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Effect Of Nanotechnology On Performance And Exhaust Characteristics Of Biodiesel Engines - A Review

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Abstract

Recently, the excessive use of diesel has caused a series of problems such as the exhaustion of fossil fuels and environmental pollution. More researchers have begun to study biodiesel. Biodiesel is a renewable alternative fuel with similar characteristics to traditional diesel, and can be used directly without changing the existing engine structure. However, biodiesel has a higher viscosity and lower calorific value and incomplete mixed with diesel, which will delay ignition, lower the ignition temperature, cause incomplete cylinder combustion, and increase exhaust emissions. In order to improve the above problems, the researchers found that the use of nanotechnology can improve the engine combustion performance and exhaust emission characteristics. This article reviews the effects of nanoparticles on the performance and emissions of biodiesel engines under different engine operating conditions, the use of nanoparticles as additives can improve engine combustion performance, increase cylinder pressure, promote combustion, and reduce HC and CO emissions.

Keywords: Nanoparticles, Biodiesel, Engine performance, Exhaust emission, Nanoparticles properties

Introduction

Due to the excessive use of industrialization and modernization, the existing fossil fuel reserves have been greatly reduced, the use cost is high, and cause great damage to the environment and human health. In order to reduce a series of problems caused by diesel, biodiesel is gradually used as engine fuel, because biodiesel is an ideal alternative fuel that can be extracted from vegetable oils and animal fats, etc. However, such as high viscosity, high density, and low calorific value, cause ignition delay and lower ignition temperature, worsen combustion, and increase exhaust emissions. In order to better improve similar problems, add nanoparticles to change the degree of fuel mixing in the cylinder, promote combustion, and improve engine emissions. Under normal circumstances, the fine particles in the range of 1-100nm produced by natural and chemical synthesis as nanoparticles will be considered [1]. Many researchers had devoted themselves to studying the effect of nanoparticles on engine performance and exhaust emissions when they are added to mix with biodiesel and biodiesel blends. There are many types of nanomaterials, such as ZnO, CuO, Al_2O_3, TiO_2, CNT, AgSCN and GNP etc.

Many researchers had done a lot of works on nano-materials and found that nano-materials improve engine performance and exhaust emission characteristics. It was found that oxygen-containing nanoparticles can reduce HC and CO emissions, while NO_x emissions increased slightly. Ramesh D. K. et al [2]. studied diesel, biodiesel-diesel mixed fuels and mixed fuels with alumina nanoparticles, the mixed fuels with alumina nanoparticles have higher brake thermal efficiency than diesel at high load, and all cylinders had the similar pressure, and reduced NO_x, HC, and CO. S. Sunil et al [3]. used sol-gel technology to produced titanium oxide nanoparticles, dispersed in various proportions in the B20 fuel using sonicator, and tested the performance and emission characteristics of a four-stroke single-cylinder diesel engine. The results showed that when the proportion of titanium oxide nanoparticles increased, the mixed fuel exhibits better engine performance and emissions, however, when titanium oxide nanoparticles exceeding 250 ppm were used, it did not show a positive effect on engine performance and emissions. P. Kannan et al [4]. found that when copper oxide nanoparticles were used as additives, the presence of a highly reactive surface prompted chemical reactivity, resulting in improved combustion, leading to increased braking thermal efficiency and brake specific fuel consumption, CO, HC and smoke emissions are also greatly reduced. K. Kalaimuruganp et al [5]. found that the neochloris oleoabundans biodiesel was made from neochloris oleoabundans algae oil through transesterification reaction, the 25, 50, 75, and 100 ppm zinc oxide nanoparticles were dispersed by ultrasonic technology to make mixed fuels according to different proportions. The results showed that when 100ppm of zinc oxide nanoparticles were mixed with biodiesel-diesel mixed fuels, they exhibited the best engine performance and reduced HC, CO and smoke emissions [5]. The reduction of NO_x in diesel engine, the use of oxygen-free nanomaterials can effectively reduce NOx emissions. Tawfik Badawy et al [6]. studied the effects of CNT nanoparticles on engine performance and emissions, and found that biodiesel with CNT nanoparticles had higher brake thermal efficiency and lower brake specific fuel consumption, reduced the emission of CO, CO_2, HC, NO_x and smoke, CNT nanoparticles with a concentration of 50 ppm have the best performance and the lowest exhaust emissions. Medhat elkelawy et al [7]. used a mechanical movement pump to stir the biodiesel-diesel mixed fuels added with AgSCN to complete the engine experiment, it was found that the engine performance was the best, and the emissions of HC and smoke were significantly reduced. Ahmed I. El-seesy et al [8]. analyzed the effects of graphene nanoparticles on engine performance, combustion and emission, they found that the addition of graphene nanoparticles improved cylinder pressure and braking thermal efficiency and reduced braking fuel consumption, when at the concentration of 25-50mg/L, CO, NO_x and HC of the engine decreased by 65%, 55%, and 65% respectively.

Many nanoparticles contain oxygen, they released oxygen during the combustion process, promote combustion, increased cylinder temperature, and reduced HC and CO emissions, and increased NO_x; The addition of oxygen free nanoparticles can accelerate the combustion rate, improve engine performance and reduce exhaust emissions by changing the mixing area and combustion area [1]. Therefore, in order to further explore the impact of nanoparticles on engine performance and exhaust emissions, the structure of this article is as follows: The first part summarizes the characteristics of oxygen-free nanoparticles and oxygen-containing nanoparticles. The second part analyzed the impact of nanotechnology on the performance of biodiesel engines under a variety of engine loads. The third part studied the effect of adding nanoparticles on engine exhaust emission characteristics under a variety of engine loads.

Characteristics of nanoparticles

Different nanoparticles have different physical and chemical properties, the main difference between oxygen-free nanoparticles and oxygen-containing nanoparticles is whether they contain oxygen. Table 1 describes the characteristics of some common nanoparticles：

Table 1. Properties of nanoparticles [2, 4, 5, 8, 12, 15, 17]

Nanoparticles / Properties	ZnO	TiO_2	CuO	Al_2O_3	CNT	AgSCN	GNP
Color	White	White	Black to	White	Black	White	Transparent

			Brown Powder				
Solubility	/	Insoluble	/	/	Dispersed in Water	Insoluble	/
Average Size	> 50 nm	35 ± 5 nm	< 100nm	10 ± 2 nm	(L: > 660 nm) and (W: 20 ± 5 nm)	/	6-8 nm
Bulk density（g/cm³）	/	0.24	6.31	3.95	1.35	/	0.03-0.1
Shape	Spherical	Spherical	/	Spherical	Tubular	/	/
Melting point（℃）	/	2116	1201	2045	/	/	/
Boiling point（℃）	/	3245	2000	2980	/	/	/
C（%）	/	/	/	/	99	7.65	/
N（%）	/	/	/	/	/	8.85	/
Molecular weight	/	79.866	/	/	/	/	/
Specific surface area (m^2/g)	/	25–45	/	> 20	/	/	300
Oxygen atom	Yes	Yes	Yes	Yes	No	No	No

From Table 2 can be found that compared with the biodiesel-diesel mixed fuels, the mixed fuels with nanoparticles has similar or higher calorific value, therefore, under the same engine working conditions, the fuel consumed by the engine to reach the same power was lower than that of biodiesel-diesel mixed fuels without nanoparticles. Moreover, the addition of nanoparticles increased the flash point of the biodiesel-diesel mixed fuels, and improved the safety of the fuel. In addition, it can be seen that with the addition of nanoparticles, improved engine performance and emissions. Among them, the oxygen-free nanoparticles reduced the oxygen for NO_x generation during the reaction process and reduced the NO_x emission.

Table 2. Effects of nanoparticles on characteristics, performance and emissions of biodiesel-diesel mixed fuels [3, 4, 5, 7, 8, 13, 15, 20]

Properties / Type		Kinematic viscosity at 40℃ (mm^2/s)	Calorific value (MJ/kg)	Cetane Number	Density (g/cm^3)	Flash point (℃)	Cloud point (℃)	BTE	BSFC	EGT	CO	HC	NO_x	CO_2	Smoke
Al_2O_3	B20	4.73	43.54	58	0.83	176	-1	/	/	/	/	/	/	/	/
	B20+ppm 100	5.6894	45.52	52	0.8319	178	-4	+6.5	-6.5	-27	-19	-18	-36	/	-4
ZnO	B20	4.81	43.41	56	0.9	155	-3	/	/	/	/	/	/	/	/
	B20+ppm 100	5.88	42.519	54	0.86	157	-4	/	/	/	/	/	/	/	/
CuO	B20	5.3	41.43	/	0.89	226	/	/	/	/	/	/	/	/	/
	B20+ppm 75	5.47	43.44	/	0.892	232	/	/	/	/	/	/	/	/	/
TiO_2	B20	2.59	41.69	/	/	69	/	/	/	/	/	/	/	/	/
	B20 with TiO2	2.71	41.57	/	/	74	/	+1.75	-1.75	-11	-14.5	-15	-23	/	-35
CNT	B20	2.59	41.69	/	/	69	/	/	/	/	/	/	/	/	/
	B20 with CNT	2.72	41.57	/	/	74	/	+2.5	-2.5	-12	-21.5	-15	-46	/	-50
AgSCN	B50	/	/	/	/	/	/	/	/	/	/	/	/	/	/
	B50+ppm 200	/	/	/	/	/	/	9.6	-13.7	/	-38.1	-40	-15.4	-1.96	-28.7
GNP	B20	3.33	41.142	51.6	/	/	/	/	/	/	/	/	/	/	/
	B20+ppm 100	4.22	41.23	57.4	/	/	/	/	/	/	/	/	/	/	/

Combustion Characteristics

In-Cylinder pressure

In the combustion process, cylinder pressure determined engine performance and combustion characteristics, compared with diesel, biodiesel had a higher viscosity, incomplete combustion and reduced cylinder pressure. K. Kalaimurugan et al [5]. studied the influence of ZnO nanoparticles on engine performance, it can be seen from Figure 1 that the cylinder pressure of mixed fuel with ZnO nanoparticles was better, with the increased of the proportion of nanoparticles, the mixed fuel added with 100ppm nanoparticles showed the highest cylinder pressure. ZnO nanoparticles have a good contact area ratio, higher cetane number, higher evaporation rate, and the addition of ZnO nanoparticles minimizes engine combustion delay, improved the combustion rate, and increased the cylinder pressure. Ramesh D. K. et al [2]. studied the effect of Al_2O_3 nanoparticles on biodiesel-diesel mixed fuels, and obtained the same trend, found that Al_2O_3 nanoparticles released oxygen during combustion, promoted the complete combustion, and increased the cylinder pressure. Under high load, the combustion temperature increased with the increase of pressure, and increased the evaporation rate, promoted better fuel combustion and increases cylinder pressure. As shown in Figure 2, S. Manigandan et al [9]. studied the effects of TiO_2, CNT, Al_2O_3 and CuO nanoparticles on cylinder pressure, added nanoparticles can promote the increase of contact area of mixed fuel, improve combustion and increase cylinder pressure; In addition, CNT nanoparticles promoted larger heat spread in the process of compression and combustion, and showed the highest cylinder pressure at 50% and 100% load.

Nanoparticles played an important role in the mixing of biodiesel and diesel, when oxygen-containing nanoparticles were added to biodiesel as catalyst, the fuel contact area ratio increases, oxygen was s released during combustion, the combustion process was improved, and the cylinder pressure was increased, compared with oxygen-containing nanoparticles, CNT nanoparticles cannot release oxygen to promote combustion, However, they had superior conducting property and high thermal conductivity, promoted larger heat spread in the process of compression and combustion.

Fig.1 Variation of In-cylinder pressure at different blend fuels [5].

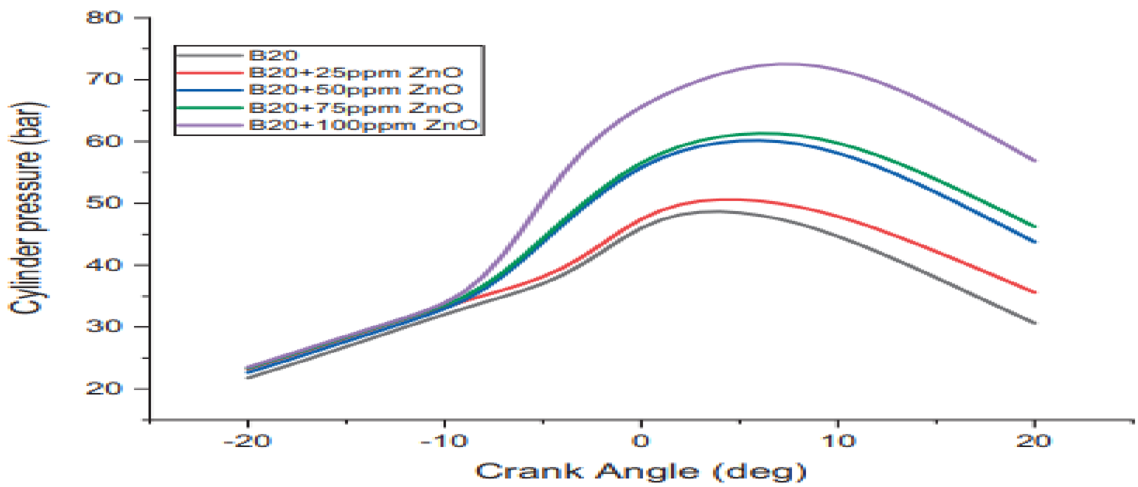
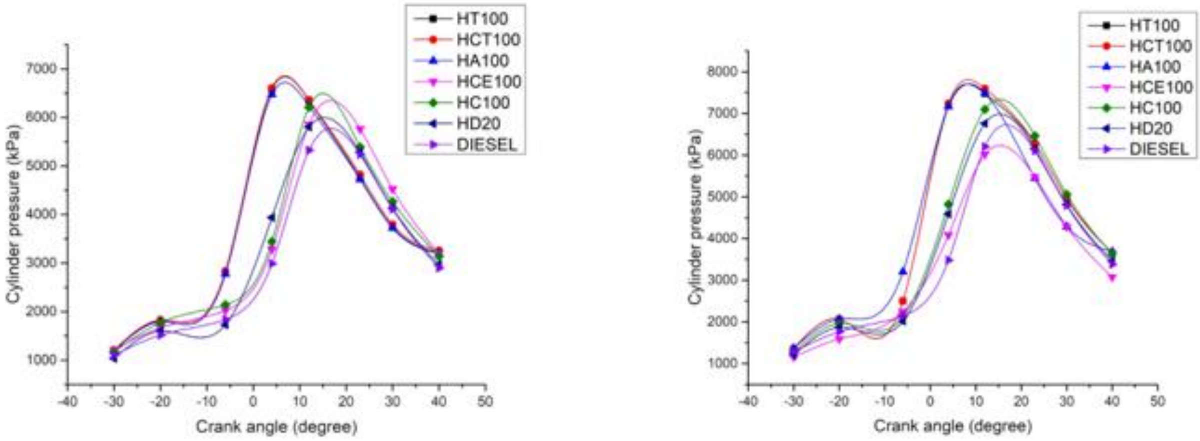


Fig.2 Variation of In-cylinder pressure at different blend fuels and loads [9].



Brake specific fuel consumption (BSFC)

The brake specific fuel consumption is an important factor that determines the efficiency of the engine [10]. Pankaj Mohan Rastogi et al [11]. studied the effect of CuO nanoparticles on brake specific fuel consumption, as shown in Figure 3, compared with diesel, biodiesel had low calorific value, under the same engine working conditions, more fuel must be consumed to obtain the same power as diesel, so the highest brake specific fuel consumption had been shown; However, with the addition of CuO nanoparticles, the contact area ratio was increased, the ignition delay was shortened, the combustion was promoted, and the brake specific fuel consumption was reduced. Figure 4 showed the change of brake specific fuel consumption of experimental fuel with load, it was found that with the increase of engine load, the brake specific fuel consumption showed a downward trend.

At low load, the combustion temperature was low, the fuel/air mixing was incomplete, resulting in incomplete combustion, relatively high heat transfer and frictional loss in the combustion chamber, and high brake specific fuel consumption; Under medium and high load, higher temperature and atomization effect minimize the negative impact of mixed fuel, completed fuel combustion, increased engine power output and reduced brake specific fuel consumption.

In addition, TiO_2 and Al_2O_3 nanoparticles increased the calorific value of the mixed fuel and promote the reduction of brake specific fuel consumption [12]. T. Dharmaprabhakaran et al [13]. found the same trend of Al_2O_3 nanoparticles-biodiesel-diesel mixed fuels, as shown in Figure 5, with the addition of Al_2O_3 nanoparticles, the area contact ratio increased, and Al_2O_3 nanoparticles released oxygen during combustion processes, improved combustion and reduced braking specific fuel consumption.

When nanoparticles were used as additives, it would affect the brake specific fuel consumption of biodiesel-diesel mixed fuels, with the addition of nanoparticles, the combustion volume was increased, the ignition delay was shortened, the combustion time of the diffusion combustion stage was increased, and the fuel burned while mixing, and the brake specific fuel consumption was reduced, in addition, some oxygen-containing nanoparticles released oxygen when burning, promoted complete combustion.

Fig.3 Variation of BSFC at different blend fuels [11].

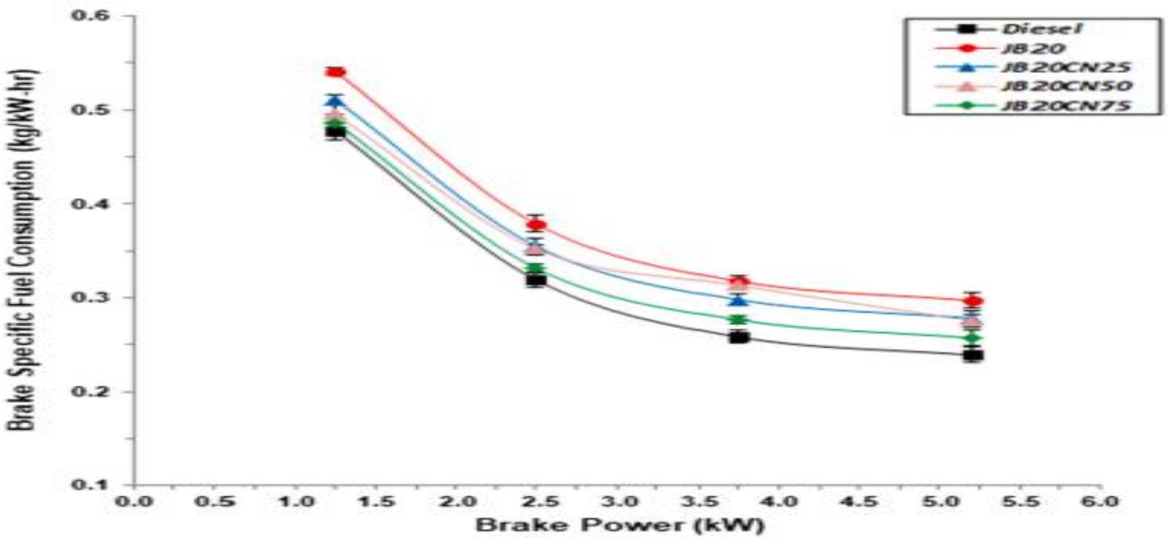


Fig.4 Variation of BSFC at different loads [12].

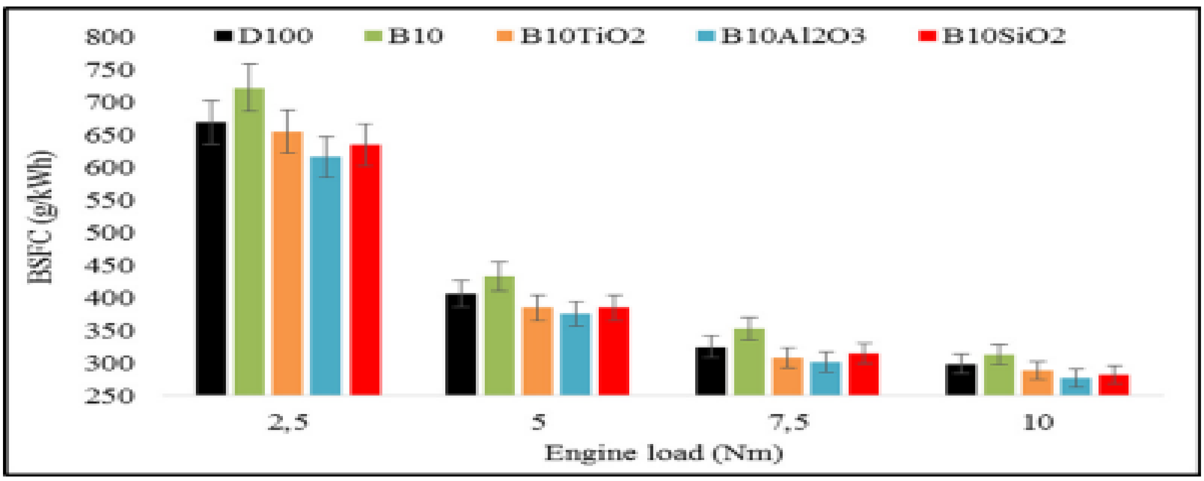
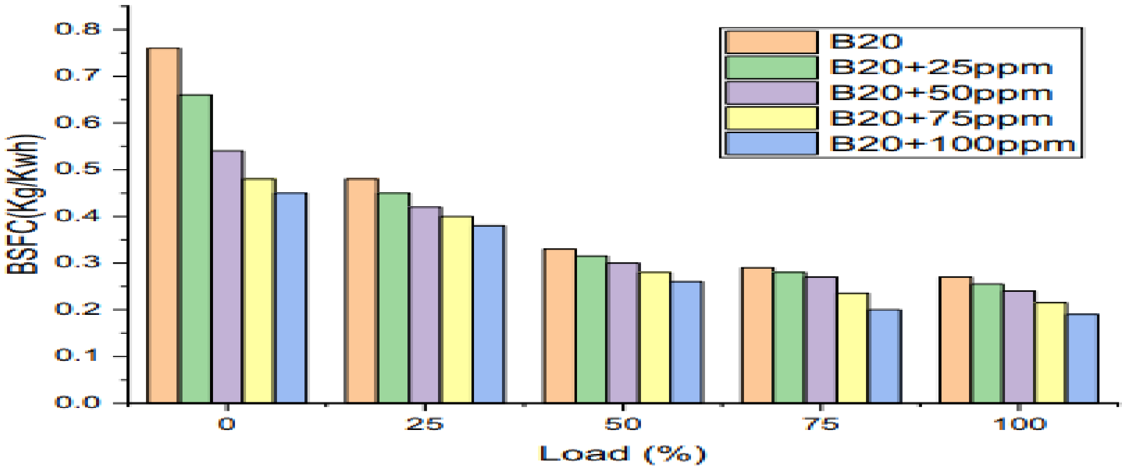


Fig.5 Variation of BSFC at different blend fuels [13].



Brake thermal efficiency (BTE)

Pankaj Mohan Rastogi et al [11]. studied the effect of CuO nanoparticles on the brake thermal efficiency of biodiesel-diesel mixed fuels, in Figure 6, biodiesel-diesel mixed fuels had low combustion temperature and poor fuel atomization, resulting in incomplete combustion, resulting in lower brake thermal efficiency than diesel fuel due to low calorific value and high viscosity; With the addition of CuO nanoparticles, CuO nanoparticles improved the contact area ratio of mixed fuel, mix evenly with air, promoted fuel combustion and improved brake thermal efficiency. Varatharaju perumal et al [14]. found that when CuO nanoparticles were added to biodiesel-diesel mixed fuels, the nanoparticles released oxygen and micro-explosion during combustion processes, which promoted fuel atomization, completed fuel combustion and improved brake thermal efficiency. M. S. GAD et al [15]. studied the effects of TiO_2, CNT and Al_2O_3 nanoparticles on biodiesel-diesel mixed fuels, and resulted the same trend shown in Figure 7, with the addition of nanoparticles, improved the combustion of mixed fuel and increased the braking thermal efficiency, moreover, the braking thermal efficiency of blends with oxygen-free nanoparticles (CNT) were slightly higher than that of fuel added with oxygen-containing nanoparticles.

on the one hand, the addition of nanoparticles reduced the ignition delay and combustion duration of fuel, resulting in higher peak cylinder pressure and faster heat release rate; On the other hand, nanoparticles improved the propagation of fuel droplets and the dispersion of injected fuel, reduced fuel viscosity and produced smaller droplets, so as to promoted combustion and improved brake thermal efficiency.

Figure 8 showed with the increase of load, the brake thermal efficiency of all fuels increased [16]; at low load, the combustion temperature was low and the fuel/air mixing was incomplete, resulting in incomplete combustion; With the increase of load, the combustion temperature increased, completed combustion, decreased brake specific fuel consumption, and increased brake thermal efficiency.

Fig.6 Variation of BTE at different blend fuels [11].

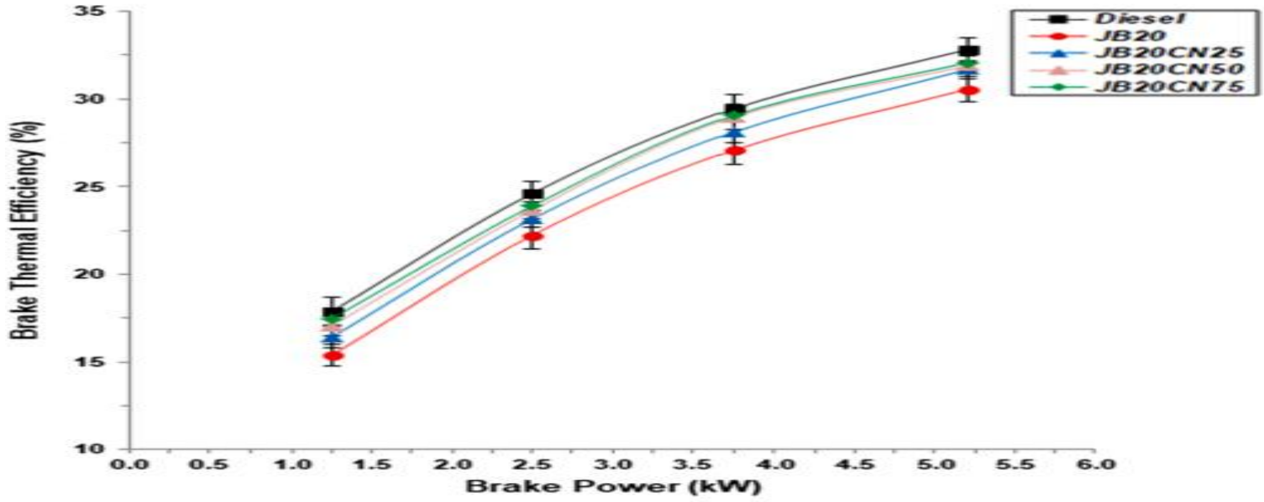


Fig.7 Variation of BTE at different blend fuels [15].

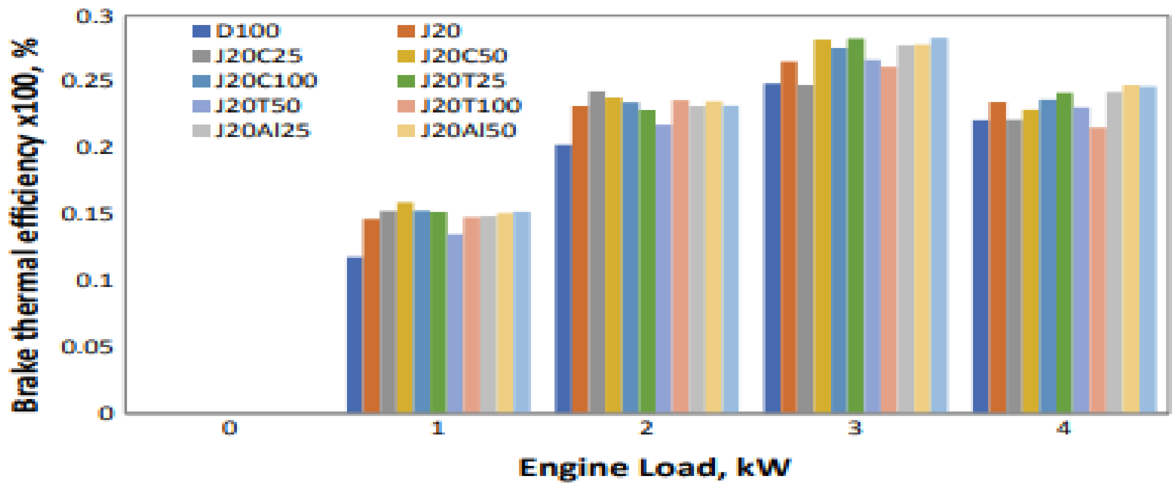
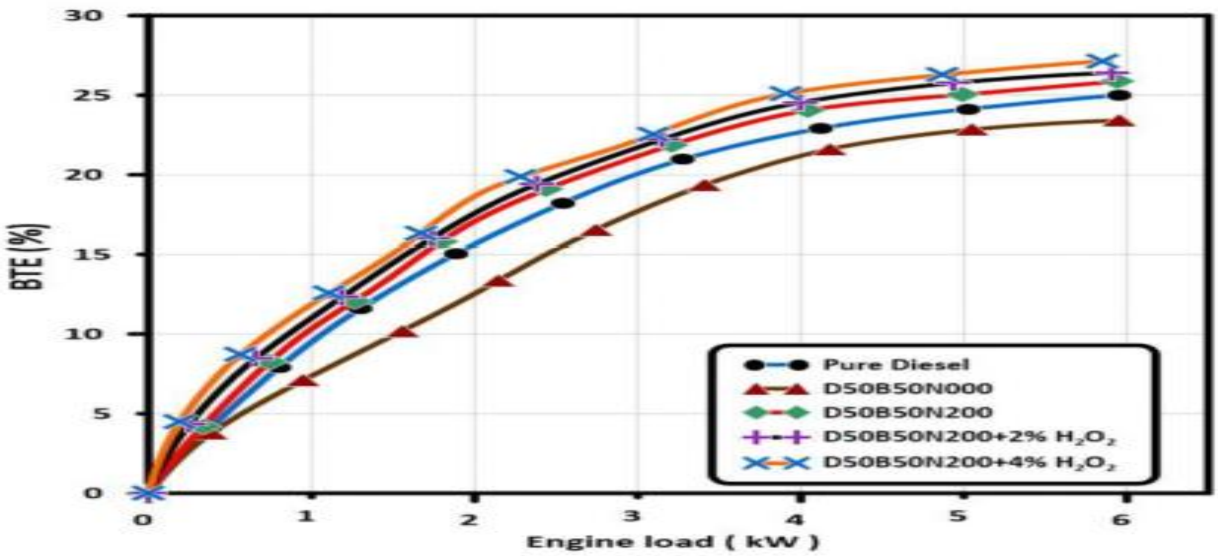


Fig.8 Variation of BTE at different loads [16].



Exhaust gas temperature (EGT)

Exhaust gas temperature is the most important index of heat release in the final stage of combustion, the higher the exhaust gas temperature, the greater the engine heat loss and the lower the brake thermal efficiency [6]. From Figure 9 that the exhaust gas temperature of biodiesel-diesel mixed fuels was higher than that of diesel, biodiesel had high viscosity and density, when mixed with diesel in the engine, it lead to poor atomization and a small amount of unburned fuel in the premixed combustion stage. These fuels continued to burn in the diffusion combustion stage, released heat and enhanced the exhaust gas temperature [13]. When Al_2O_3 nanoparticles were added to biodiesel-diesel mixed fuels as catalyst, on the one hand, the fine dispersion of nanoparticles increased the contact area ratio, increased the contact area between fuel and air, improved the fuel/air mixing ratio, improved engine efficiency and reduced the loss of exhaust heat; On the other hand, Al_2O_3 as an oxygen-containing nanoparticle, released oxygen during combustion, promoted the combustion of mixed fuel, shortened ignition delay, promoted heat transfer and reduced exhaust gas temperature during combustion [15]. S. Manigandan et al [9]. studied the effect of added TiO_2, CNT, Al_2O_3, CuO and CeO_2 nanoparticles on the exhaust gas temperature, the results were shown in Figure 10. It can be found among all mixed fuels, the heat release and calorific value of the mixed fuel added TiO_2 and CuO were higher, and the exhaust gas temperature was slightly higher; The addition of CNT nanoparticles promoted the fuel mixing ratio, the heat release rate was expanded, and CNT nanoparticles showed the lowest exhaust gas temperature. In addition, carbon nanotube nanoparticles and other oxygen-free nanoparticles reduced the oxygen content in the combustion process, and had faster heat transfer speed, which could effectively reduce the exhaust gas temperature.

Fig.9 Variation of EGT at different blend fuels [13].

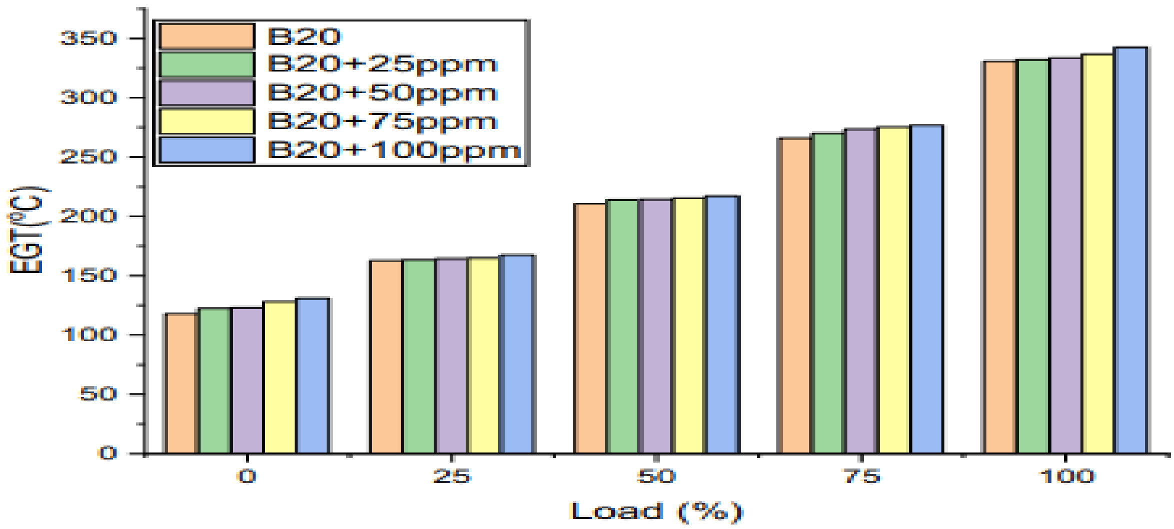
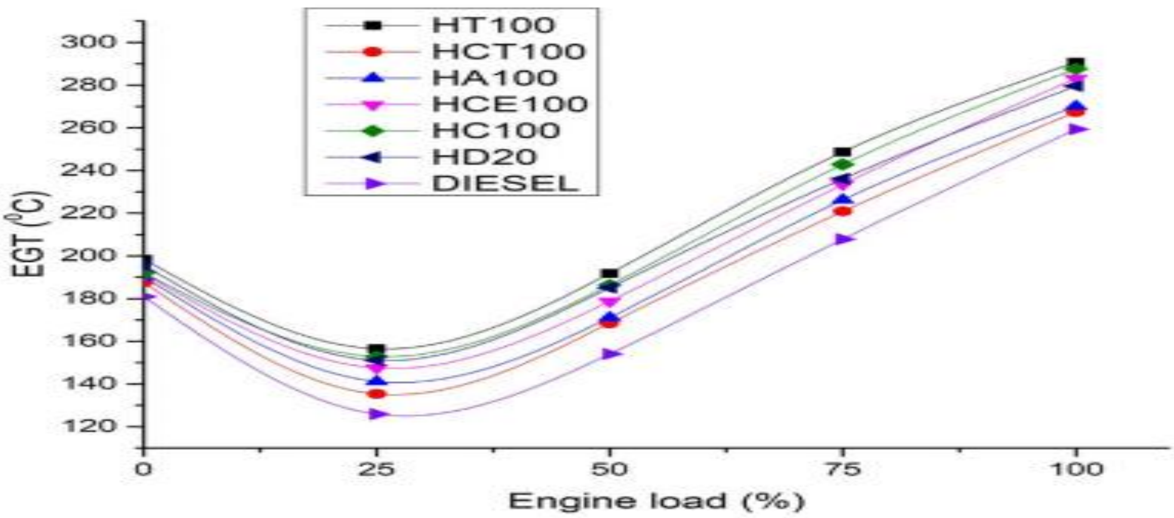


Fig.10 Variation of EGT at different blend fuels [9].



Exhaust gas emissions

The emissions of diesel engine included CO, HC, CO_2, NO_x and smoke. Generally, the use of biodiesel-diesel mixed fuels will reduce the emissions of CO, HC, CO_2 and smoke, but the emissions of NO_x will be increased, in order to further to reduce exhaust emissions, the impact of various nanoparticles additives on the emissions of biodiesel-diesel mixed fuels were be described in below:

CO emission

CO is the product of incomplete combustion, the main factors affecting CO emission are insufficient oxygen and low combustion temperature. It can be seen from Figure 11 that the CO emission of biodiesel-diesel mixed fuels were lower than that of diesel fuel, because biodiesel contained oxygen, which can promote combustion and reduce CO emission, with the addition of TiO_2 nanoparticles as additives, cetane number was increased, ignition delay was shortened, promoted complete combustion and reduced CO emission [17]. Deepak Kumar T. et al [18]. studied the impact on CO emission when adding ZnO nanoparticles to biodiesel-diesel mixed fuels, and found the same trend, the addition of ZnO nanoparticles increased the calorific value, increased the average temperature of combustion chamber, released oxygen during combustion, promoted combustion and reduced CO emission. When CNT nanoparticles were added to biodiesel-diesel mixed fuels, increased the contact area ratio, promoted complete combustion and reduced CO emission [6].

AWith the addition of CNT nanoparticles, the contact area ratio increased, which promoted better atomization and better mixing, enhanced the fuel combustion process and reduced CO emission.

Figure 12 showed the relationship between CO emission and engine load, with the increase of load, CO emission showed an increasing trend [9]. With the increase of load, the amount of fuel injectionwas increased, resulting in fuel rich area, incomplete combustion and increased CO emission. Tawfik Badawy et al [6]. found that the CO emission decreased with the increase of load. As shown in Figures 11 and 13, with the increase of engine load, the oxidation reaction rate of CO increased with the increase of combustion temperature, and decreased the CO emission.

Fig.11 Variation of CO at different blend fuels and loads [17].

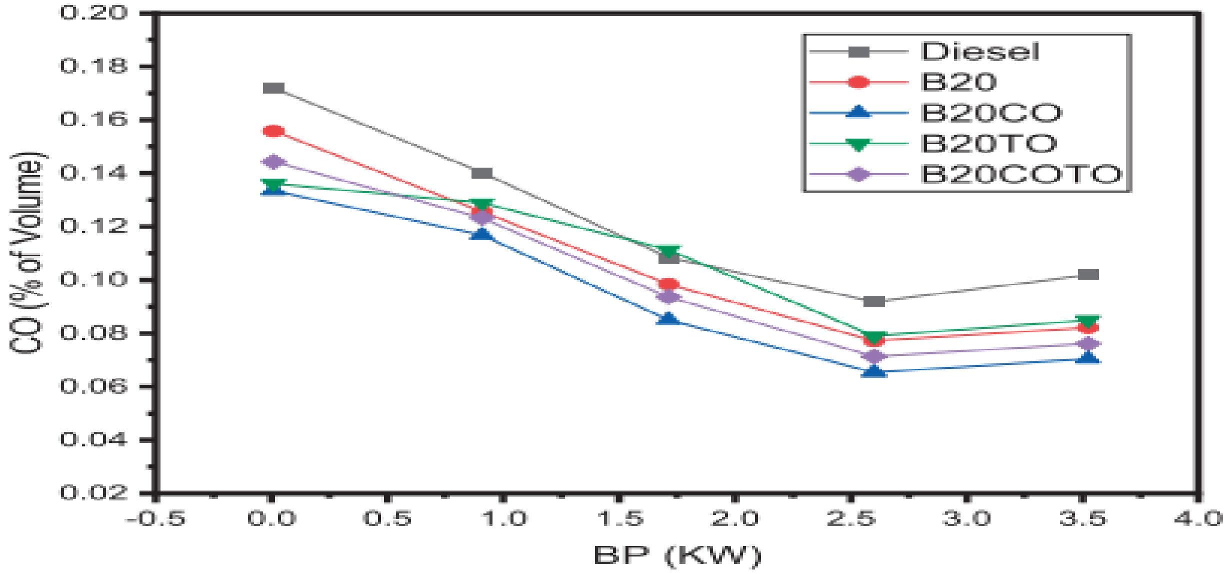


Fig.12 Variation of CO at different loads [9].

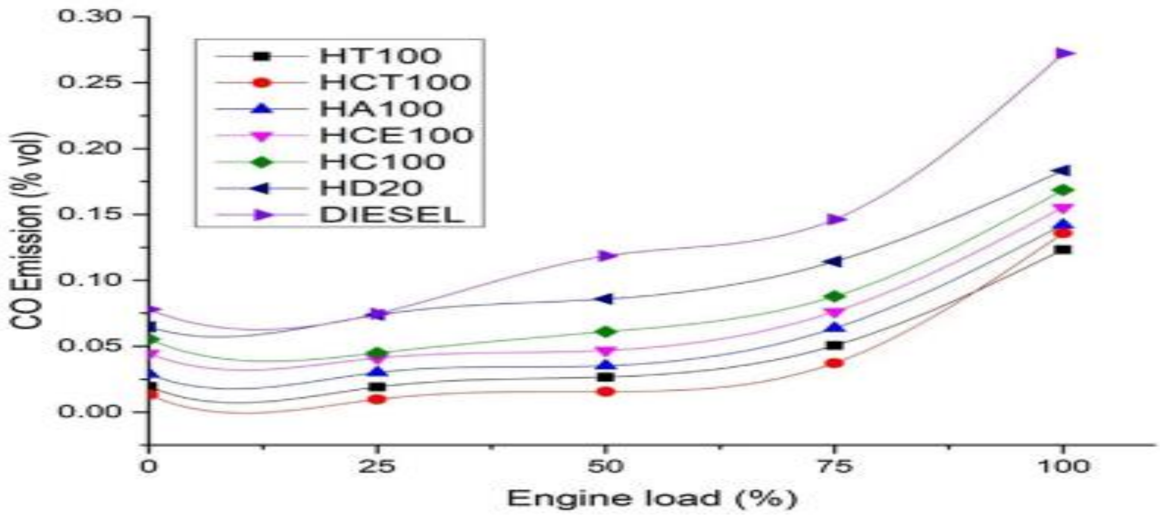
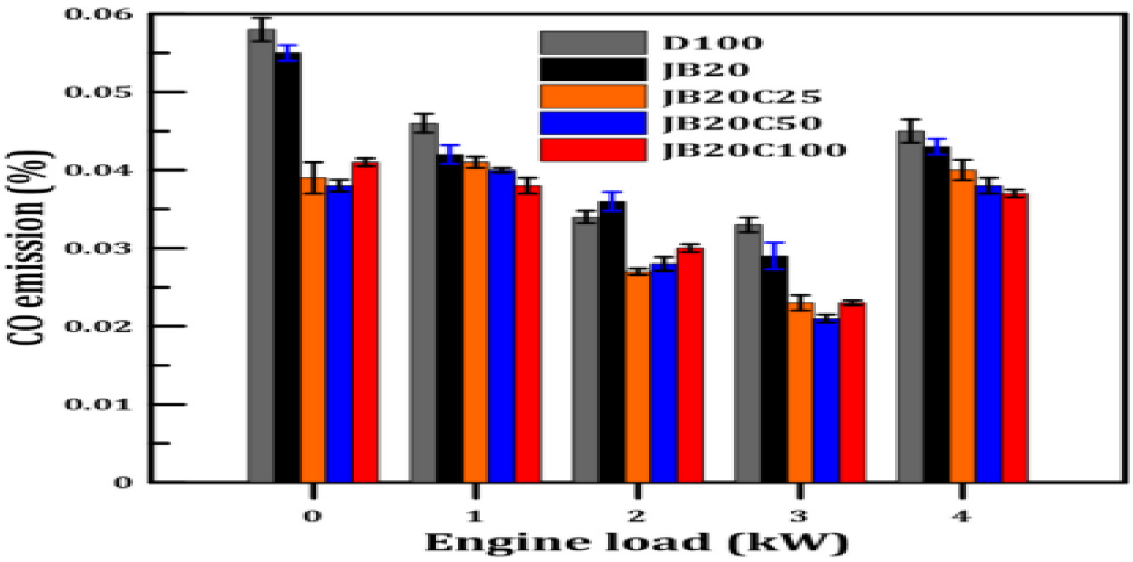


Fig.13 Variation of CO at different loads [6].



HC emission

The emission of HC was similar to that of CO, and the product of incomplete combustion. As shown in Figure 14, with the addition of CuO nanoparticles, the fuel/air mixture was uniform, the contact area ratio was increased, and oxygen was released during combustion to promote the oxidation reaction of HC, therefore, compared with biodiesel-diesel mixed fuels, the fuels with nanoparticles showed lower HC emission, and with the increase of CuO nanoparticles addition ratio, the lower the HC emission [4]. Mani ghanbari et al [19]. found that the addition of nanoparticles increased the flame propagation speed, improved the combustion process, promoted complete combustion and reduced HC emission. S. Sunilet al [3]. found that the viscosity of mixed fuel added with TiO_2 nanoparticles increased, decreased the calorific value, resulting in incomplete combustion, therefore, appropriate nanoparticles could reduce HC emission, and excessive addition of nanoparticles would weaken the effect of reducing HC emission, as shown in Figure 15. Figure 16 showed the change trend of HC emission and load, found that the HC emission of all test fuels was lower at low load and increases at higher load, which was related to more injected fuel and less oxygen availability at higher load, in addition, higher viscosity and low volatility at higher load lead to weakening of air/fuel mixing effect, incompleted combustion and increased of HC emission [15].

Nanoparticles played an important role in the HC emission of biodiesel-diesel mixed fuels, on the one hand, with the addition of nanoparticles, the ignition delay was shortened, the premixing time was reduced, and the duration of diffusion combustion phase was increased, the fuel was mixed and burned in the diffusion combustion stage, so as to improve the combustion process and reduced HC emission; On the other hand, appropriate nanoparticles had a great impact on reducing HC emission, with the addition of nanoparticles beyond the critical point, the viscosity of mixed fuel will increase and HC emission would increase, but HC emission was still lower than that of pure diesel.

Fig.14 Variation of HC at different blend fuels [4].

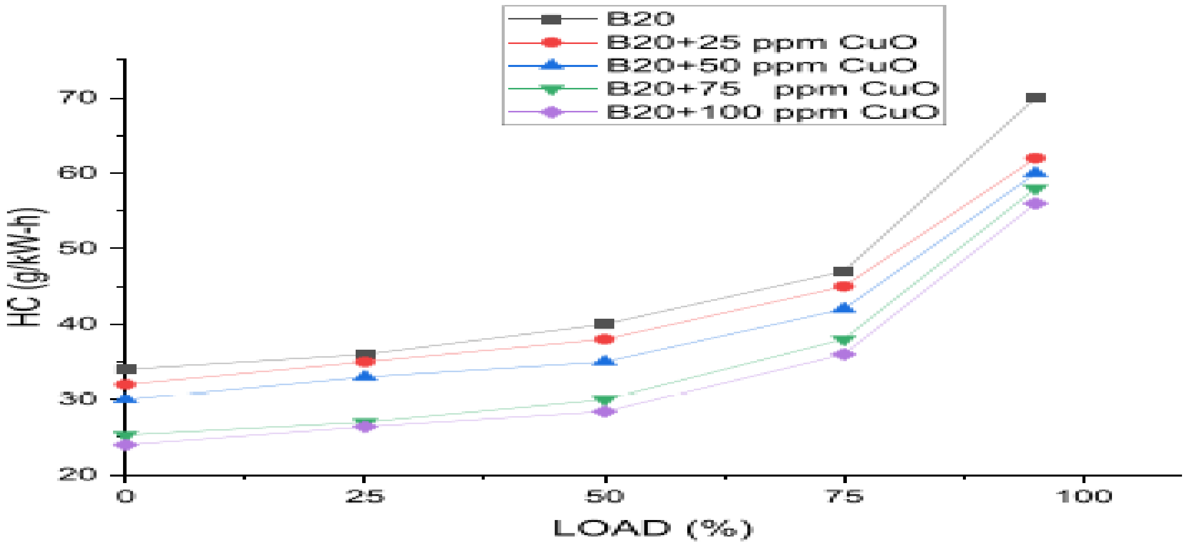


Fig.15 Variation of HC at different blend fuels [3].

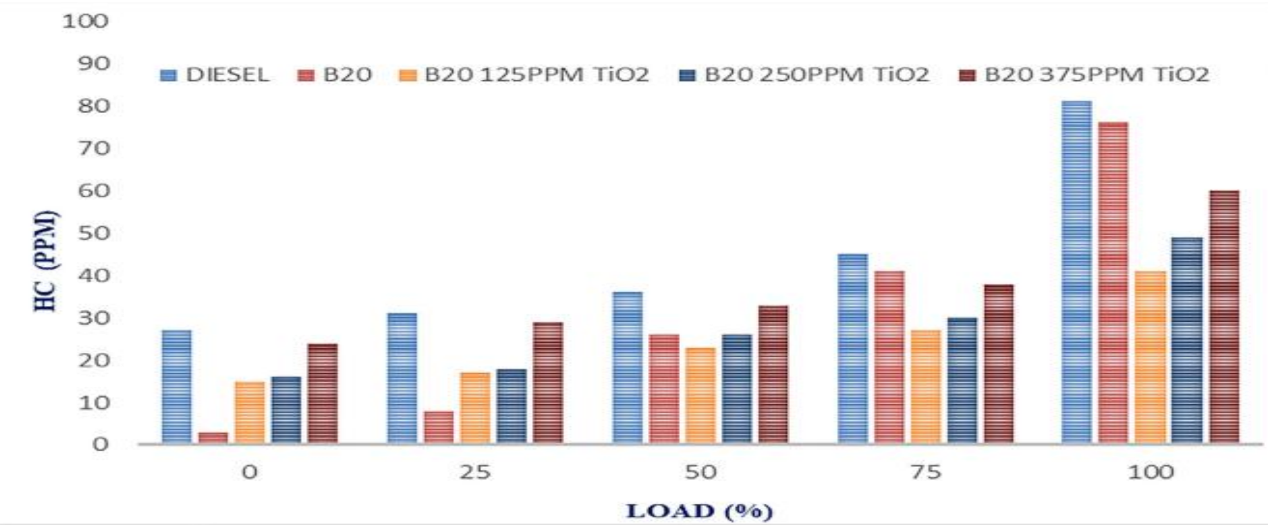
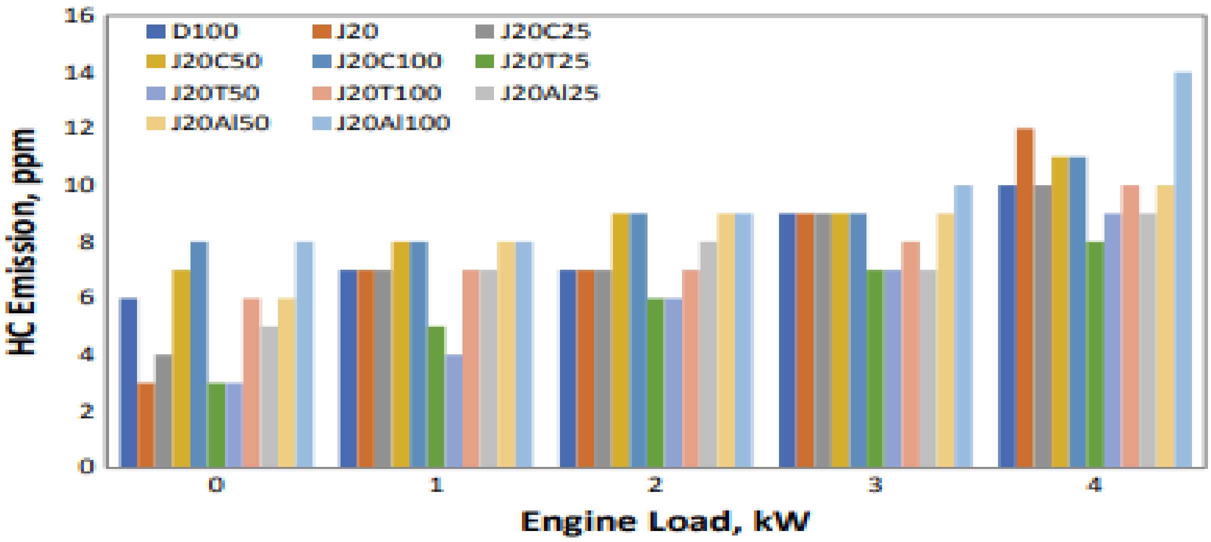


Fig.16 Variation of HC at different loads [15].



NO_x emission

NO_x emission is related to the oxygen content of the fuel combustion and the combustion temperature, excess oxygen atoms reacted with nitrogen atoms to generate NO_x, the higher the combustion temperature of the fuel, the higher the NO_x emission [20]. When NO_x came into contact with sunlight, it would produce smoke and pollute the atmosphere, in addition, $NO_x$was also the main substance of acid rain [21]. Tawfik Badawy et al [6]. studied the effect of CNT nanoparticles on biodiesel-diesel mixed fuels, it can be found from Figure 17 that when CNT carbon nanotubes were added, improved convective heat transfer, acting as a radiator, reduced in-cylinder temperature and reduced NO_x emissions. As shown in Figure 18, S. Manigandan et al [9]. compared the effects of TiO_2, CNT, Al_2O_3, CuO and CeO_2 nanoparticles on NO_x emission, when Al_2O_3 and CuO nanoparticles were added, oxygen was released during combustion processes, promoted cylinder combustion, increased the combustion temperature, and increased NO_x emissions; When CNT nanoparticles were used as additives, the heat transfer rate was effectively improved, the exhaust gas temperature was relatively low. M. S. GAD et al [15]. studied the effects of TiO_2, CNT and Al_2O_3 nanoparticles on emissions and showed the same NO_x emission trend. Figure 19 described the impact of load on Al_2O_3 nanoparticle-biodiesel-diesel mixed fuels, with the increase of load, in order to maintain the engine output power, the fuel consumption increased, resulting in the increase of combustion chamber temperature and NO_x emission [2].

With the addition of CNT, GNP and other nanoparticles shortened the ignition delay, lengthened the diffusion combustion stage, burned the fuel while mixing in the combustion chamber, the combustion temperature was relatively low, and reduced the NO_x emission; compared with oxygen-containing nanoparticles, oxygen-free nanoparticles (CNT, GNP, AgSCN etc.) reduced the oxygen necessary for the formation of NO_x and effectively reducedNO_x emissions.

Fig.17 Variation of NO_x at different blend fuels [6].

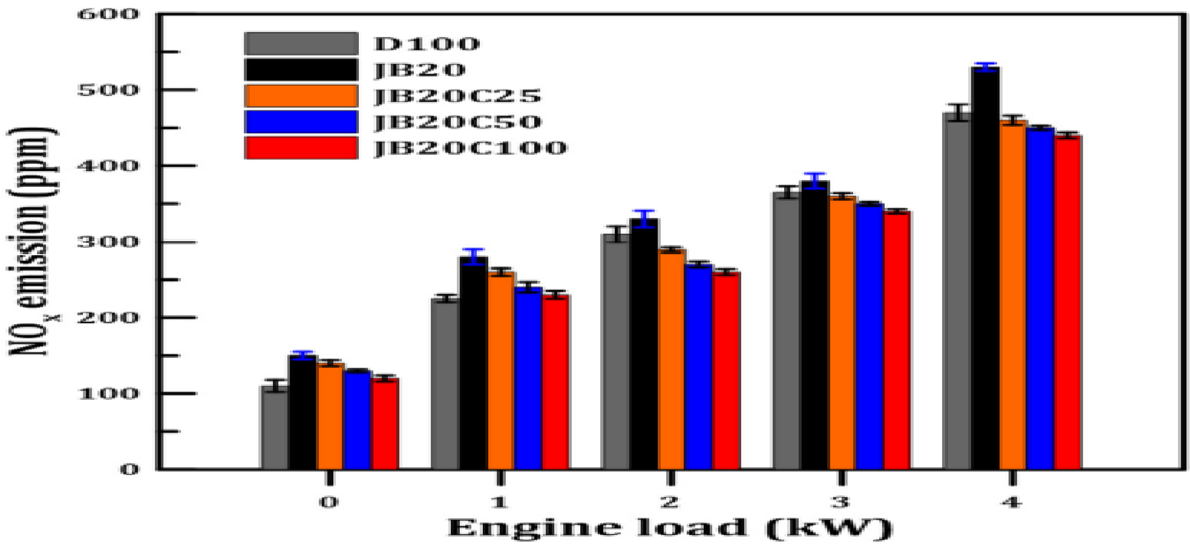


Fig.18 Variation of NO_x at different blend fuels [9].

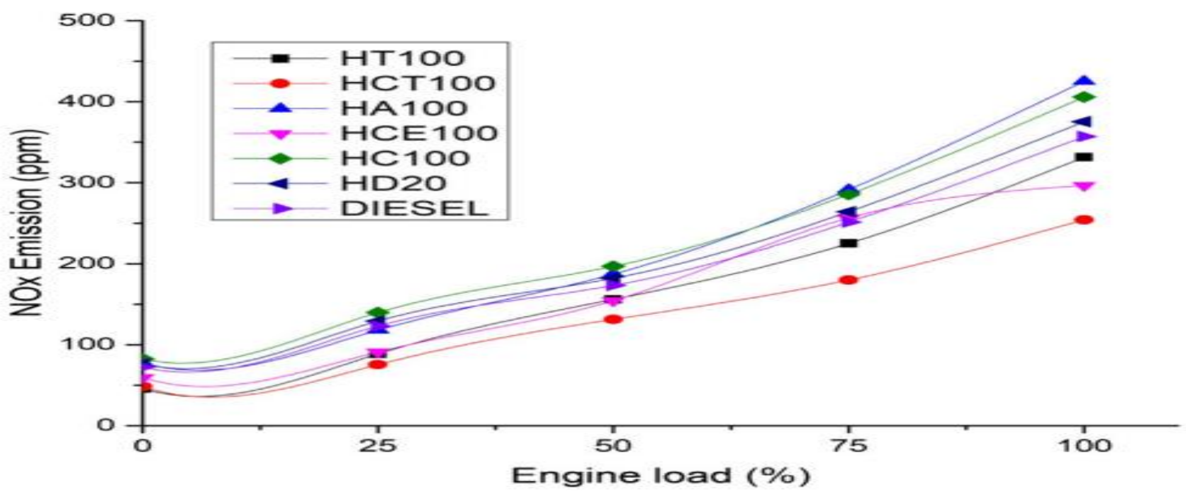
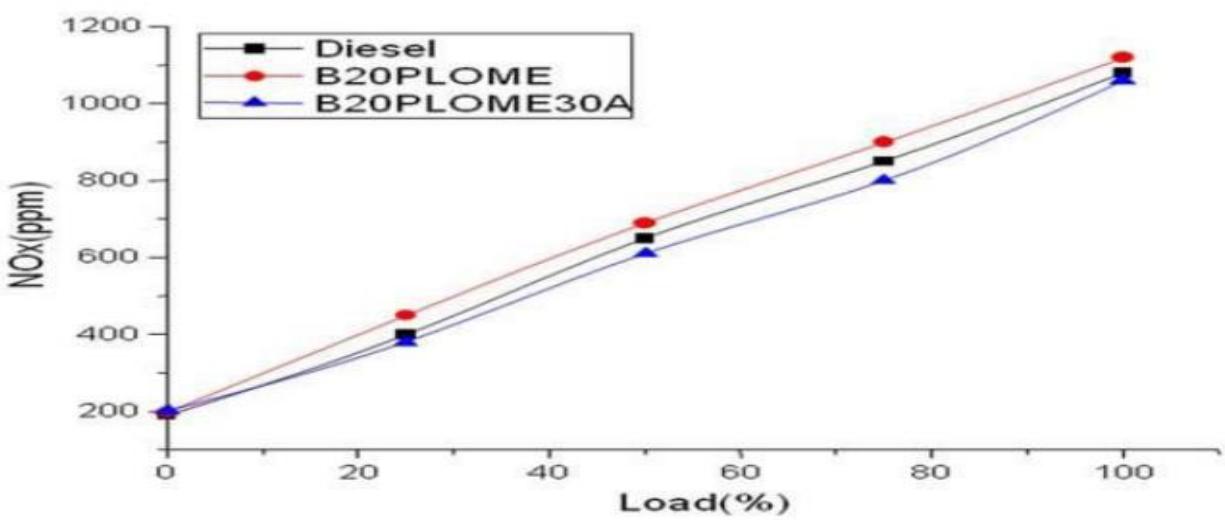


Fig.19 Variation of NO_x at different loads [2].



CO_2 emission

CO_2 emission is the product of complete combustion in the engine cylinder [11]. Medhat Elkelawy et al [16]. studied the impact of AgSCN nanoparticles on engine emissions, as shown in Figure 20, biodiesel promoted combustion and increased CO_2 emissions due to its high oxygen content and low C/H ratio, the addition of nanoparticles shortened the ignition delay, improved the combustion efficiency, promoted complete combustion, and increased CO_2 emissions. Pankaj Mohan Rastogi et al [11]. studied the CO_2 emission of CuO nanoparticles-biodiesel-diesel mixed fuels and found the same emission trend, as shown in Figure 21.

When CuO and other nanoparticles were added to biodiesel-diesel mixed fuels, improved the fuel atomization, increased the combustion chamber temperature, improved the combustion efficiency, and promoted the conversion of CO to CO_2, increased CO_2 emissions.

Figure 22 showed the variation trend of CO_2 emission level of various experimental fuels with load, the results showed that CO_2 emission increases with the increase of load, because the increased of load leads to the increased of fuel consumption and cylinder temperature, promoted the complete combustion of fuel and increases CO_2 emission [6].

Fig.20 Variation of CO_2 at different blend fuels [16].

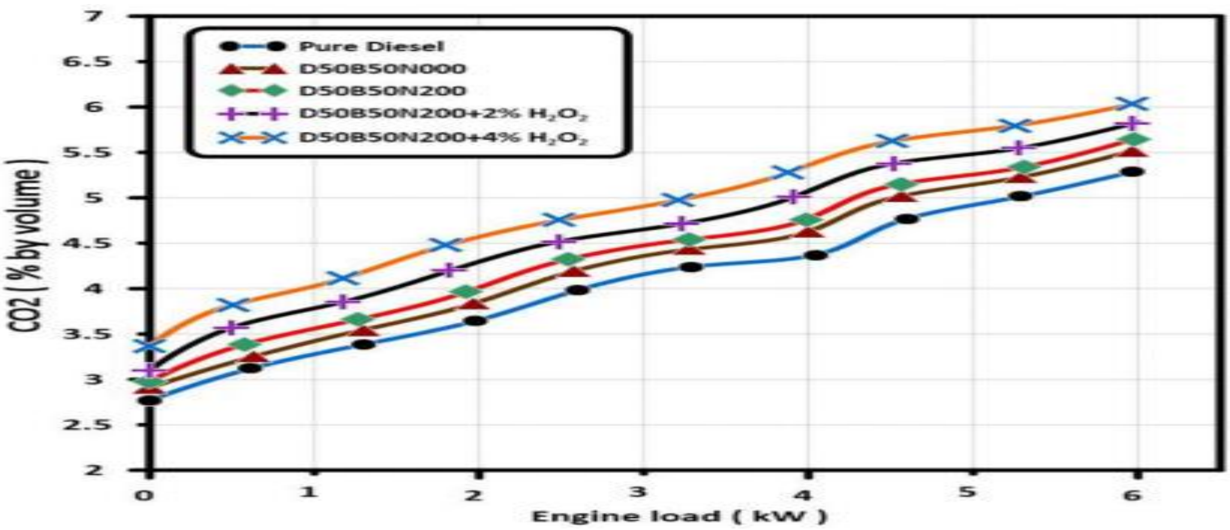


Fig.21 Variation of CO_2 at different blend fuels [11].

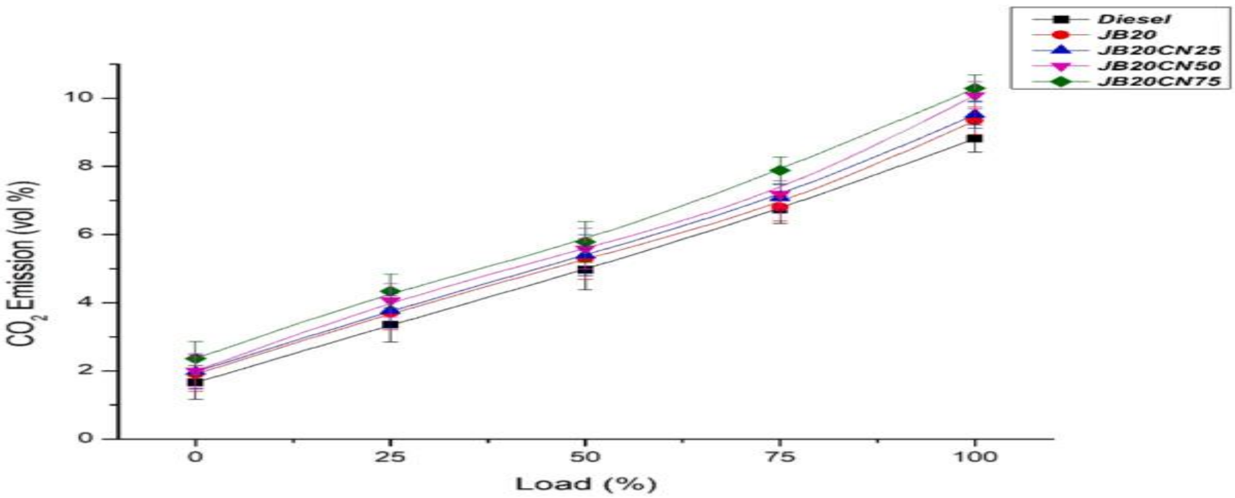
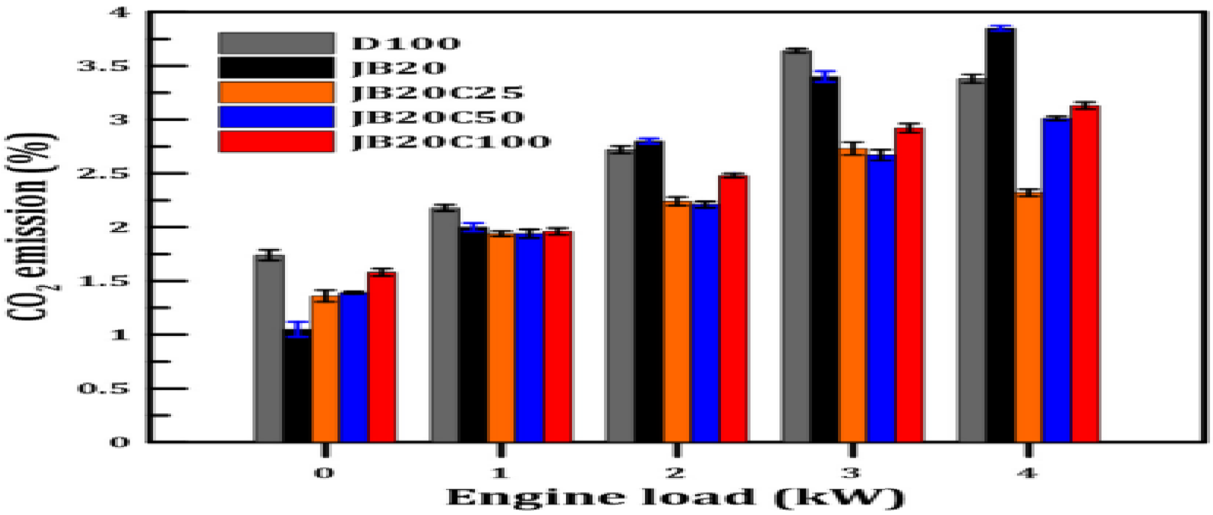


Fig.22 Variation of CO_2 at different loads [6].



Smoke emission

Smoke is caused by local hypoxia and incomplete combustion during engine combustion, the best way to reduce smoke emission to promote the mixing ratio of mixed fuel to air and provide sufficient oxygen [22]. As shown in Figure 23, Ramesh D. K.et al [2]. found that biodiesel-diesel mixed fuels have high viscosity, poor volatility of fuel droplets and poor mixing effect with air, so the smoke emission was higher than diesel fuel. Deepak Kumar T. et al [18]. studied the effect of ZnO nanoparticles on smoke emission and found the addition of nanoparticles increased the content of oxygen and sulfur, promoted combustion and reduced smoke emission. From Figure 24 found that when CuO nanoparticles were mixed with biodiesel-diesel, they had high contact area ratio, improved the mixing ratio of fuel, enhanced evaporation, shortened ignition delay and reduced smoke emission [4]. Tawfik Badawy et al [6]. studied the impact on smoke emission when using CNT nanoparticles under different engine loads, with the increased of engine load, the smoke emission of all test fuels showed an increasing trend, as shown in Figure 25, the increase of engine load lead to the increase of fuel consumption, thus forming a rich combustion area, incomplete combustion and smoke emission; But with the increased of carbon nanoparticles, the smoke emission was showed an downward trend. Oxygen-free nanoparticles, carbon nanoparticles cannot release oxygen to improve combustion, but improved the contact area with fuel, improved the volatility of fuel and reduced smoke emission.

Fig.23 Variation of smoke at different blend fuels [2].

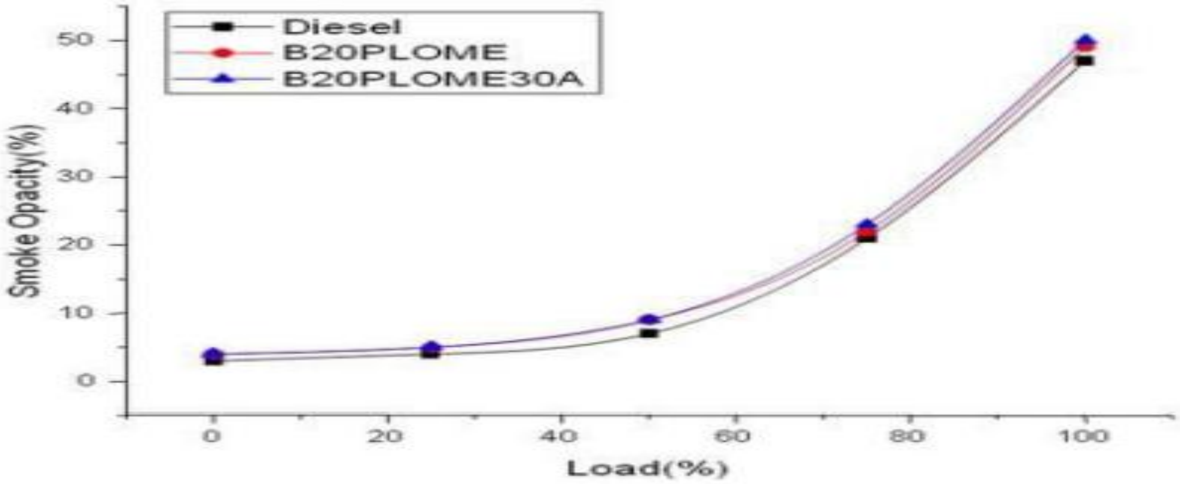


Fig.24 Variation of smoke at different blend fuels [4].

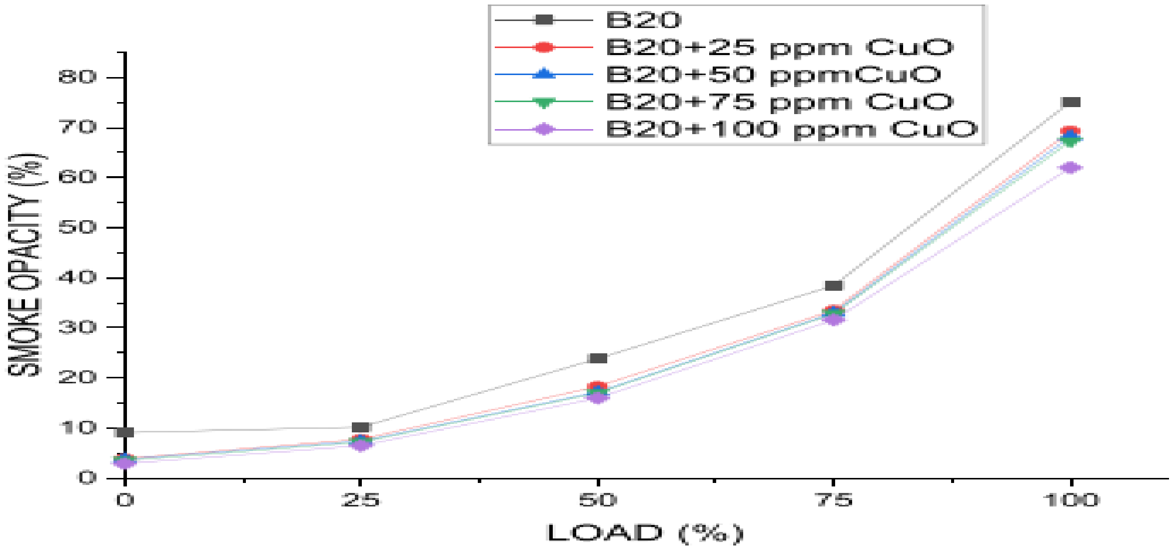
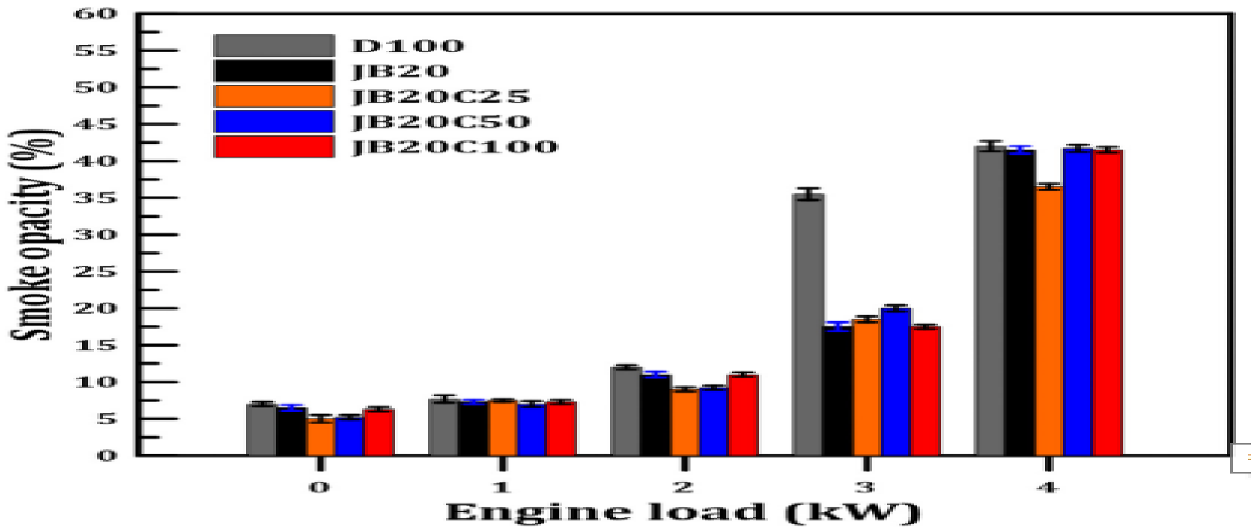


Fig.25 Variation of smoke at different loads [6].



Conclusions

With the consumption of traditional fuel and the aggravation of environmental damage, using biodiesel as a substitute fuel can reduce emissions and environmental damage, adding nanoparticles to biodiesel-diesel mixed fuels can effectively improve engine combustion performance and reduce exhaust emissions.

1. Nanoparticle-biodiesel-diesel mixed fuels can be used directly without changing the existing engine structure, compared with biodiesel-diesel, the mixed fuels engine with nanoparticle had better combustion performance and lower exhaust emissions.
2. Compared with biodiesel-diesel, the use of biodiesel-diesel mixed fuels with nanoparticles can increase cylinder pressure, improve exhaust gas temperature and brake thermal efficiency, and reduce brake specific fuel consumption. Moreover, the mixed fuels with nanoparticles further reduced the emissions of CO, HC and NO_x, but the CO_2 emission was increased. Although both oxygen-containing nanoparticles and oxygen-free nanoparticles can reduce NO_x emissions, oxygen-free nanoparticles reduce the oxygen necessary for NO_x generation, therefore, compared with oxygenated nanoparticles, when using oxygen-free nanomaterials, reducedNO_x emissions significantly. There is no significant difference between the use of oxygen-containing nanoparticles and oxygen-free nanoparticles on the improvement of engine performance and emissions. Therefore, oxygen-free nanoparticles have greater advantages than oxygen-containing nanoparticles.
3. With the increase of engine load, the brake thermal efficiency, exhaust gas temperature, cylinder pressure, HC, NO_x, CO_2 and smoke all were showed an upward trend, while the brake specific fuel consumption was decreased. On the one hand, caused local hypoxia and increased CO emission; On the other hand, the oxidation reaction rate increased with the increase of temperature, and reduced CO emission.

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CONFLICTS OF INTEREST

The authors have no conflicts of interest to declare.

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