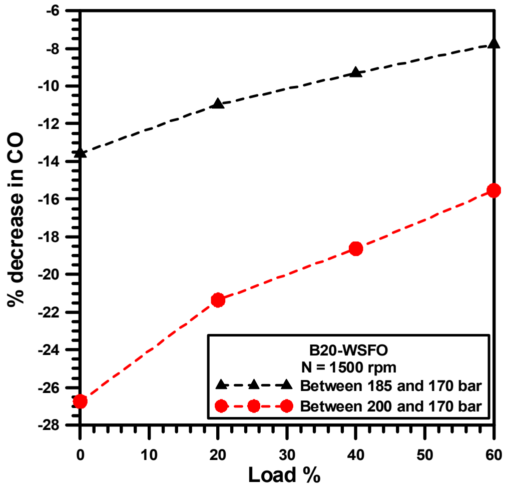

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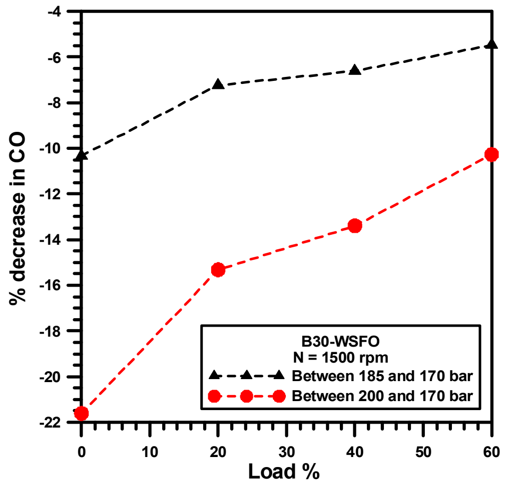


Figure (A.6) %age. decrease in CO for B30-WSFO

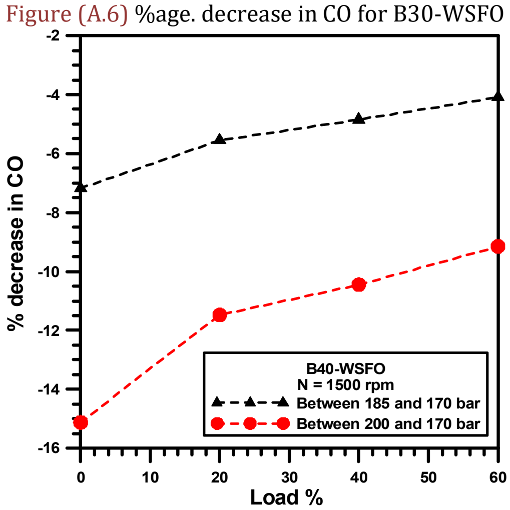


Figure (A.7) %age. decrease in CO for B40-WSFO

Figure (A) %age. decrease in CO for different fuels

Annex (B)

$$\%\text{age. decrease in } CO2_j = \frac{CO2_{i,j} - CO2_{170bar,j}}{CO2_{170bar,j}}$$

At the same load

Where,

$i = 185 \text{ or } 200 \text{ bar}$

$j = DF, B20 - WPKO, B30 - WPKO, B40 - WPKO,$

$B20 - WSFO, B30 - WSFO \text{ and } B40 - WSFO$

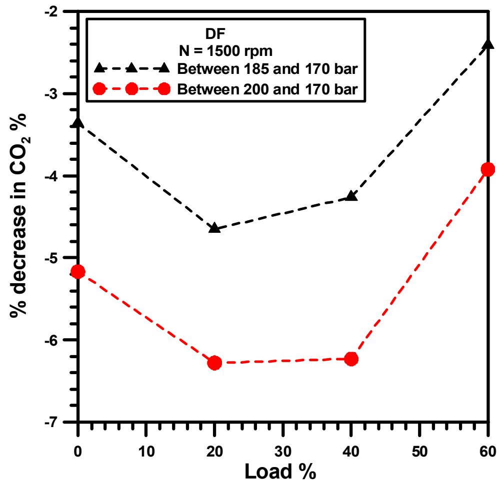


Figure (B.1) %age. decrease in CO_2 for DF

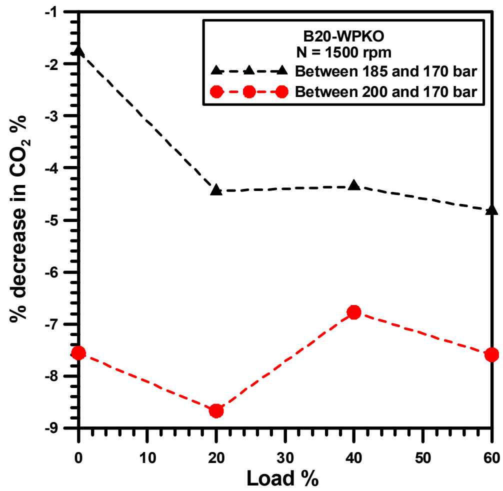


Figure (B.2) %age. decrease in CO_2 for B20-WPKO

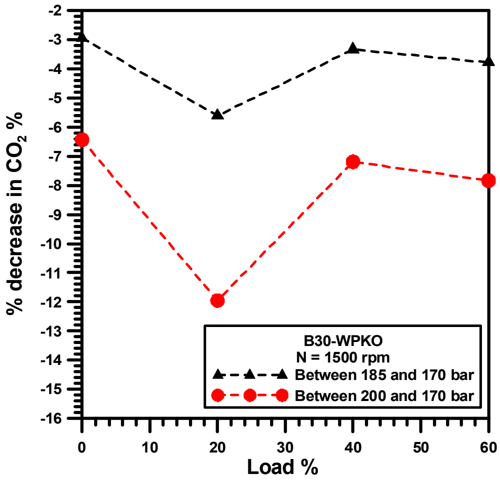
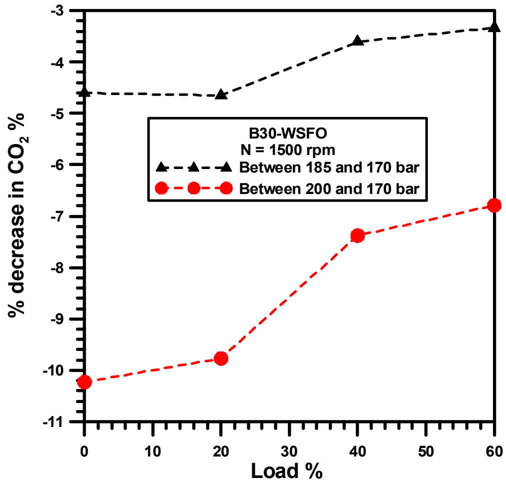


Figure (B.3) %age. decrease in CO_2 for B30-WPKO



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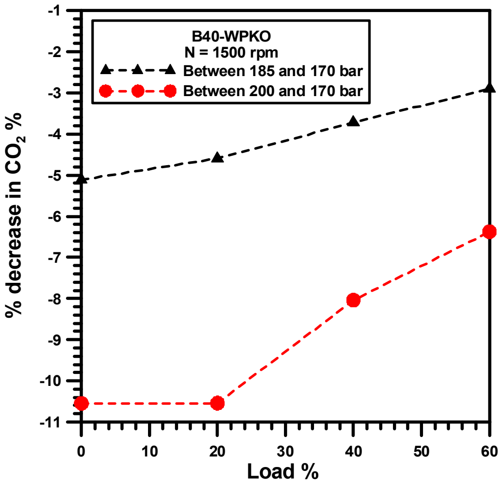

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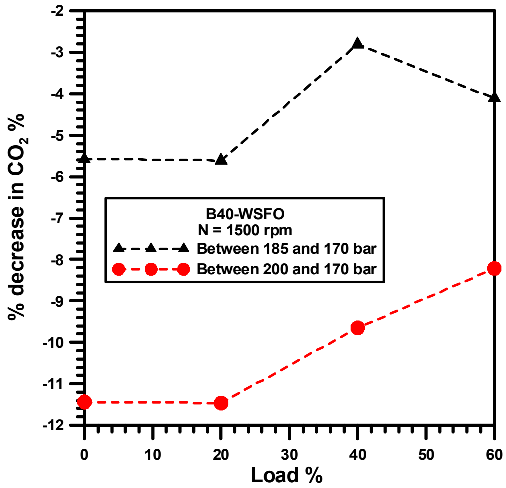


Figure (B.7) %age. decrease in CO2 for B40-WSFO

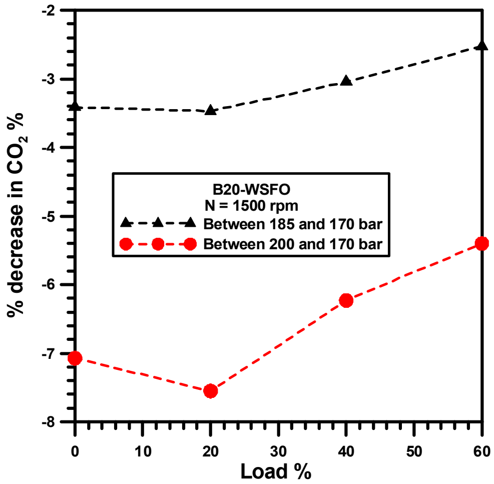


Figure (B.5) %age. decrease in CO_2 for B20-WSFO

Figure (B) %age. decrease in CO2 for different fuels

Annex (C)

$$\%\text{age. increase in } NOx_j = \frac{NOx_{i,j} - NOx_{170bar,j}}{NOx_{170bar,j}}$$

At the same load

Where,

$i = 185 \text{ or } 200 \text{ bar}$

$j = DF, B20 - WPKO, B30 - WPKO, B40 - WPKO,$

$B20 - WSFO, B30 - WSFO \text{ and } B40 - WSFO$

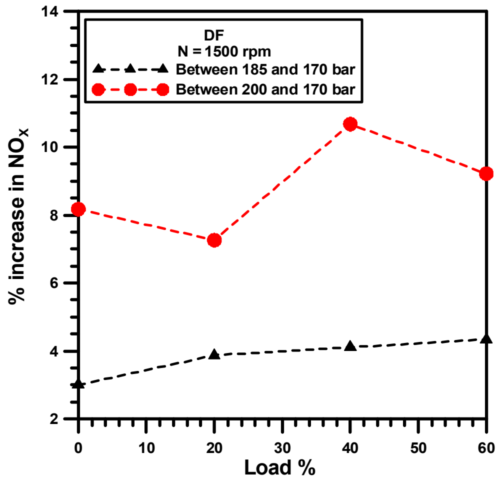


Figure (C.1) %age. increase in NO_X for DF

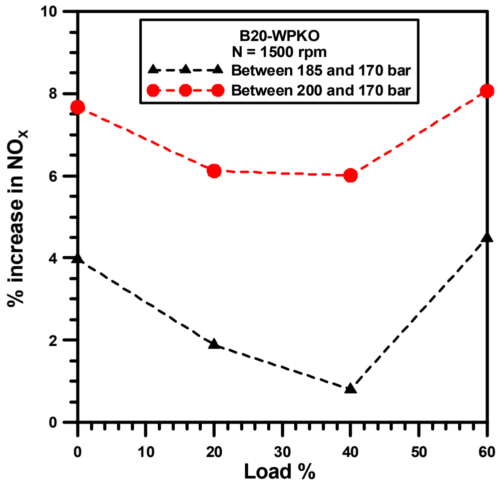


Figure (C.2) %age. increase in NO_X for B20-WPKO

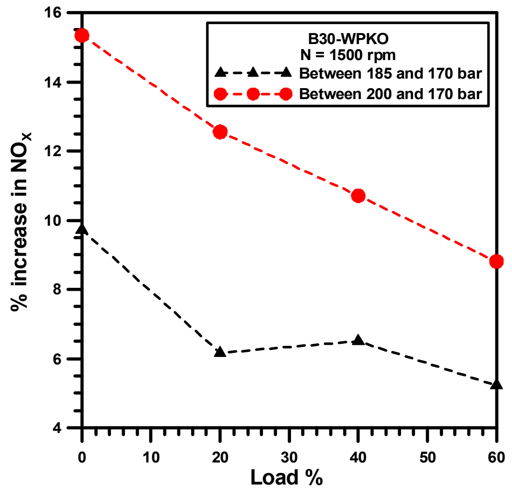
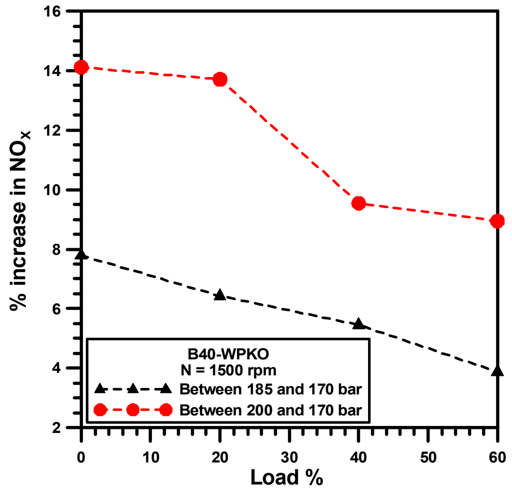


Figure (C.3) %age. increase in NO_X for B30-WPKO



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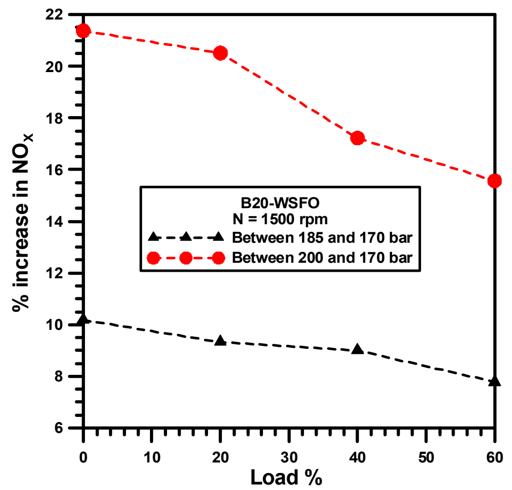

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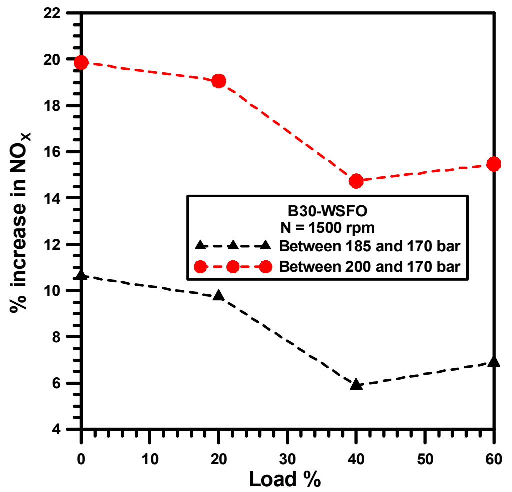

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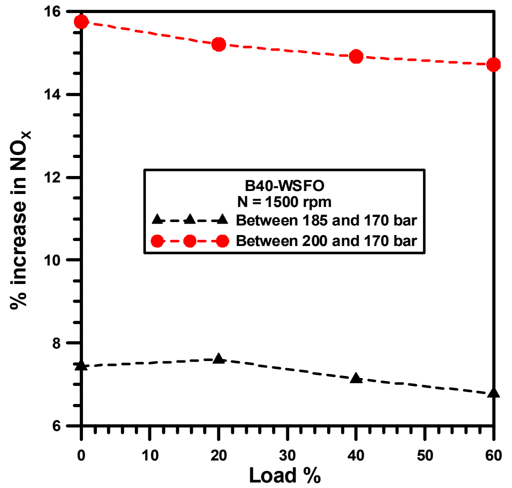


Figure (C.7) %age. increase in NO_X for B40-WSFO

Figure (C) %age. increase in NO_X for different fuels

Annex (D)

$$\%\text{age. incerase in } HC_j = \frac{HC_{i,j} - HC_{170bar,j}}{HC_{170bar,j}}$$

At the same load

Where,

$i = 185 \text{ or } 200 \text{ bar}$

$j = DF, B20 - WPKO, B30 - WPKO, B40 - WPKO,$
$B20 - WSFO, B30 - WSFO \text{ and } B40 - WSFO$

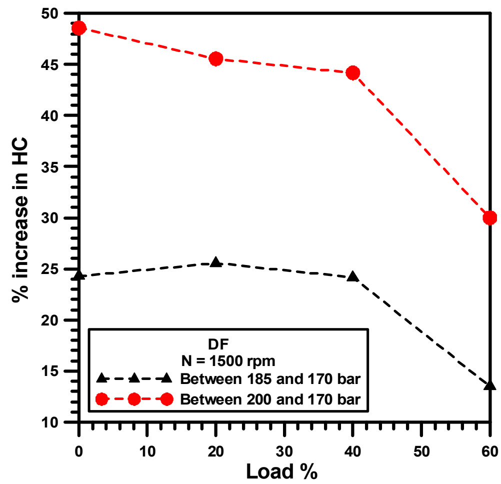


Figure (D.1) %age. increase in HC for DF

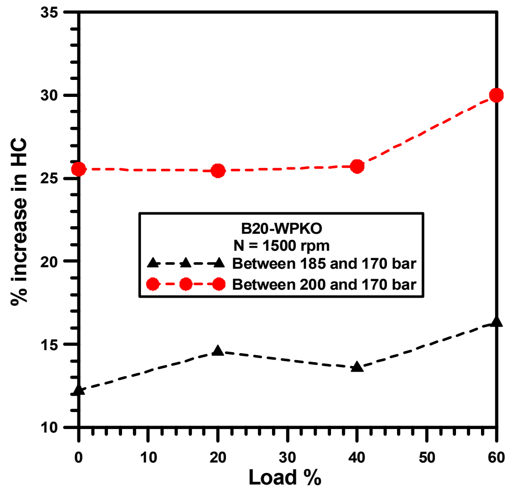
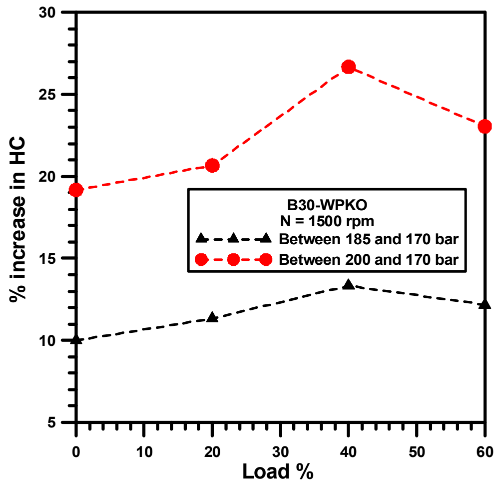


Figure (D.2) %age. increase in HC for B20-WPKO



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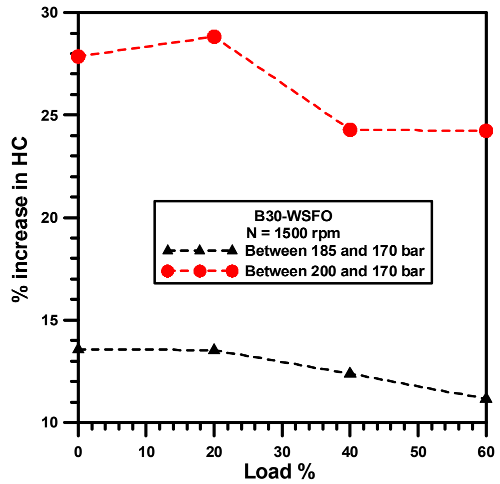

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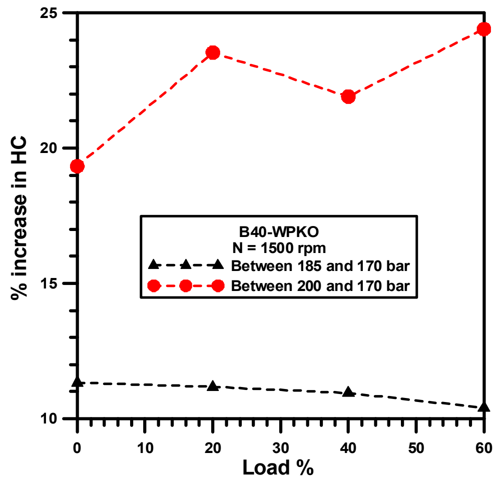

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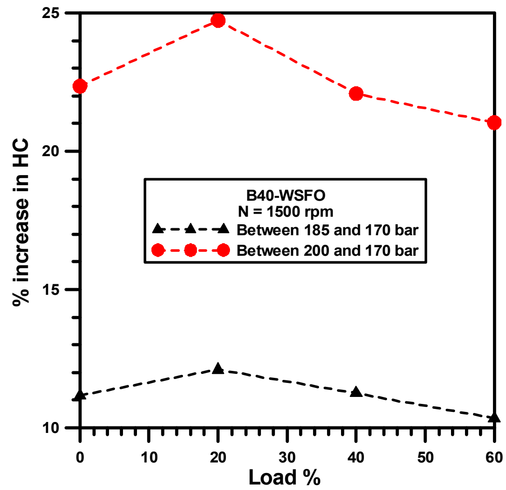

Figure (D.7) %age. increase in HC for B40-WSFO

Figure (D) %age. increase in HC for different fuels

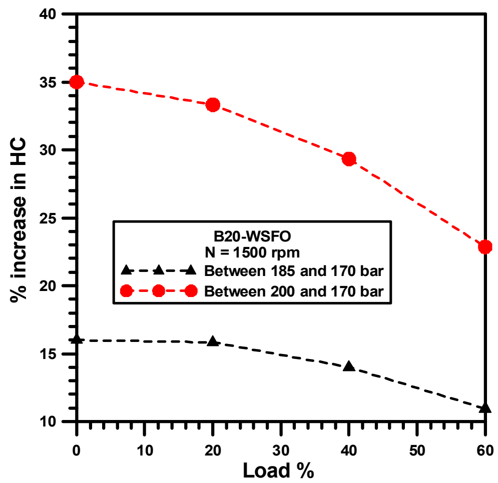

Figure (D.5) %age. increase in HC for B20-WSFO