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PAPER

Investigation on effects of cobalt-chromite nanoparticle blends in compression-ignition engine

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Abstract

This work provides a high-level overview of the performance parameters of a nanoparticle-fuelled engine emulsion. The nanoparticle of cobalt chromite was created by a straightforward laboratory procedure. The nanoparticles were introduced at concentrations of 20 ppm, 40 ppm, 60 ppm, and 80 ppm, with the optimal concentration being found to be a Kapok methylester-20 (KME20) blend. Varying the timings and operated the engine at a constant speed 1800 rpm. Injections can be given at 19, 23, or 27 degrees before the before top dead centre, which are referred to as retardation, standard, and advanced, respectively. The Brake thermal efficiency is increased by 7.2% when the blend of KME20 with 80 ppm advanced is compared to the triggered ignition delay. Unburnt hydrocarbon and carbon monoxide levels in the 80 ppm-Advanced KME20 mix are reduced by 37.86% and 41.66%, respectively, when compared to the standard injection period. Oxides of nitrogen and carbon monoxide in the blend KME20 with 20 ppm - retardation rose by 16.45 and 9.5 percent, respectively, compared to the duration of normal injections. Increased the brake thermal efficiency for KME20 with nanoparticles at concentration of 80 ppm is 7.5% as related to same blend without doping of nanoparticles. Using kapok methyl ester with nanoparticles doped in the standard engine can improve efficiency and performance.

Abbreviations

KME 20	Kapok methyl ester with 80 diesel + 20 Kapok biodiesel
$CoCr_2O_4$	Cobalt chromite Nano particles
CO	Carbon monoxide
UBHC	Unburn Hydrocarbon
BSEC	Brake Specific Energy Consumption
BTE	Brake Thermal Efficiency
UHC	Unburn Hydrocarbon
NOx	Oxides of nitrogen
D100	Diesel
ADV	Advanced
RET	Retardation
PPM	Parts per million

1. Introduction

Energy requirements are rising dramatically due to the rapid increase in the global population. Fossil fuels, such as coal, gasoline, etc, are the primary source of today's global energy needs. Non renewable energy sources are the sole or primary source of electricity for homes and businesses in many developing countries. The majority of today's energy demands are met by non-renewable sources [1]. Biofuel may provide to reduce the energy demand in future, so nowadays researchers are focus on biofuel with adding the nanoparticles [2]. Biofuels can be made from a variety of materials, including wood scraps, agricultural waste, and even food scraps. Due to the fact that biofuels are produced from natural materials, they can potentially be renewed in a shorter amount of time than the millions of years required by fossil fuels. Most people think of biofuels as a viable alternative energy source since they are inexpensive, effective, and practical. Biofuels are made from a wide variety of plant sources, both edible and non-edible, including Kapok, Karanja, Microalgae, soybean, and Jatropha [3]. The main aim of this study is to find better injection timing, improve the performance, and reduce the emissions of the engine using nanoparticle doping with biodiesel blend. The high viscosity of biodiesel makes it difficult to vaporize all of the fuel. It may also be attributed to the shorter amount of time that the fuel-air combination spends in the cylinder. Adjusting the timing of the fuel injection could remedy the problem. Potentially, this is lengthening the amount of time the fuel spends in the cylinder before it evaporates. Injecting the fuel at a later period helps reduce the increase in nitrogen oxides that occurs when using biodiesel in diesel engines. Adjusting the injection time could enhance the A/F mixer rate and the combustion parameter.

2. Literature review

In many ways, these alternative fuels stand in stark contrast to diesel in both physical and chemical composition [1–3]. Researchers from all across the world have come up with novel strategies for making compression ignition engines more efficient and less polluting. A feasible alternative fuel, biodiesel can improve the efficiency of a compression ignition engine and reduce harmful emissions since it contains more oxygen than conventional diesel. However, some research has suggested that biodiesel's lower heating value and increased viscosity make it more effective at decreasing engine exhaust emissions than at boosting performance [4–6]. Dispersing nanoparticles into fuel has been suggested by numerous researchers, who have found that it enhances combustion and reduces exhaust emissions [7, 8]. Biodiesel's primary benefit is that it cuts down on emissions of harmful gases, including carbon monoxide and hydrocarbon (HC). Tests for emissions and performance have been promising, but the technology is not yet reliable enough for widespread use in industry. Certain uses are limited because of the potential for an increase in viscosity, gum formation, Nitrogen oxide, and other issues [9]. Due to their ease of production and the qualitative improvement they provide, nanoparticles have been used as additives in biofuels [10, 11]. According to the study's findings, this limitation may be overcome by including certain antioxidant additives to slow the formation of oxides and improve the engines' performance. Interestingly, the power and torque were both increased by 4.91 percent but the fuel economy dropped by 4.5 percent [12]. When Pongamia biodiesel was mixed with copper oxide nanoparticles, researchers [9] measured the results on engine performance. They discovered a 4.01% increase in BTE, a 1% drop in BSFC, and a 12.8% reduction in smoke. Nanoparticle-enhanced diesel-biodiesel blends are the subject of a large body of literature. Previous studies combined biodiesel with nanoparticle additives such as copper oxide, carbon nanotubes, cerium oxide, and zinc oxide. Diesel and biodiesel were tested in a CI engine by Saxena *et al* [13]. Authors used yttria-stabilized zirconia in studies with a diesel engine (both uncoated and coated single cylinders) that had been fed fuel mixed with ferric chloride nanoparticles. Single-cylinder engines with coatings were found to have lower BSFC and higher BTE, and to create less HC, CO, smoke, and ozone than their uncoated counterparts [14]. The effects of dosing butanol-diesel blends with zinc oxide nanoparticles at concentrations over 100 ppm on performance, emissions, and combustion characteristics were studied [15]. According to their findings, the increased use of BTE resulted in lower emissions of nitrogen oxides, unburned hydrocarbons, and carbon monoxide compared to diesel.

3. Research gap

This study provides a concise overview of the performance characteristics of nanoparticle-fueled engine emulsion. A straightforward laboratory procedure produced the cobalt chromite nanoparticle. The nanoparticles were included in the mix at 20 ppm, 40 ppm, 60 ppm, and 80 ppm, with the best results coming from the KME20 ratio. The consistency of the homogenous mixture was maintained with the use of an ultra-sonicate device. In addition, the length of combustion and the time between ignition and combustion are greatly affected by injection timing in a CI engine. Biodiesel has a high viscosity, making it challenging to vaporize all of

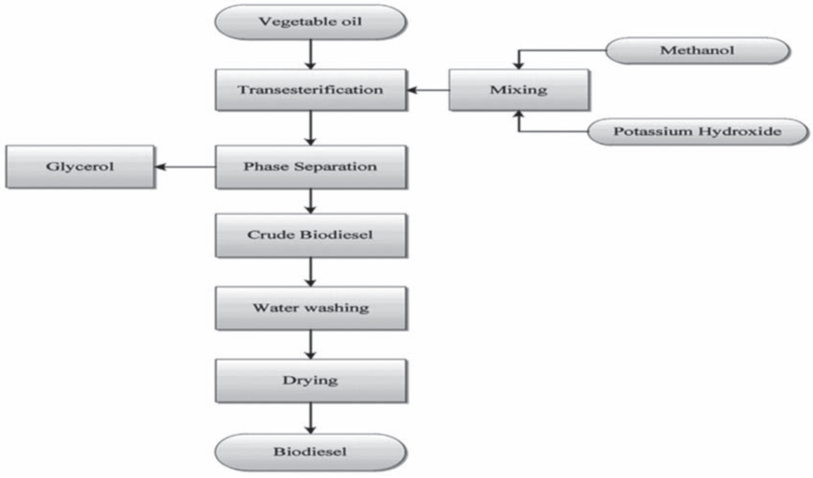

Figure 1. Production of biodiesel.

the fuel. It may also be attributable to a shorter amount of time that the fuel-air combination spends in the cylinder. Changing the timing of the fuel injection might remedy the problem. It's possible that this is lengthening the amount of time gasoline spends in the cylinder, allowing more time for fuel vaporization. Adjusting the injection time might enhance the A/F mixer rate and the combustion parameter. This research also investigates how changing the injection time (IT) affects the CI engine's performance and efficiency under these conditions.

4. Materials and methods

4.1. Novelty of the work

The literature review reveals a comprehensive examination of global research on the production, performance, combustion, and emission characteristics of various biodiesel fuels, as well as the diverse parameters that have been investigated in relation to engine performance. The current research investigation introduces a novel approach through the use of cobalt chromite nanoparticles as catalysts in the transesterification process for synthesizing biodiesel. The feedstock utilized in this process is kapok methyl ester. To find the optimum performance and emissions by varying the injection timings (Advanced- 25°, standard-23°, retarded injection timing19°), with doping of cobalt chromite nanoparticles (concentrations of 20 ppm, 40 ppm, 60 ppm, and 80 ppm).

4.2. Biodiesel production

Kapok oil, commonly known as silk cotton seed oil, was chosen for this study, since it is not suitable for human consumption. Biodiesel was made using a conventional technique called transesterification. This process involves the breakdown of long-chain triglycerides into their constituent constituents. Figure 1 is a block diagram showing the process of making biodiesel from non-edible seed oils [16]. Raw kapok oil was heated to around 60 °C for a brief time in order to remove any remaining moisture. A mixture of 200 ml of methanol and 10 g of potassium hydroxide were dissolved separately and then blended together. It's the name given to the resulting potassium methoxide solution. After adding the warm oil and methoxide solution, the mixture was regularly stirred for around 60 min at 80 degrees Celsius. The Soxhlet condenser was utilized to lower the amount of methanol that leaked into the atmosphere. After waiting the required amount of time, the solution was poured into a separating funnel and left to sit undisturbed for over a day. It was discovered that the kapok oil esters formed the upper layer, while glycerine, impurities, and an excess of alcohol made up the lower layer. Biodiesel quality was improved by transferring the kapok oil esters one more time through a separating funnel and rinsing them three times with water. The solution was subsequently heated to about 60 °C, at which point the water molecules were evaporated [17].

4.3. Nano particles of cobalt chromite

Nanoparticles of cobalt chromite are included by a conventional co-precipitation method. Cobalt nitrate (0.5 M), chromium nitrate (1 M), and smelling salts (25%), were individually dissolved in an appropriate volume of distilled water and then arranged in 25 ml volumetric jars. The cobalt nitrate solution is measured out

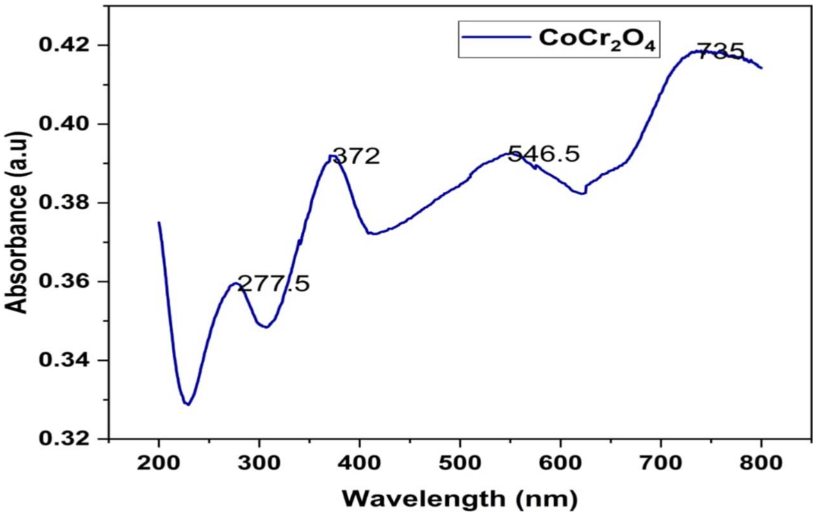

Figure 2. UV spectra of cobalt chromite.

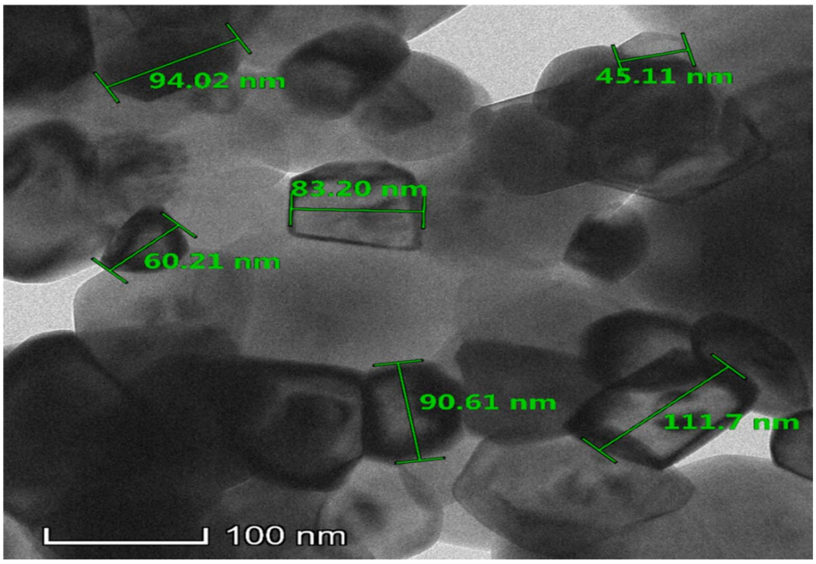

Figure 3. TEM images of cobalt chromite Nano-particles.

into a 100 ml glass, and the chromium nitrate solution is slowly added while stirring. The combined ingredients should be mixed together at room temperature for 2 h. Blended solution is adjusted to a pH of 9 by adding a smelling salt solution (with a concentration of 25%) drop by drop. We shift and wash the hydroxide accelerator numerous times. After relocating the hydroxide accelerate and rinsing it with clean water several times, the pH of the filtrate is predicted to be around 7 [18]. The resulting material is dried in a stove at 120 °C for 16 h, and then calcined at 600 °C for 4 h, yielding a finely milled jasper green powder. After that, we checked the synthetic nanoparticles in the testing lab using UV spectra, TEM images, and energy-dispersive x-ray spectroscopy (EDX). In figure 2, the UV spectra of cobalt chromite are shown, and in figure 3, a TEM image of cobalt chromite is shown. Energy-dispersive x-ray spectroscopy (EDX) is shown in figure 4. From the images, we were able to identify that the cobalt chromite nanoparticles had been made [19]. The nanomaterials primarily exposed through inhalation of suspended nanoscale particulates lead to inflammation of the airways, bronchitis, asthma, emphysema, lung cancer, neurodegenerative diseases, and cardiovascular effects, which can be avoided by ensuring the safety of nanoparticle preparation.

4.4. Test fuel preparation

Jasper green powder is obtained by allowing material to dry in a stove at 120 °C for 16 h, followed by sintering at 600 °C for 4 h, when the nanoparticles are formed and obtained. When it comes to oxygen concentration, cobalt

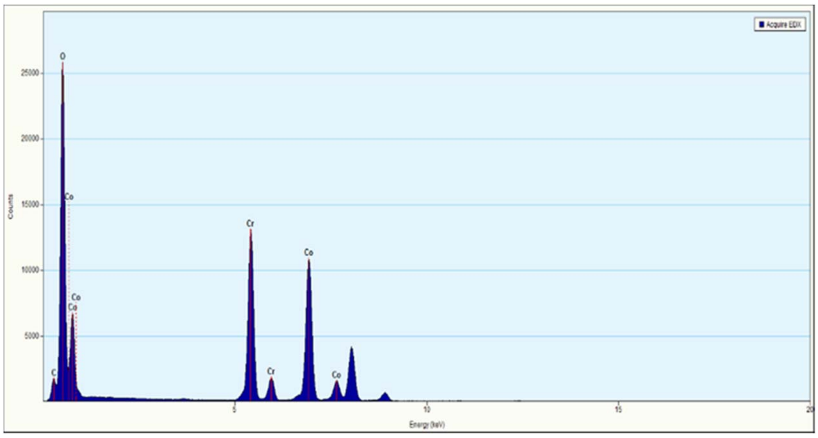

Figure 4. Energy-Dispersive X-ray spectroscopy (EDX).

Table 1. Fuel Properties of the fuel.

Property	Diesel	Raw Oil	B20 + 20 ppm	B20 + 40 ppm	B20 + 60 ppm	B20 + 80 ppm
Specific gravity (40 °C) (kg/m^3)	0.85	0.875	0.858	0.853	0.854	0.846
Density (40 °C) (kg/m^3)	822	931	842	853	872	864
Viscosity(40 °C) mm^2/S	3.1	4.2	3.5	3.4	3.6	3.1
Calorific Value MJ/m^3	44	38	36	35	37	39
Cetane Number	54	48	46	48	49	53
Acid Number	—	0.2	0.3	0.2	0.4	0.1
Fire Point (°C)	74	174	151	159	162	158
FlashPoint (°C)	59	170	142	148	156	162

chromite is the nanoparticle of choice. Blends are made by adding various amounts of kapok biodiesel to the main fuel source [20]. The nanoparticles and the kapok biodiesel are mixed together by mechanical churning. Different concentrations of the KME20 with adding nanoparticles like 20, 40, 60, and 80 ppm are mixed with biodiesel. The different mixtures are produced by adjusting the injection time to 19 degree bTDC, 23 degree bTDC, and 27 degree bTDC, respectively. The data presented here is associated with the normative injection timing. The properties of the fuel are listed in table 1 [16].

4.5. FTIR analysis

In figure 5, that kapok oil is represented by a peak that was obtained using FT-IR spectroscopy. Some very faint peaks at 1700 to 3000 cm1 are present in kapok oil, and they seem to be in agreement with the CH band. In addition to cobalt chromite, biomolecules were also detected by FT-IR at 1236 cm1 in the N-H band. After making the sample visible, the N-H band is seen because of the sharp peak at 3492 cm-1, which is larger compared to the other generated peaks in this region, the aromatic ring and carbonyl stretching modes. To get close to the NH2 amine group, you can utilize a scissor-like in-plane twist at 1746 cm1 [21].

4.6. XRD analysis

Figure 6 shows the results of an XRD test done on kapok oil. It shows that there are plane-related deflection peaks at 2, 46, and 66. Scherrer's technique estimates particle size distributions by measuring the peak of the deflection (1 1 1). Particles have an average size of 5.2 nm. In conclusion, the results show that kapok oil, on a similar nanoscale, is present in the sample and contributes to increased catalytic activity during the reaction [21].

5. Experimental set up

Figure 7 shows the basic engine configuration for the study, which employs a typical, single-cylinder, four-stroke, direct-ignition engine. Table 2 displays the basic engine's specifications. When the inspection equipment is initially prepared for use, it is calibrated to the appropriate values for the exhaust emission parameters. The default setting for the engine speed is 1500 rpm, and the eddy current dynamometer is hooked up to the base engine to measure the output power of the engine. An AVL 444 N gas analyzer is used to measure various

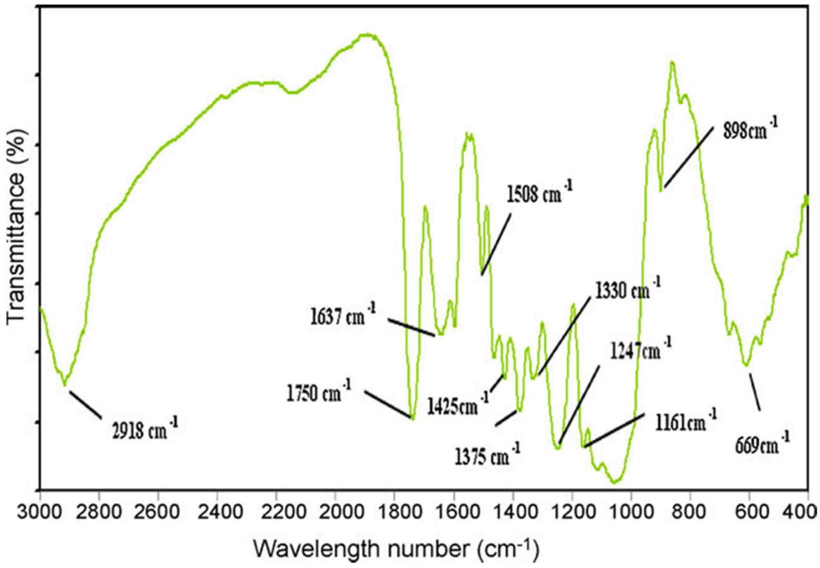

Figure 5. FTIR analysis for kapok oil.

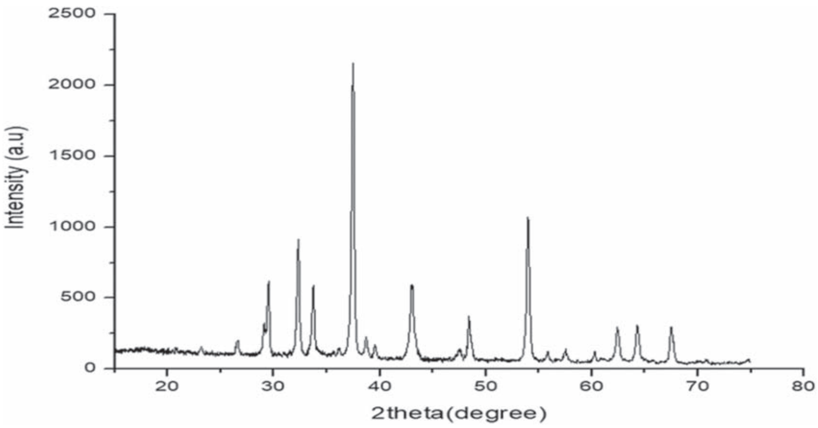

Figure 6. XRD analysis for kapok oil.

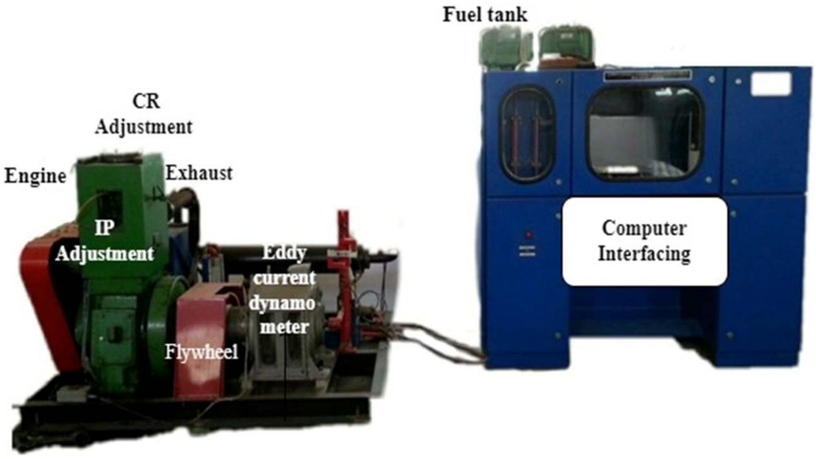

Figure 7. Experimental Set-Up.

Table 2. Specification of engine.

Specification of engine	
Brand and Model	Kirloskar, SV1
Number of cylinders	1
Cooling Types	Water-cooled
Stroke volume	661 c.c.
Engine speed	1800 rpm
No. of strokes	4
Clearance volume	37.8
Rated output	5.9 kW
Diameter of Bore	87.5 mm
Length of Stroke	110 mm
Lubrication system	Forced feed system
Compression Ratio	19:1

emission characteristics like carbon monoxide, carbon dioxide, nitrogen oxides, and hydrocarbons. The smoke meter's output power is determined using an AVL 443 N device. IT is modified from its typical form by impeding and then propelling the body into an alternate posture. The SIT (23 degrees bTDC), the AIT (27 degrees bTDC), and the RIT (at 19 degrees bTDC) are all employed here.

6. Results and discussion

6.1. Combustion characteristics

6.1.1. Cylinder pressure

The trend of the variation of cylinder pressure for KME20 with nanoparticles at various injection timing is shown in figure 8. The addition of nanoparticles with KME20 has a negligible impact on fuel viscosity and density characteristics, but is more active during the combustion process. At the minimum level of $CoCr_2O_4$ with KME20, the Peak Cylinder Pressure (PCP) values were 50.4 bar, 53.2 bar and 55.8 bar for retarded, standard and advanced IT, respectively compared to Diesel of 59 bar at CR 18. It was noticed that the peak CP of Diesel at CR 18 was 15.5%, 11.0% and 6.5% higher as compared to KME20 with retarded, standard and advanced IT. It might be due to superior fuel quality of Diesel-burning completely during combustion and therefore releasing more heat energy. In a similar way, it can be seen that doping of 40 ppm $CoCr_2O_4$ with KME20 at CR 19, the peak PCP values were 50.7 bar, 54.8 bar and 56.8 bar for retarded, standard and advanced IT, respectively, as compared to the same fuel without Nano additive of 54.2 bar. It might be attributed to the S/V ratio of $CoCr_2O_4$ influencing the burning characteristics [21].

Moreover, the peak PCP of KME20 with 60 ppm of $CoCr_2O_4$ at different ITs of retarded, standard and advance was 54.0 bar, 56.9 bar and 59.8 bar, respectively. Furthermore, mixing 80 ppm of $CoCr_2O_4$, the peak CPP values are 54.0 bar, 58.2 bar and 61.4 bar for retarded, standard and advanced IT, respectively. This result showed a reasonable increment in PCP for all load conditions. It was evident that the peak CP gradually raised with an increase in the concentration of $CoCr_2O_4$ in the blend for all injection timings. The mentioned results also showed that the PCP was 3.4%, 4.2%, 9.7% and 12.1% higher for 20 ppm, 40 ppm, 60 ppm and 80 ppm of $CoCr_2O_4$ with KME20 as compared to the same fuel without nanoparticles. The increment in the PCP was ascribed to the fact that more heat was produced with the doping of nanoparticles. The doping of $CoCr_2O_4$ in the blend leads to enhanced energy values owing to the higher combustion enthalpy of $CoCr_2O_4$ [22].

6.1.2. Heat release rate

The variation of HRR for KME20 with different doping rates of $CoCr_2O_4$ and IT are shown in figure 9. It was interesting to show that the HRR rises with an increase in doping of $CoCr_2O_4$ due to a drop in the delay period [23]. As noticed previously, the mixing of nanoparticles enhances the heating value of the blend, which results in improved HRR. The KME20 blend with 20 ppm of $CoCr_2O_4$, the HRR was 47.5 J/°CA, 53.2 J/°CA and 57.5 J/°CA for retarded, standard and advanced IT, respectively, as compared to Diesel of 69 J/°CA at CR 18. It can be seen that the HRR of Diesel at CR 18 was 22.3%, 14.3% and 10.3% higher as compared to KME20 with retarded, standard and advanced IT. It was because of the higher heating range of Diesel with improved evaporation rate at standard injection timing, therefore attaining better HRR. It can be observed that doping of 40 ppm $CoCr_2O_4$ with KME20 at CR 19, the HRR values were 53.2 J/°CA, 57.5 J/°CA and 62.5 J/°CA for retarded, standard and advanced IT, respectively, as compared to blend KME20 of 62.52 J/°CA at CR 18. This trend was accomplished by enhancing the combustion of the blend with optimized injection timing. In addition, the HRR of KME20

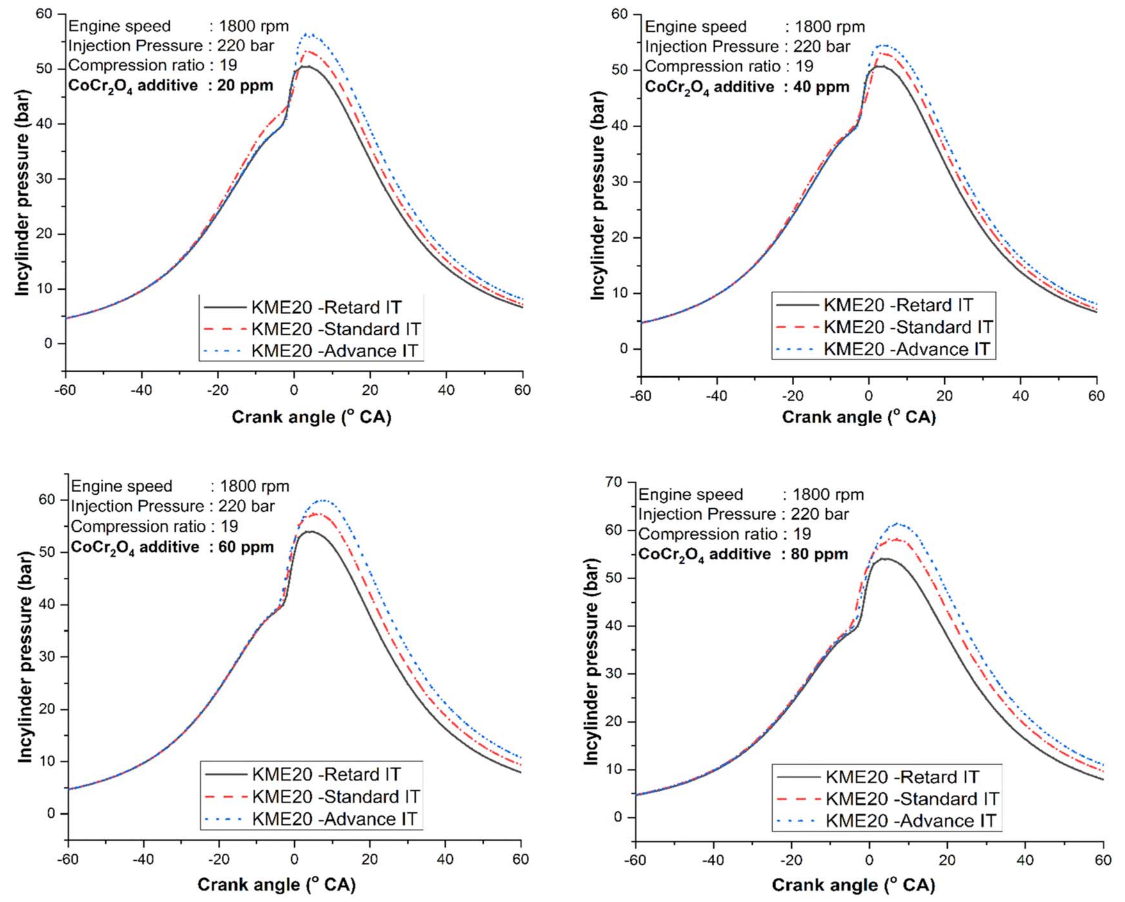

Figure 8. Variation of cylinder pressure with crank angle for different concentration of Cobalt Chromite.

with 60 ppm of $CoCr_2O_4$ at different IT of retarded, standard and advance were 62.8 J/°CA, 66.9 J/°CA and 69.6 J/°CA, respectively. 80 ppm of $CoCr_2O_4$ with KME20, the HRR values were 67.9 J/°CA, 71.3 J/°CA and 77.5 J/°CA for retarded, standard and advanced IT, respectively, compared to Diesel of 69 J/°CA. The HRR value was also steadily increased with the rise in the concentration of $CoCr_2O_4$ in the blend. From this result it can also be observed that the HRR values were 11.3%, 18.5%, 26.6% and 33.3% higher for 20 ppm, 40 ppm, 60 ppm and 80 ppm of $CoCr_2O_4$ with KME20 as compared to KME100. The higher magnitude of HRR is achieved by elevated heating value and evaporation rate of blends, which leads to shortening the delay period and more fuel burnt at the primary stage of combustion. The high post-combustion temperature and enhanced combustion rate due to excess oxygen buffer by nanoparticles are the significant reasons for higher HRR [24].

6.2. Performance characteristics

6.2.1. Brake thermal efficiency

Thermal efficiency is the ratio of engine power to the energy consumed by the engine. The energy consumed is the amount of fuel entering into cylinder and calorific value of the fuel. It can be seen from figure 10 that the concentration of nanoparticles increases with gradually improving the BTE for all test fuels, the low range of calorific value and abundant O_2 presence of kapok methyl ester showed lower BTE trends as compared to Diesel. BTE of biodiesel blend could be improved by increasing the compression ratio. In this chapter, the investigation was extended to adopt the nanoparticle with optimum blend at various concentrations such as 20 ppm, 40 ppm, 60 ppm and 80 ppm. The results also showed the combined effect of nanoparticle and Injection Timing (IT) strategies on CI engines fueled with biodiesel blend [25]. For KME20 at 20 ppm of $CoCr_2O_4$, the BTE are 27.52%, 28.46% and 29.15% for retarded, standard and advanced IT, respectively, as compared to neat Diesel of 29.6%. Doping 40 ppm of $CoCr_2O_4$ with KME20, the BTE are 28.18%, 28.96% and 29.34% for retarded, standard and advanced IT, respectively, as compared to neat KME of 25.68%. It was evident that BTE of KME100 was observed to be lowest at standard CR and IT. Similarly, at 60 ppm of $CoCr_2O_4$ with KME20 at CR 19, the thermal efficiencies are 28.36%, 29.13% and 29.71% for retarded, standard and advanced IT, respectively. In addition, at a maximum concentration of $CoCr_2O_4$ with blend at CR 19, the BTE are 28.45%, 29.1% and 30.21% for retarded, standard and advanced IT, respectively, as compared to neat Diesel of 29.6% at

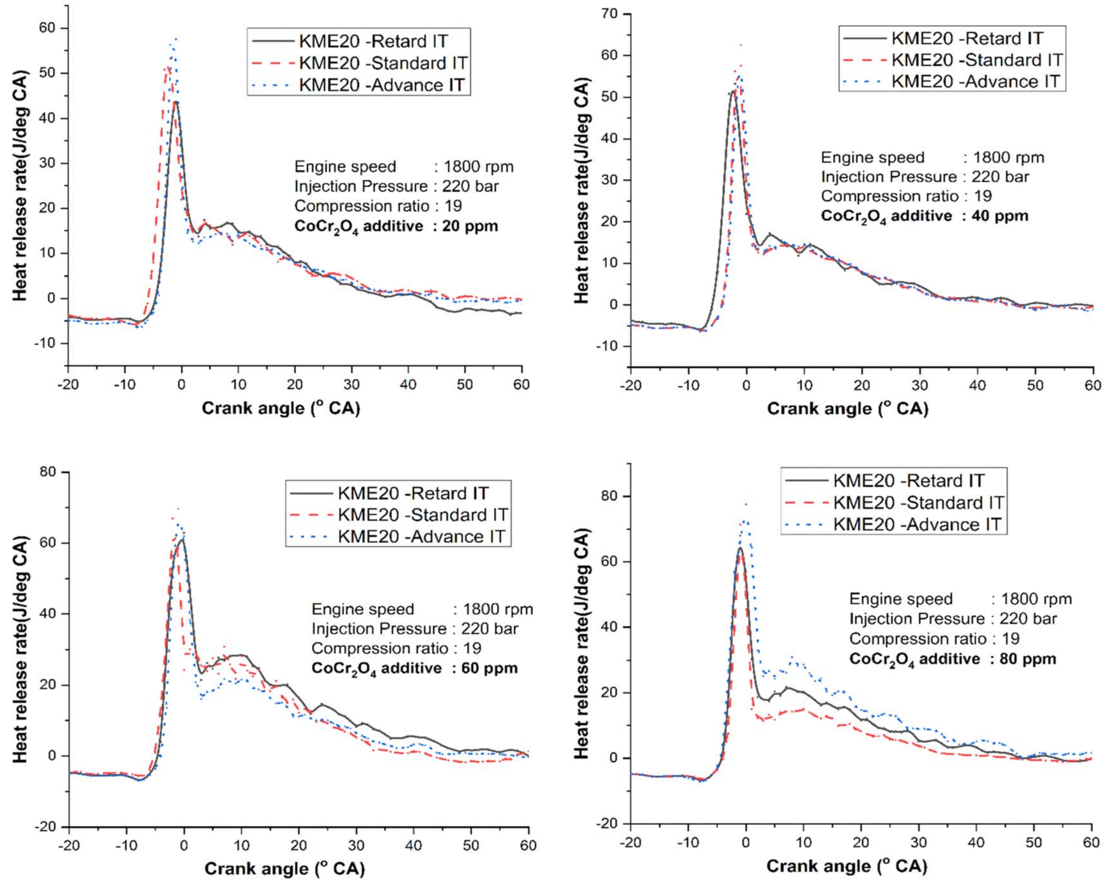

Figure 9. Variation of Heat Release Rate with crank angle for different concentration of Cobalt Chromite.

CR 18. These results indicated reasonable improvement in thermal efficiency when doping nanoparticles. The results also noticed that retarded IT found lower thermal efficiency than standard and advanced IT. This was because of inconsistent ignition timing and fuel burn rate, which results in inferior combustion. The superior performance in BTE was noted in advanced IT owing to sufficient time availability for the fuel oxidation process and homogenous mixture formation [26].

6.2.2. Brake specific energy consumption

It can be noted from figure 11 that the BSEC drops with the rise of the doping concentration of $CoCr_2O_4$ for all injection timings. At 20 ppm of $CoCr_2O_4$ with KME20, the BSEC are 13.08 MJ kWh^{-1}, 12.64 MJ kWh^{-1} and 12.34 MJ kWh^{-1} for retarded, standard and advanced IT, respectively, as compared to Diesel of 12.12 MJ kWh^{-1} at CR 18. It was noticed that the BSEC of Diesel at CR 18 was 7.3%, 4.2% and 1.8% lower, as compared to KME20 with retarded, standard and advanced IT. The results showed that the addition of 40 ppm $CoCr_2O_4$ with KME20, the BSEC are 12.77 MJ kWh^{-1}, 12.43 MJ kWh^{-1} and 12.26 MJ kWh^{-1} for retarded, standard and advanced IT, respectively, as compared to blend KME20 of 13.18 MJ kWh^{-1} These results could be attributed to the combined effect of nanoparticles and high CR, thereby promoting the combustion process that results in lower energy consumption. Also, for 60 ppm of $CoCr_2O_4$ with KME20, the BSEC are 12.69 MJ kWh^{-1}, 12.35 MJ kWh^{-1} and 12.11 MJ kWh^{-1} for retarded, standard and advanced IT, respectively, as compared to neat KME of 14.01 MJ kWh^{-1}. The BSEC of KME100 at CR 18 was 9.3%, 11.7% and 13.5% higher for blend KME20 at various ITs of retarded, standard and advanced IT, respectively. The addition of nanoparticle acts as a catalyst to enhance combustion efficiency and therefore promote complete combustion. Doping 80 ppm of $CoCr_2O_4$ with KME20, the BSEC are 12.6 MJ kWh^{-1}, 12.3 MJ kWh^{-1} and 11.9 MJ kWh^{-1} for retarded, standard and advanced IT, respectively, as compared to Diesel of 12.12 MJ kWh^{-1} An increase in BSEC has been noted for retarded IT at all nanoparticle concentrations due to the reason of shortening of fuel preparation and improper atomization, therefore, dropping the combustion efficiency [27]. In contrast, the energy consumption of advanced IT was noticeably decreased compared to standard IT. This is because of a proper homogeneous mixture, which results in combustion near TDC and, therefore, leads to higher power output. The result of BSEC showed 3.2%, 2.5%, 1.6% and 0.3% lower for KME20 with 20 ppm, 40 ppm, 60 ppm and 80 ppm of $CoCr_2O_4$ at advanced IT, as

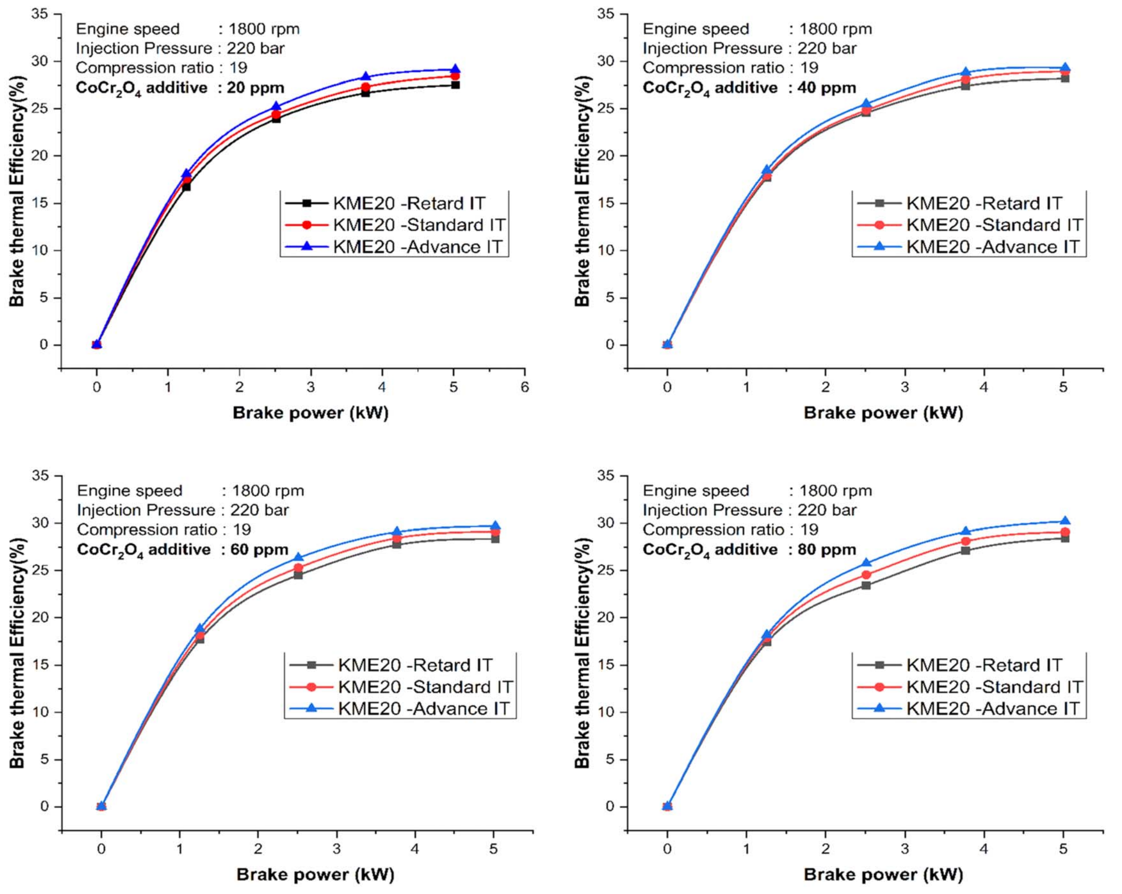

Figure 10. Variation of BTE with Brake power for different concentration of Cobalt chromite.

compared to Diesel at standard IT. The lower energy consumption with $CoCr_2O_4$ was ascribed to its enhanced S/V ratio and elevated energy value of the fuel. Correspondingly, $CoCr_2O_4$ with KME20 displayed a lesser BSEC than without nanoparticles in KME20 owing to inbuilt O_2 in the case of $CoCr_2O_4$ that enhance the combustion process [28].

6.3. Emission characteristics

6.3.1. Unburnt hydrocarbon

The trend noted for Unburnt Hydrocarbon emission for KME20 with various concentrations of $CoCr_2O_4$ nanoparticles at different ITs are exposed in figure 12. The low concentration of $CoCr_2O_4$ with KME20and the UBHC are 59 ppm, 57 ppm and 54 ppm for retarded, standard and advanced IT, respectively, as compared to Diesel of 66 ppm at CR 18. This result exhibited that the UBHC of Diesel at CR 18 was 10.1%, 13.4% and 18.6% higher than KME20 with retarded, standard and advanced IT. It can be attributed to advance IT, which gives sufficient time to make a homogenous mixture of fuel and air that results in combustion [20]. It can be seen that doping of 40 ppm $CoCr_2O_4$ with KME20 at CR 19, the UBHC are 56 ppm, 54 ppm and 53 ppm for retarded, standard and advanced IT, respectively, as compared to blend KME20 of 61 ppm at CR 18. These results could be ascribed to the pooled effect of $CoCr_2O_4$ and optimum IT. Further, it leads to the enhancement of the hydrocarbon oxidation process, thereby resulting in lesser UBHC formation. In addition, the UBHC emission of KME20 with 60 ppm of $CoCr_2O_4$ at different ITs of retarded, standard and advanced was 55 ppm, 53 ppm and 50 ppm, respectively. Doping 80 ppm of $CoCr_2O_4$, the UBHC are 56 ppm, 54 ppm, and 49 ppm for retarded, standard and advanced IT of KME20 with $CoCr_2O_{4,}$ respectively, as compared to Diesel of 66 ppm. The UBHC emission was gradually dropped with an increase in the concentration of $CoCr_2O_4$ in the blend for all injection timings. because the addition of nanoparticles enhances the air-fuel mixture during the fuel injection process. Additionally, the propagation of nanoparticles results in complete combustion within the chamber, which in turn reduces the amount of unburn hydrocarbons emitted from the exhaust. From the above results, it can be observed that the UBHC are 18.5%, 20.6%, 25.6% and 28.3% lower for 20 ppm, 40 ppm, 60 ppm and 80 ppm of $CoCr_2O_4$ with KME20, as compared to Diesel. Doping of nanoparticles with biodiesel blend enhances the chemical reaction, therefore, resulting in complete combustion. Further, the increase in resident time of the

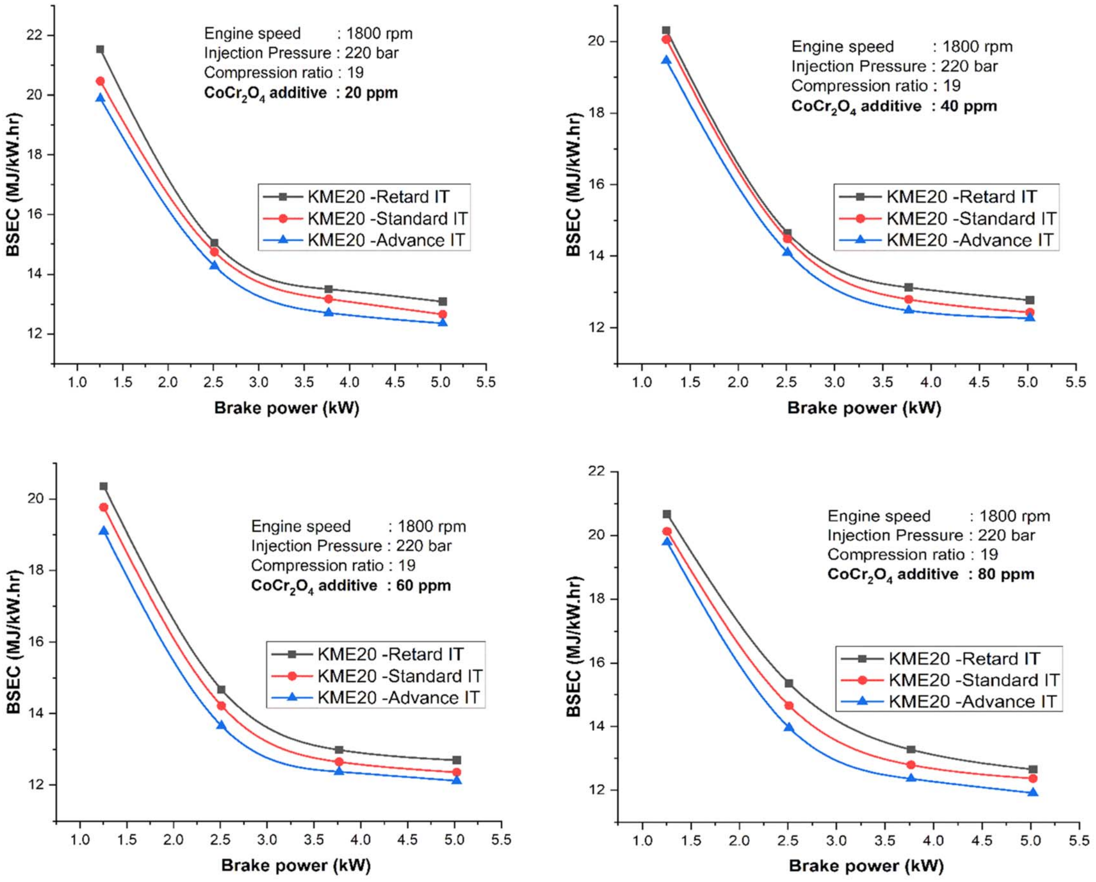

Figure 11. Variation of BSEC with brake power for different concentration of Cobalt Chromite.

mixture inside the cylinder leads to homogeneous mixture formation, which chemical kinetics of fuel that results in more oxidation of hydrocarbon [18].

6.3.2. Carbon monoxide

The decrease in CO emission for KME20 blend with doping of $CoCr_2O_4$ nanoparticles is shown in figure 13. It could be attributed to enhanced vaporization of fuel due to the minimizing of the viscosity. At a higher concentration of $CoCr_2O_4$, the advanced injection timing exhibited lesser CO emission, followed by retard and standard injection timing. For the 20 ppm of nanoparticle with KME20, the CO emissions are 0.113%, 0.112% and 0.1159% vol. for retarded, standard and advanced IT, respectively, as compared to Diesel of 0.13%vol. at peak load. It can be seen that the CO of Diesel at standard conditions was 13.07%, 14.2% and 15.8% higher as compared to KME20 with retarded, standard and advanced IT. It might be due to complete combustion, thereby leading to lower CO formation [22]. From the results, it was noticed that addition of 40 ppm $CoCr_2O_4$ with KME20 at CR 19, the CO emissions are 0.114%, 0.111% and 0.107% vol. for retarded, standard and advanced IT, respectively, as compared to blend KME20 of 0.121% vol. The elevated compression temperature with the catalytic activity of nanoparticles buffers the CO oxidation process, which enhances the CO conversion into CO_2 formation. Besides, inherent O_2 availability and formation of chemically correct mixture leads to improved CO_2 conversion [24]. Moreover, the CO emission of KME20 with 60 ppm of nanoparticles at various injection timing of retarded, standard and advanced IT was 0.112%, 0.109% and 0.106%vol., respectively. While, doping 80 ppm of $CoCr_2O_4$, the CO is 0.11%, 0.104% and 0.1% vol. for retarded, standard and advanced IT of KME20 with $CoCr_2O_4$, respectively, as compared to Diesel of 0.13% vol. It can be seen that CO emissions were linearly reduced with advanced (earlier injection) inject the fuel in the cylinder. It was noticed that the CO emissions are 15.3%, 17.6%, 18.4% and 23.0% lower for 20 ppm, 40 ppm, 60 ppm and 80 ppm of $CoCr_2O_4$ with KME20 at advanced injection timing (25°bTDC), as compared to Diesel fuel operation.

6.3.3. Nitrogen oxide

Figure 14 illustrates the formation of NOx emission for KME20 blend with various injection timing at a compression ratio of 19. From the results, it was noted that the NOx decreases with a gradual rise in the

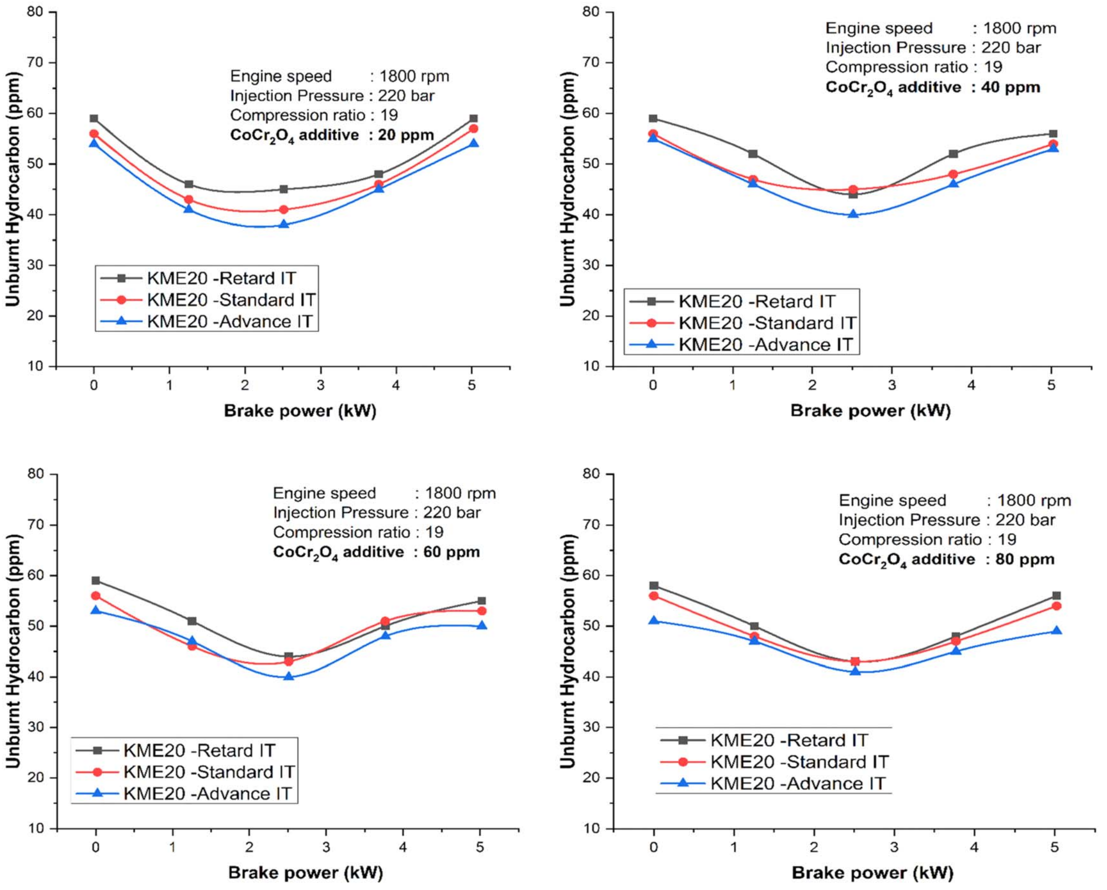

Figure 12. Variation of UBHC with Brake power for different concentration of cobalt chromite.

concentration of nanoparticles in the blend. At the lower doping rate of nanoparticles, a high NOx emission was observed, but it could be slightly decreased at the higher doping rate of nanoparticles. It might be due to the multicomponent activity of nanoparticles restricting the oxidation of nitrogen, which results in lower NOx formation. Adding 20 ppm of $CoCr_2O_4$ with blend at peak load, the NOx emissions are 765 ppm, 799 ppm and 836 ppm for retarded, standard and advanced IT, respectively. It was higher than the Diesel operation. It was also noted that the NOx of Diesel at standard condition was 11.1%, 14.8% and 18.6% lower as compared to KME20 with retarded, standard and advanced IT at a doping rate of 20 ppm. It was mainly due to inborn O_2 in the nanoparticle and biodiesel blend that resulted in improved combustion efficiency, therefore, increasing the cylinder temperature [26]. From the result, it can be noticed that by mixing 40 ppm of $CoCr_2O_4$ with KME20 at a higher compression ratio, the NOx emissions are 742 ppm, 761 ppm and 799 ppm for retarded, standard and advanced IT, respectively, when related to optimum blend. Furthermore, the NOx of KME20 with 60 ppm of $CoCr_2O_4$ at various fuel injection timings of retarded, standard and advanced IT were 710 ppm, 745 ppm and 785 ppm, respectively. Blending 80 ppm of $CoCr_2O_4$ into KME20, the NOx emissions are 707 ppm, 738 ppm and 759 ppm for varying ITs of retarded, standard and advanced, respectively, as related to Diesel of 680 ppm. Remarkably, high doping of nanoparticles in the blend led to drastic reduction of NOx emission for all injection timings. It was discovered that nanoparticle added fuel had lower levels of NOx emissions than diesel. The decrease in emissions may be attributable to an increase in the convective heat transfer occurring within the cylinder, which results in a decrease in the average temperature of the cylinder [25]. Also, late injection timing has a great influence on reducing the NOx emission for all load conditions due to restrictions in oxidation. Meanwhile KME and KME blends have a higher level of NOx emission than Diesel fuel at peak load owing to an elevated temperature in the cylinder by the release of more oxygen molecules during a chemical reaction [20]. In contrast, the result was noticed that NOx emission was 4.68%, 9.3% and 10.6% lower for 40 ppm, 60 ppm and 80 ppm of $CoCr_2O_4$ with KME20, as compared to neat kapok biodiesel. It may be because nanoparticles act as an antioxidant agent at the combustion stage, leading to the post-combustion temperature and finally resulting in lower NOx formation.

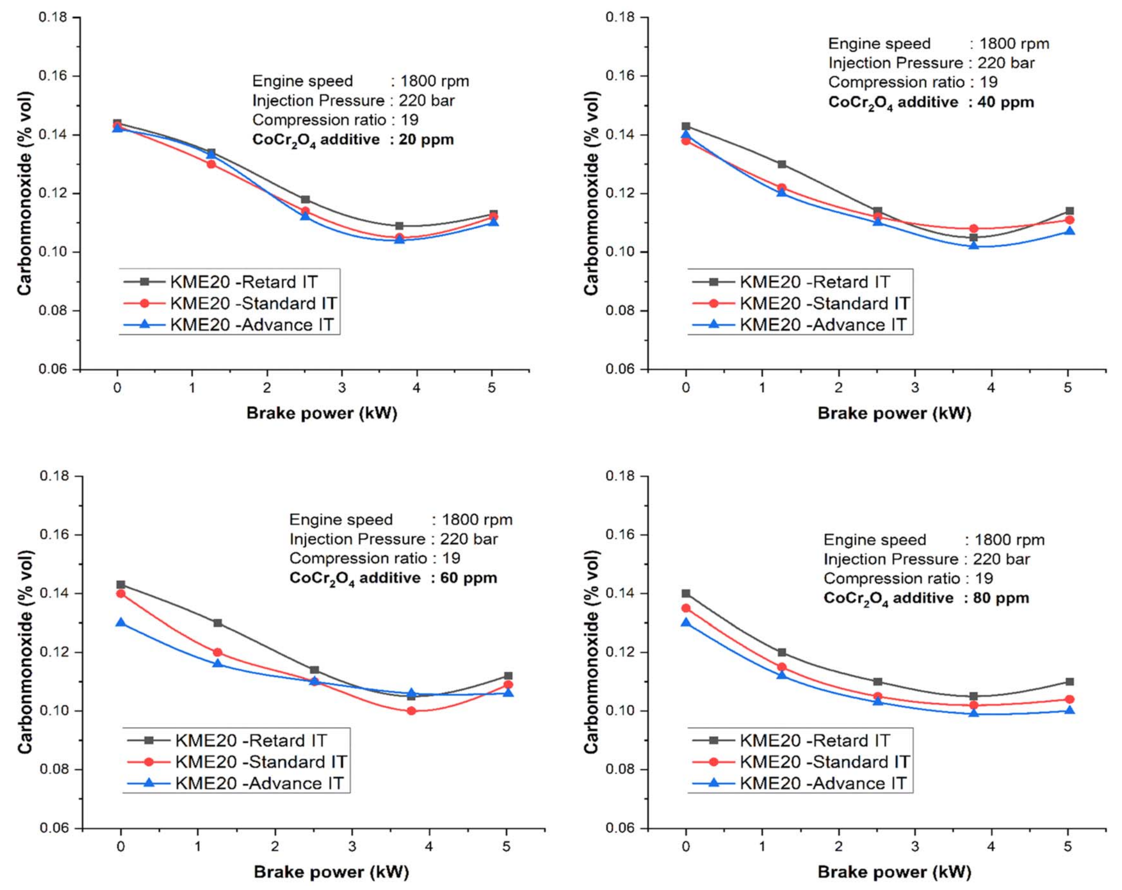

Figure 13. Variation of CO with Brake power for different concentration of cobalt chromite.

6.3.4. Smoke

While comparing HC and CO emissions, smoke opacity also reduces with the rise in the doping rate of $CoCr_2O_4$ in biodiesel blend, as noted in figure 15. Also, the fuel droplet size and volatility of fuel have great influence on smoke formation. Due to oxygen inadequacy and poor fuel evaporation rate, sufficient heat is not carried out to the inner layer of fuel at the given time, resulting in partially burnt carbon particles in the exhaust. This partially burnt carbon particle is called smoke emission. From the investigation, the addition of $CoCr_2O_4$ enhances the S/V of the mixture, therefore, increasing the heat transfer rate from the outer layer to the inner layer of the fuel droplet. This could be because of the amount of oxygen in mixed fuel and the nanoparticle additive, which breaks down the fuel so it burns more completely and with less smoke. It results in improving combustion and minimizing the smoke. From the results, 20 ppm of $CoCr_2O_4$ with KME20, the smoke emissions are 62%, 56% and 52% for retarded, standard and advanced IT, respectively, as compared to Diesel of 74% at standard CR 18. It was exhibited that the smoke of Diesel at CR 18 was 16.2%, 24.3% and 29.7% higher, as compared to KME20 with retarded, standard and advanced IT. It was mainly due to earlier injection of fuel observe the heat from compressed air, thereby enhancing the evaporation rate and making a homogeneity mixture, which results in better combustion. While doping 40 ppm of $CoCr_2O_4$ with KME20 at CR 19, the smoke emissions were 61%, 54% and 50% for retarded, standard and advanced IT, respectively, as related to blend KME20 of 69% at CR 18. It reasonably increased the O_2 availability in the chamber due to the inherent O_2 presence in nanoparticles and biodiesel that results in complete combustion [27]. Also, the smoke of KME20 with 60 ppm of $CoCr_2O_4$ at various ITs of retarded, standard and advance were 60%, 53% and 49%, respectively. While adding 80 ppm of $CoCr_2O_4$, the smoke was 52%, 48% and 46% for retarded, standard and advanced IT of KME20, respectively, as compared to Diesel of 74%. It was observed that the smoke was 32.3%, 48%, 51.0% and 60.8% lower for 20 ppm, 40 ppm, 60 ppm and 80 ppm of $CoCr_2O_4$ with KME20 compared to Diesel. It was mainly due to the increase in the S/V ratio and enhanced heat transfer rate within the biodiesel droplet layer, which exhibits a shorter ID period, thereby improving the combustion efficiency [19].

The comparison between kapok methyl ester and some other biodiesels in terms of performance and emissions characteristics is shown in table 3 above. This table indicates that, in comparison to the other three biodiesels, kapok methyl ester reveals a slight increase in performance while simultaneously lowering emissions.

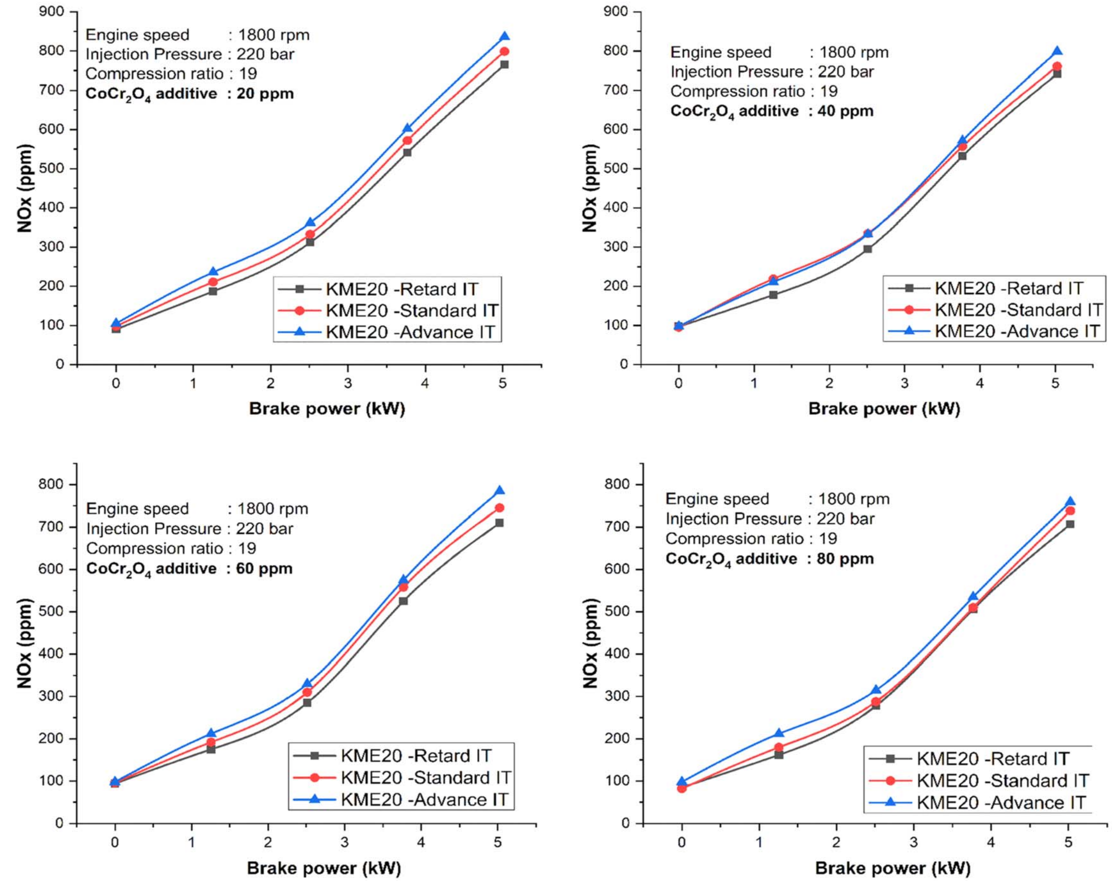

Figure 14. Variation of NOx with Brake power for different concentration of Cobalt Chromite.

7. Conclusions

The experimental analysis found that the NOx emission was drastically reduced along with marginal reduction in UBHC, CO and smoke emission. The role of $CoCr_2O_4$ nanoparticles in the Diesel engine operation is highlighted in the results given below:

- Cobalt chromite nanoparticle has buffered the excess oxygen in the chamber when dosage with optimum KME blend, which leads to an increase in the oxidation of hydrocarbon. While adding the nanoparticle to the biodiesel blend, blend properties were slightly enriched, reduced the viscosity and enhanced the heating value of the blend.

- The results of BTE were 11.9%, 12.4%, 13.5% and 14.9% higher for 20 ppm, 40 ppm, 60 ppm and 80 ppm of $CoCr_2O_4$ with KME20 at advanced injection timing (27°bTDC), as compared to neat KME. Moreover, improvements in BTE for KME20 with nanoparticles at various concentrations of 20 ppm, 40 ppm, 60 ppm and 80 ppm were 3.6%, 4.2%, 5.4% and 7.5%, as related to the same blend without doping of nanoparticles.

- Exhaust emission of KME20 with nanoparticle blend leads to a drastically drop-in hydrocarbon, carbon monoxide, oxides of nitrogen and smoke emissions related to Diesel fuel owing to various factors such as secondary atomization, enhanced heating value and the catalytic reaction of the nanoparticle. A reasonable improvement was also noticed for varying the injection timing of KME20. The retarded IT produce lower NOx emission but the penalties of that lower BTE value.

- The combined effect of nanoparticle addition and varying injection timing of the KME20 blend was found to have a remarkable improvement in combustion characteristics such as peak cylinder pressure, HRR due to higher momentum of $CoCr_2O_4$ and enhanced heat transfer rate through fuel droplet layers. it was concluded that KME20 with 80 ppm of cobalt chromite nanoparticle resulted in superior engine performance and effective emission reduction characteristics at advanced injection timing, i.e., 27° bTDC, as compared with its rivals.

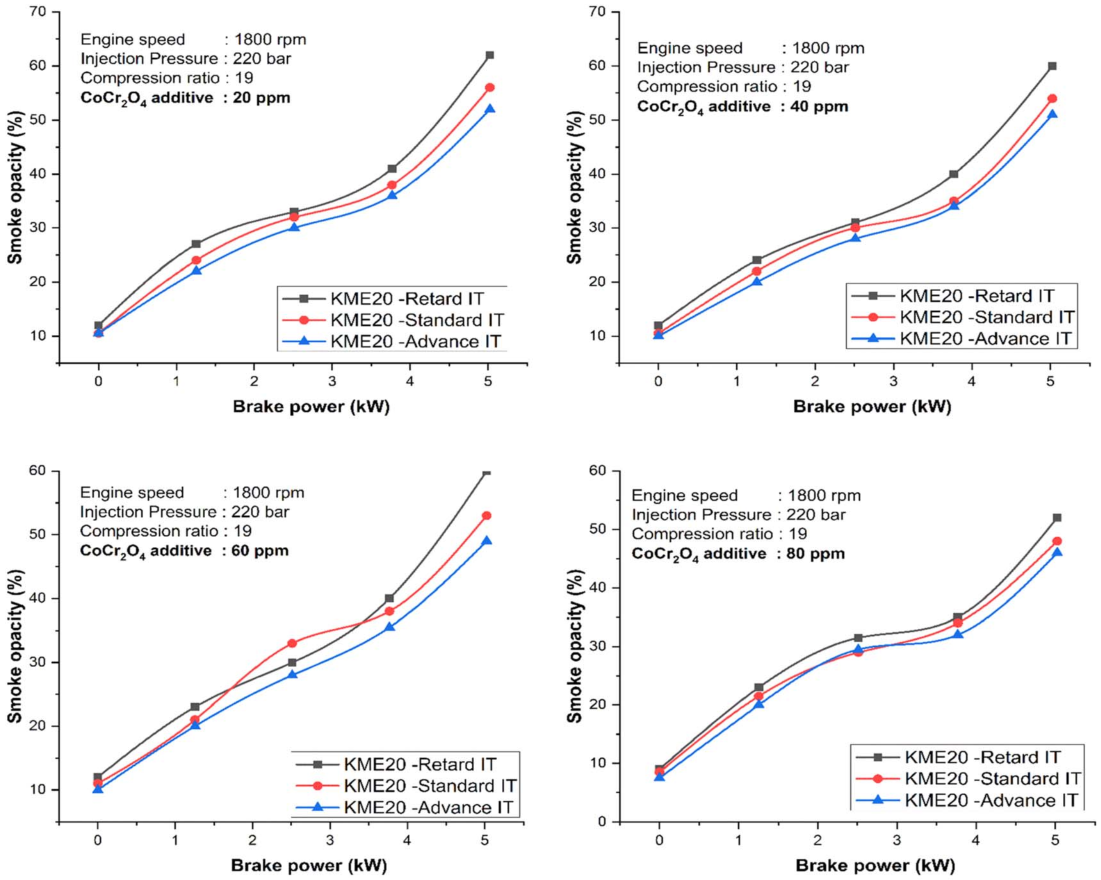

Figure 15. Variation of smoke with brake power for different concentration of cobalt chromite.

7.1. Scope of future work

The present investigation on kapok methyl ester with cobalt chromite nanoparticles and engine modification can be further extended in future work.

- In order to completely reduce the NOx emission by adding an after treatment device like a lean NOx trap or Selective Catalytic Reduction.
- Experiments continued with an advanced common rail direct injection system.

Acknowledgments

Not applicable.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Declarations

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Table 3. Comparison table of other biodiesel performance and emission characteristics.

Authors	Engine type	Biodiesel fuels	Fuel properties	Performance	Emissions	References
K Vijayaraj A P Sathiyagnanam.	1-Cylinder, 4 stroke, WC, DI, CR: 17.5:1, RP: 4.4 Kw, 1500 rpm	Mango Seed Oil	Calorific value –39 MJ m^{-3} Cetane number-51.3 Viscosity-3.33mm^2 S^{-1} Density-845 kg m^{-3}	B25 Blend BSFC—0.29 kg $kW^{-1}h^{-1}$ BTE – 28.13%	CO-0.07% HC-32% NOx-5.88 ppm Smoke-36.8%	4
B Prem Anand *et al*	1-Cylinder, 4 stroke, WC, DI, CR: 16.5:1, RP: 5.2 Kw,1500 rpm	Turpentine Oil	Calorific value—37.28MJ m^{-3} Cetane number- 38 Viscosity- 3.89 mm^2 /S Density-920 kg m^{-3}	TPOF Blend BSFC—0.31 kg $kW^{-1}h^{-1}$ BTE – 28.5%	CO-Reduced HC-Reduced NOx-Increased	2
K Muralidharan & D Vasudevan	1-Cylinder, 4 stroke, WC, DI, CR: 19, RP: 3.7 Kw, 1500 rpm	Waste cooking oil	Calorific value –40 MJ m^{-3} Cetane number-52 Viscosity-1.4mm^2 S^{-1} Density-840 kg m^{-3}	WCO20 Blend BSFC—0.31 kg $kW^{-1}h^{-1}$ BTE – 28.5%	CO-0.15% HC-25.3% NOx-720 ppm Smoke–	6
Present work	1-Cylinder, 4 stroke, WC, DI, CR: 19:1, RP: 5.9 Kw, 1800 rpm	Kapok methyl ester	Calorific value –39 MJ m^{-3} Cetane number-53 Viscosity-3.1mm^2 S^{-1} Density-842 kg m^{-3}	KME20 Blend BSFC—0.21 kg $kW^{-1}h^{-1}$ BTE – 28.46%	CO-0.112% HC-28.3% NOx-799 ppm Smoke-56%	—

Conflict of interest

The authors declare that they have no conflict of interest.

Availability of data and material

Not applicable.

Author contributions

Anbarasan Baluchamy- Conceptualization, Investigation, Writing, **Muralidharan Karuppusamy-**Resources, Supervision**, Sakthi Rajan C** -Review, Editing **Balamurugan Senthamaraikannan**- Validation.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

Compliance with ethical standards

Declaration of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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