
CHAPTER 5

ANALYSIS OF DIESEL ENGINE ENERGY, EXERGY, AND EMISSION PARAMETERS WITH OPB, SOB, WiDE & NANO

FUELS

The experimental outcomes have been noted to varying engine power and engine speed with five different sets of fuel samples mentioned below:

- Diesel, OPB10, OPB20, and OPB30 fuel
- Diesel, SOB10, SOB20, and SOB30 fuel
- Diesel, WiDE5, WiDE10, and WiDE15 fuel
- Diesel, 5% water emulsified OPB20, 5% water emulsified Al_2O_3 incorporated OPB20, and 5% water emulsified CNT incorporated OPB20 fuel.
- Diesel, 5% water emulsified SOB20, 5% water emulsified Al_2O_3 incorporated SOB20, and 5% water emulsified CNT incorporated SOB20 fuel.

In this chapter, The performance parameters, i.e., BTE, exergy efficiency, BSFC, exhaust gas temperature, engine sustainability, exergy destruction rate, and entropy generation rate, and emissions attributes, i.e., HC, CO, CO_2 , NO, and smoke opacity variation of different fuel samples against engine power and engine speed was discussed for various set of fuel shown above.

5.1 Analysis of Diesel Engine Performance and Emission Parameters Fuelled with OPB Blended Fuel

5.1.1 Effect of Engine Power, Engine Speed, and OPB Blending on BSFC and BTE

Fig.5.1 illustrates the engine BSFC variation of different fuel samples with engine power and speed. The engine BSFC with each fuel reduces with increasing engine power and speed. Engine BSFC is the function of brake power and fuel consumption rate; as engine power increases at a constant speed, the mechanical efficiency of the engine increases while indicated fuel conversion efficiency first increases to an optimum value and then reduces. The increased mechanical efficiency and indicated fuel conversion efficiency reduce engine BSFC and reduced indicated fuel conversion efficiency enhances engine BSFC. The engine BSFC decreases with an increase in engine power at a constant speed because of dominating mechanical efficiency factor over indicated fuel conversion efficiency factor. The engine BSFC with an increase in engine speed at constant engine power reduces insignificantly. With an increase in engine speed at constant engine power time for heat losses reduce which reduces engine BSFC, while engine friction losses increase which reduces engine BP and increases engine BSFC. Also, with an increase in engine speed at constant engine power fuel consumption rate and air breathing rate both increase which provides better fuel combustion in the engine cylinder. Due to the better fuel combustion efficiency, and reduced heat losses the engine BSFC is observed reduced with an increase in engine speed at constant engine power. BSFC of the engine is observed increasing with an increasing blend of biofuel in diesel because of higher kinematic viscosity and lowering the calorific value of blended fuel compared to fuel which led to injecting a higher quantity of fuel during the mixing fuel combustion process to meet the same power output as diesel fuel and found highest for 30% OPB diesel blend fuel at each

engine power and speed. The BSFC of the engine with OPB10, OPB20, and OPB30 fuel blends is 2.23%, 1.69%, and 3.70% higher than the diesel fuel, respectively, at 5.5kW of engine power and 1500 rpm speed condition. The effect of engine speed variation on BSFC is lower than that of engine power.

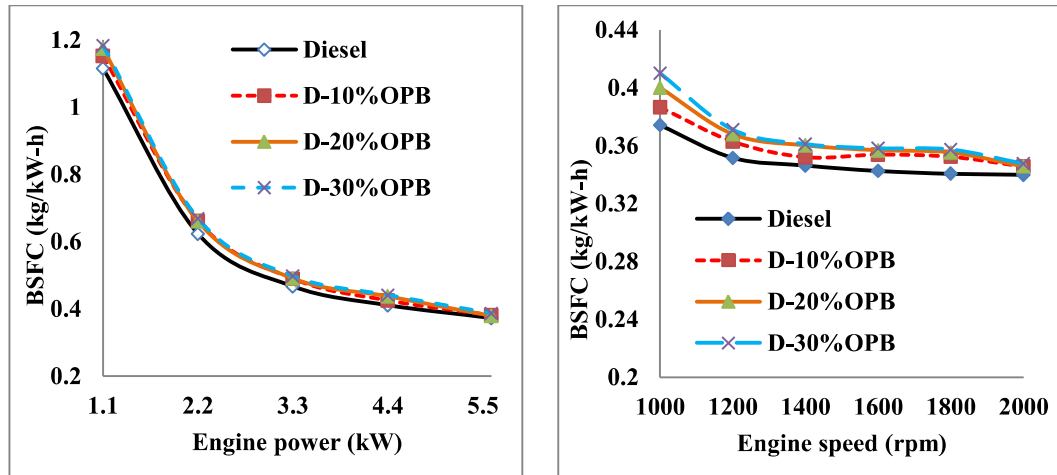


Figure 5.1 BSFC variations versus engine power and speed with OPB blended to diesel

Fig.5.2 illustrates the engine BTE variation of different fuel samples with engine power and speed. The engine BTE is the function of brake power and thermal energy input; as engine power at constant speed increases mechanical efficiency of the engine improves, and the indicated fuel conversion efficiency enhances due to the fuel energy required to produce one unit of brake power reducing and BTE efficiency increasing. With an increase in engine power at constant engine speed, the fuel-air ratio increases, this improves the combustion phenomenon inside the cylinder and is also beneficial for engine BTE. The increase in engine speed at constant load enhances the frictional power which reduces engine BTE and the utilization of fuel energy increases by diminishing the heat losses to surroundings which increases engine BTE; due to that,

growth in engine BTE is insignificant. The engine BTE with OPB10, OPB20, and OPB30 diesel blend fuels have been observed to be lower than diesel fuel due to the higher fuel viscosity, larger fuel droplet size, and lower fuel atomization rate of biodiesel blended fuel than diesel fuel. The BTE of the engine with OPB10, OPB20, and OPB30 diesel blend fuels is 4.14%, 7.25%, and 10.73% lower than diesel fuel, respectively, at 5.5kW engine power and 1500 rpm speed condition. The effect of engine speed variation on engine BTE is lower than the variation of engine power.

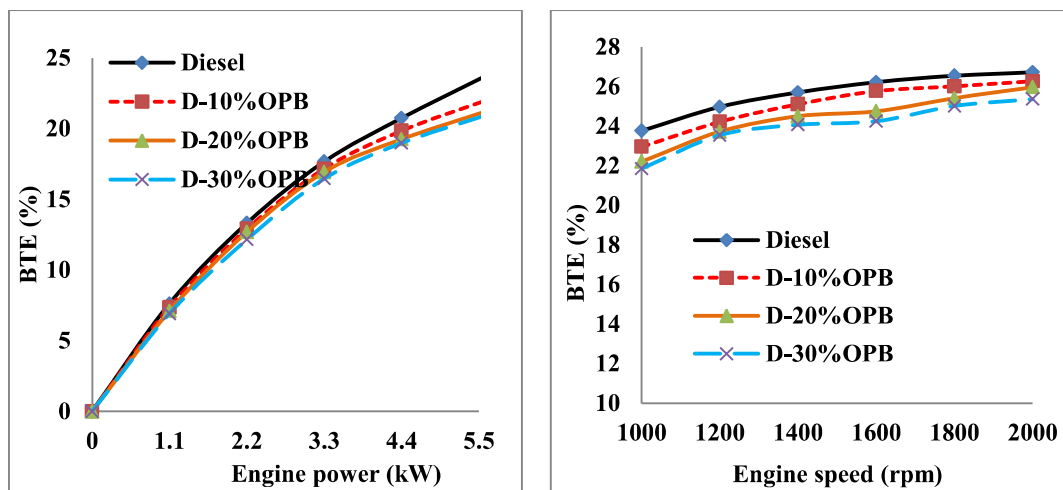


Figure 5.2 BTE variation versus engine power and speed with OPB blended fuel

5.1.2 Effect of Engine Power, Engine Speed, and OPB Blending on Exergy

Efficiency and Exhaust Gas Temperature

Fig.5.3 illustrates the engine exergy efficiency variation of different fuel samples with engine power and speed. The engine exergy efficiency is the function of available brake power and fuel exergy rate; as engine power at constant speed increases, exergy efficiency increases due to a significant increase in brake power due to increased mechanical efficiency. The fuel exergy rate depends upon the fuel combustion rate, fuel combustion efficiency, and calorific value of the fuel. With the

increase in engine power fuel consumption rate and fuel combustion efficiency increases which increases the fuel exergy rate. The rate of increase of brake power is observed higher compare to the rate of increase in fuel exergy rate, due to which exergy efficiency is observed to increase with engine power.

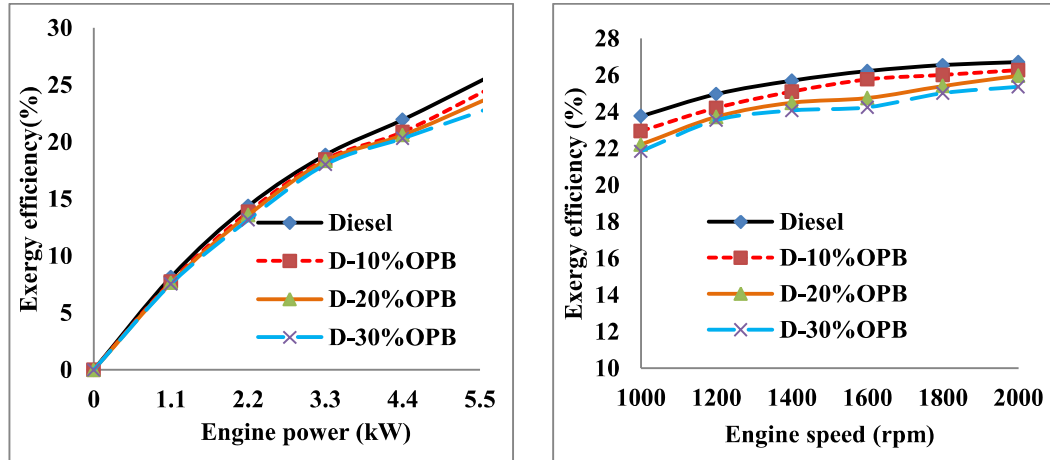


Figure 5.3 Exergy efficiency variation versus engine power and speed with OPB blended fuel

The engine exergy efficiency is observed to be higher than the BTE due to the lower combustion efficiency and lower fuel exergy rate to the fuel energy rate. The engine exergy efficiency with OPB10, OPB20, and OPB30-diesel blend fuels have been observed to be lower than the diesel fuel due to the higher fuel viscosity, larger fuel droplet size, and lower fuel atomization rate of biodiesel blended fuel than diesel fuel. The exergy efficiency of the engine with OPB10, OPB20, and OPB30 diesel blend fuels is 7.34%, 10.65%, and 11.75% lower than diesel fuel, respectively, at 5.5kW engine load and 1500 rpm speed conditions.

Fig.5.4 illustrates the engine exhaust gas temperature variation of different fuel samples with engine power and speed. The engine exhaust gas temperature with each

fuel escalates with escalating engine power at a constant speed and with escalating engine speed at constant power because with escalating engine speed and power, the rate of fuel utilization escalates due to a higher equivalence ratio and improved combustion phenomenon inside engine cylinder, and fuel energy rate with each fuel escalates. The engine exhaust gas temperature with OPB10, OPB20, and OPB30-diesel blend fuels have been observed to be higher than the diesel fuel due to the higher fuel energy rate of OPB blend fuels. The fuel energy rate with biofuel blending enhances due to the reduction of ignition delay period and fuel consumption rate due to higher fuel cetane number, viscosity, and lower fuel atomization rate. The exhaust gas temperature of the engine with OPB10, OPB20, and OPB30 diesel blend fuels is 1.02%, 5.03%, and 6.05% higher than diesel fuel, respectively, at 5.5kW engine power and 1500 rpm speed condition.

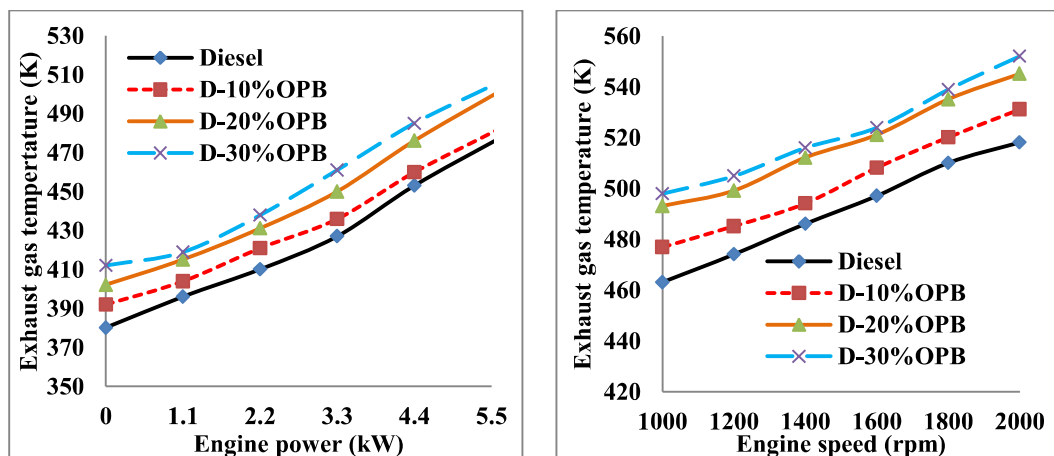


Figure 5.4 Exhaust gas temperature variation versus engine power and speed with OPB fuel

5.1.3 Effect of Engine Power, Engine Speed, and OPB Blending on Exergy

Destruction Rate and Engine Sustainability Index

The influence of engine power and speed on the exergy destruction rate and engine sustainability has been presented in Fig.5.5 and Fig.5.6, respectively. The growth in engine power and engine speed ascribes more thermodynamic irreversible processes such as mechanical friction, mixing of fuel and air at high speed and power, heat transfer, and chemical reaction; due to that, the exergy destruction rate enhances with an increase in the engine power and speed. The engine BSFC and the fuel's calorific value affect the exergy destruction rate. The fuel burning rate of diesel fuel is lower than OPB blend fuels due to the higher ignition lag period of diesel fuel, due to which the exergy destruction with standard diesel fuel is found to be 19.10%, 17.09%, and 6.91% lower than OPB30, OPB20, and OPB10 at 5.5kW engine power and 1500 rpm speed condition.

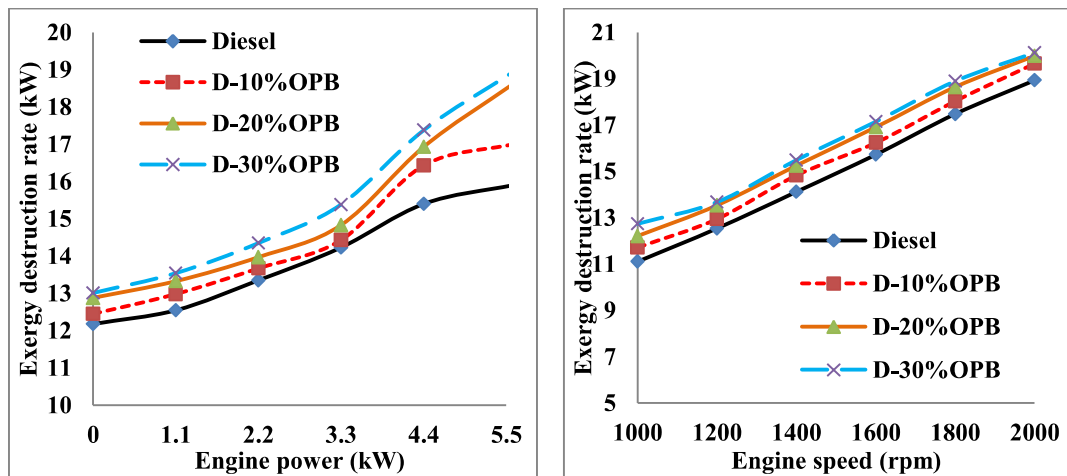


Figure 5.5 Exergy destruction rate variation versus engine power and speed with OPB blended fuel

Moreover, the sustainability index is a direct function of exergy efficiency. The sustainability index enhances if either available energy increases at a constant fuel

exergy rate or for constant available energy, fuel exergy rate reduces. The engine sustainability improves with an increase in engine power due to the reduction in the fuel exergy rate for constantly available energy. The fuel properties, i.e., viscosity and calorific value affect the engine's sustainability. However, the calorific value reduces, the viscosity value increases and the engine sustainability reduces with an increase in OPB blend proportion in standard diesel fuel. The engine sustainability with standard diesel fuel has 3.51%, 3.20%, and 2.21%, higher values than OPB30, OPB20, and OPB10 fuel blends, respectively, at 5.5kW engine power and 1500 rpm speed conditions.

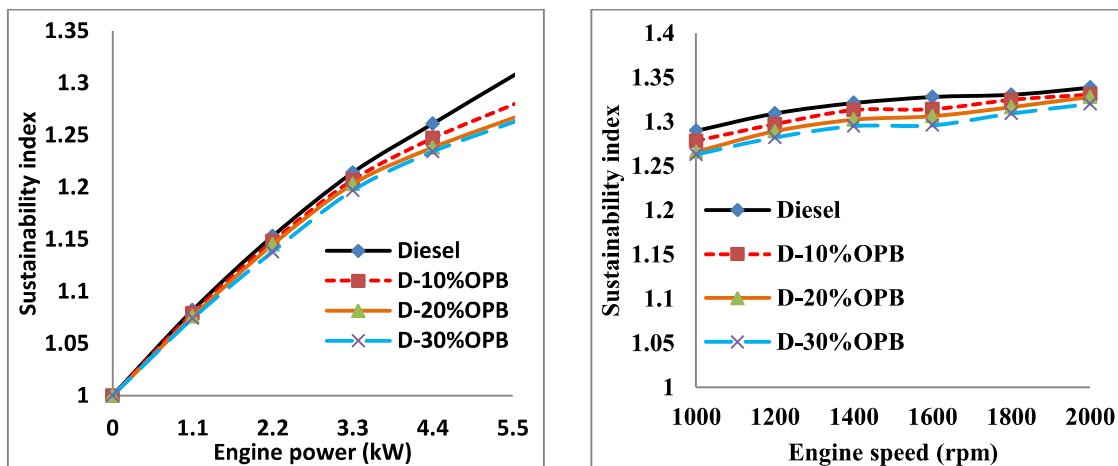


Figure 5.6 Engine sustainability index variation versus engine power and speed with OPB fuel

5.1.4 Effect of Engine Power, Engine Speed, and OPB Blending on Entropy

Generation Rate and HC Emissions

The influence of engine speed and power on the entropy generation rate is illustrated in Fig.5.7. The engine entropy generation rate is a function of the exergy destruction rate due to irreversibility. The entropy generation rate increased with engine power and speed because the exergy destruction rate rose. The entropy generation rate

with standard diesel fuel has 19.10%, 17.09%, and 6.91% higher values than OPB30, OPB20, and OPB10 fuel blends, respectively, at 5.5kW engine power and 1500 rpm speed conditions.

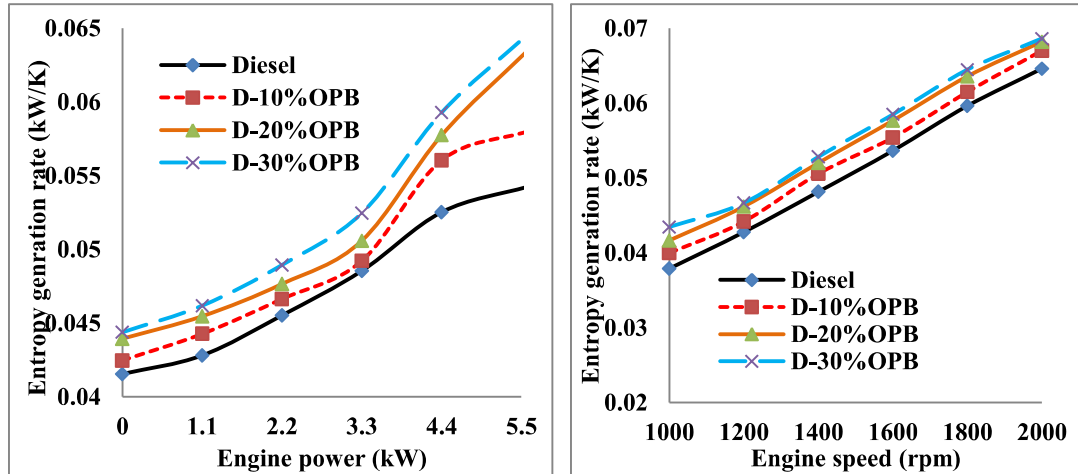


Figure 5.7 Entropy generation rate variation versus engine power and speed with OPB fuel

The effect of engine power and speed on HC emissions has been presented in Fig.5.8. The HC emission with each fuel sample enhances by escalating the engine power and speed. With the escalation of engine power at constant speed fuel supply rate increases, while the air supply rate remains constant, due to the rich mixture is supplied in the cylinder incomplete combustion of fuel increases and HC emissions increase. With the escalation of engine speed at constant power both fuel and air supply rates enhance, but the reduced time between fuel injection and exhaust gas exit increases the incomplete combustion, and HC emissions increase. The blending of biofuel in diesel reduces HC emissions due to the availability of a higher oxygen level with biofuel. The oxygen-rich biofuels provide post-flame oxidation and higher flame speed throughout the air-flame interaction process. The cetane number also plays an important role in the fuel ignition process. The higher value of cetane number of biofuel blends provides

better fuel combustion due to a shorter ignition delay period, reducing the HC emissions. It is observed from the experimental results that HC emissions reduced up to 20% of OPB blending in diesel, and beyond this, HC emissions are found, HC

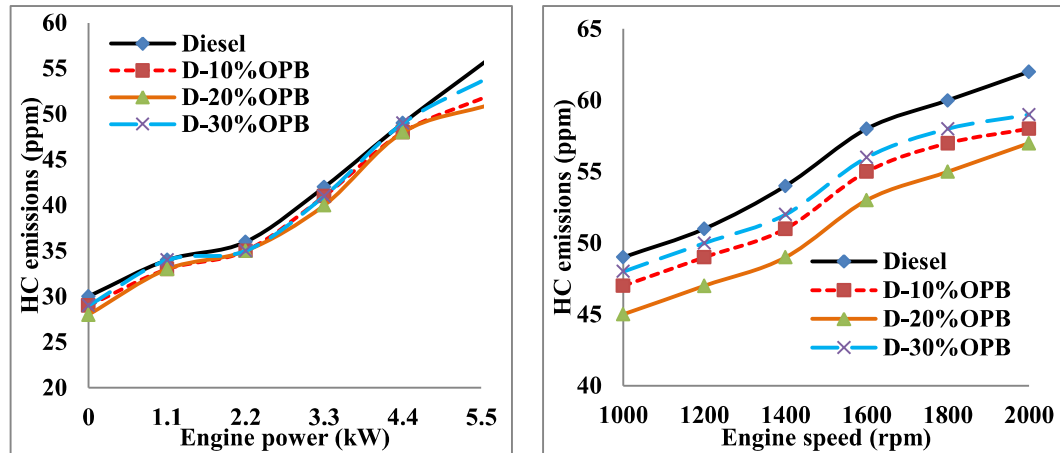


Figure 5.8 HC emissions variation versus engine power and speed with OPB

blended fuel

emissions are found to be enhanced. With enhancing blending of OPB beyond 20%, the fuel supply rate enhances drastically, and a rich mixture is supplied in the cylinder which further enhances the HC emissions. The HC emissions are found to be the lowest for OPB20 fuel. The HC emissions of the engine with OPB10, OPB20, and OPB30 diesel blend fuels are 7.14%, 8.93%, and 3.57% lower than diesel fuel, respectively, at 5.5kW engine power and 1500 rpm speed conditions.

5.1.5 Effect of Engine Power, Engine Speed, and OPB Blending on CO Emissions and CO₂ Emissions

The effect of engine power and speed on CO emissions has been presented in Fig.5.9. The major cause of CO formation is incomplete combustion due to a lack of oxygen. The CO emissions with each fuel sample increases by escalating the engine

power and speed due to a higher fuel consumption rate, and lower oxygen availability inside the cylinder means a higher fuel-air equivalence ratio. It is also observed that beyond 4kW engine power, CO emissions enhance drastically due to a much higher rate

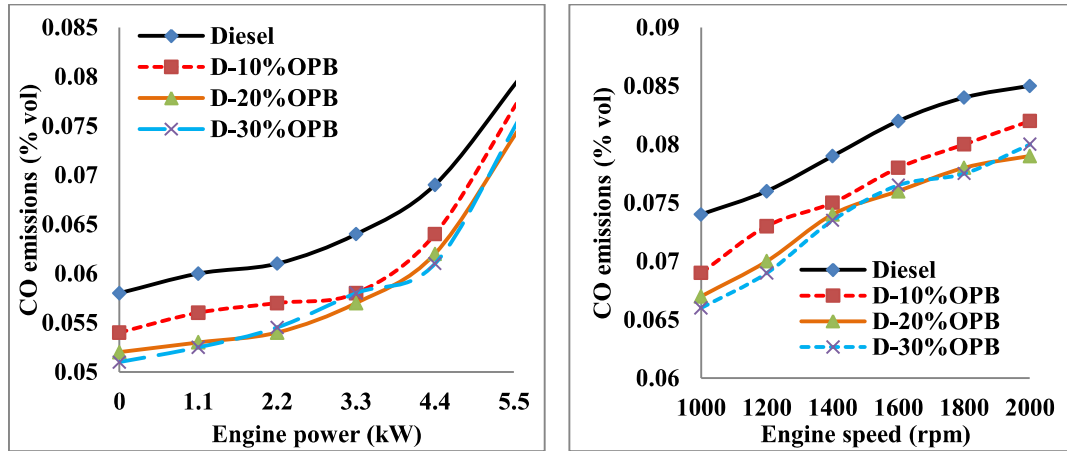


Figure 5.9 CO emissions variation versus engine power and speed with OPB blended fuel

of fuel consumption, lower availability of oxygen, and formation of fuel-rich zones. The CO emissions of the engine with OPB diesel blend fuels has been reduced compared to diesel fuels at each engine power and speed because of the higher O_2 content of biodiesel fuel. The higher O_2 content of biodiesel as a fuel makes its distribution more homogenous and diminishes the probability of forming a fuel-rich zone. The higher value of cetane number of biofuel blends provides better fuel combustion due to a shorter ignition delay period which also reduces CO emissions. The CO emissions of the engine with OPB10, OPB20, and OPB30 diesel blend fuels are 2.5%, 6.25%, and 5.0% lower than diesel fuel, respectively, at 5.5kW engine power and 1500 rpm speed conditions.

The effect of engine power and speed on CO_2 emissions has been presented in Fig.5.10. The CO_2 emissions indicate the complete combustion of the fuel. At low

power conditions, a lean mixture of fuel is burnt, so CO_2 emission is observed lower for each fuel sample. The CO_2 emissions with each fuel sample are enhanced by escalating the engine power and speed due to a higher fuel consumption rate, higher equivalence ratio, and higher post-combustion temperature inside the cylinder. The level of CO_2

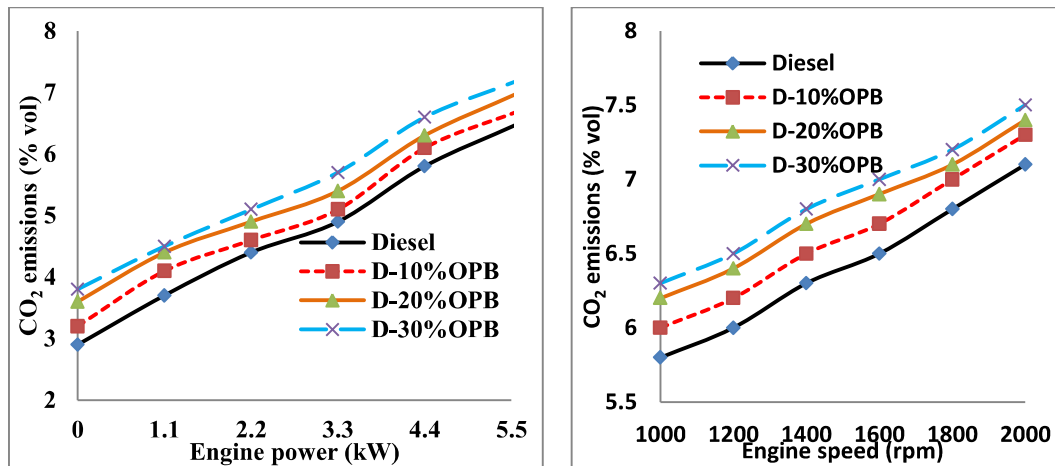


Figure 5.10 CO_2 emissions variation versus engine power and speed with OPB blended fuel

emissions increases with blends of OPB due to the higher availability, which converts CO into CO_2 through hydroxyl radicals (OH). However, the level of engine CO_2 emissions with standard diesel fuel has 10.76%, 7.69%, and 3.07% lower values than OPB30, OPB20, and OPB10 fuel blends, respectively, at 5.5kW engine power and 1500 rpm speed conditions.

5.1.6 Effect of Engine Power, Engine Speed, and OPB Blending on NO Emissions and Smoke Emissions

Fig.5.11 illustrates the engine NO emissions variation of different fuel samples with engine power and speed. With the escalation of engine power and speed, the NO emissions increases for each fuel due to a higher fuel-air ratio and higher post-

combustion temperature and pressure inside the cylinder. The NO emissions of the engine with OPB diesel blend fuels is enhanced compared to diesel fuels at each engine power and speed because of the higher O₂ content of biodiesel fuel, which promotes rapid fuel combustion and provides higher pressure and temperature. The cetane

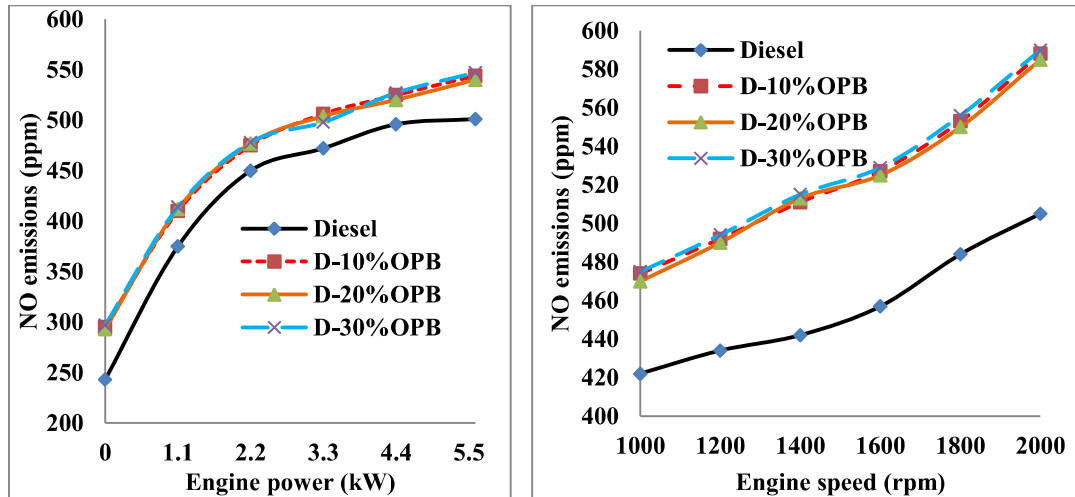


Figure 5.11 NO emissions variation versus engine power and speed with OPB blended fuel

number of OPB blended fuel is higher, supporting rapid combustion due to a shorter ignition delay period and enhancing NO emissions due to higher post-combustion temperature and pressure. The double bond of biodiesels produces more radicals which also promotes NO emissions. The NO emissions of the engine with OPB30 fuel is highest compared to all other fuels at each engine load and speed because of reduced ignition lag and higher O₂ content of biodiesel fuel. The NO emissions of the engine with OPB10, OPB20, and OPB30 diesel blend fuels is 8.58%, 7.78%, and 9.18% higher than diesel fuel, respectively, at 5.5kW engine power and 1500 rpm speed conditions.

Fig.5.12 illustrates the engine smoke emissions variation of different fuel samples with engine power and speed. With the engine power and speed escalation, the

smoke emissions increase for each fuel due to a higher fuel-air ratio and lower oxygen availability. The smoke emissions of the engine with OPB blend fuel has been observed to be lower than standard diesel fuels at each engine load and speed because of reduced ignition lag and higher O_2 content of biodiesel fuel, which promotes higher fuel oxidation. Another reason for smoke emissions reduction is the lower carbon-hydrogen ratio and higher combustion temperature. The smoke emissions of the engine with OPB10, OPB20, and OPB30 diesel blend fuels are 14.75%, 18.03%, and 21.31% lower than diesel fuel, respectively, at 5.5kW engine power and 1500 rpm speed conditions

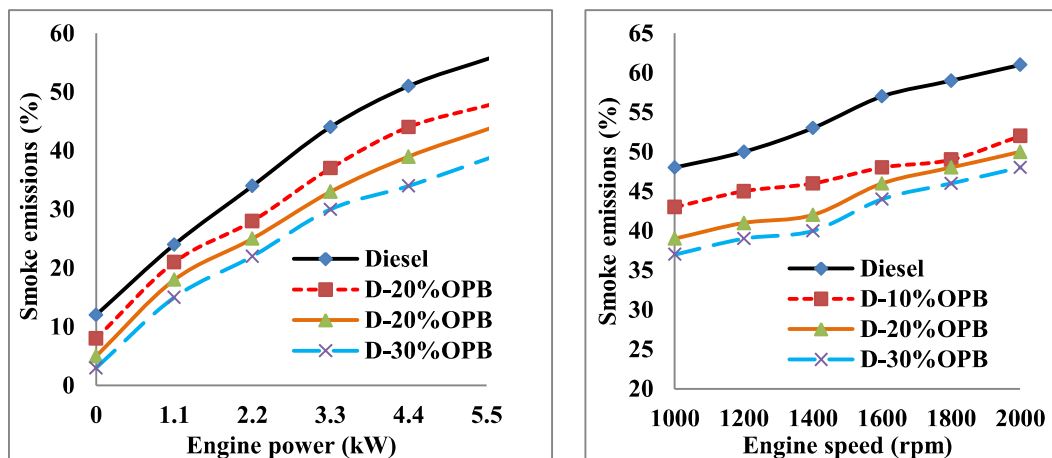


Figure 5.12 Smoke emissions variation versus engine power and speed with OPB fuel

5.2 Analysis of Diesel Engine Performance and Emission Parameters Fuelled with SOB Blended Fuel

5.2.1 Effect of Engine Power, Engine Speed, and SOB Blending on BSFC and BTE

Fig.5.13 illustrates the engine BSFC variation of different fuel samples with engine power and speed. The engine BSFC with each fuel reduces with increasing engine power and speed. The causes of the reduction of BSFC have been discussed in 5.1.1. Engine BSFC is observed enhancing with an increasing blend of biofuel in diesel.

The reasons for the growth of BSFC with biodiesel blending have been addressed in 5.1.1. The BSFC of the engine with SOB10, SOB20, and SOB30 blended fuel is 1.58%, 2.09%, and 3.13% higher than the diesel fuel, respectively, at 5.5kW of engine power and 1500 rpm speed condition.

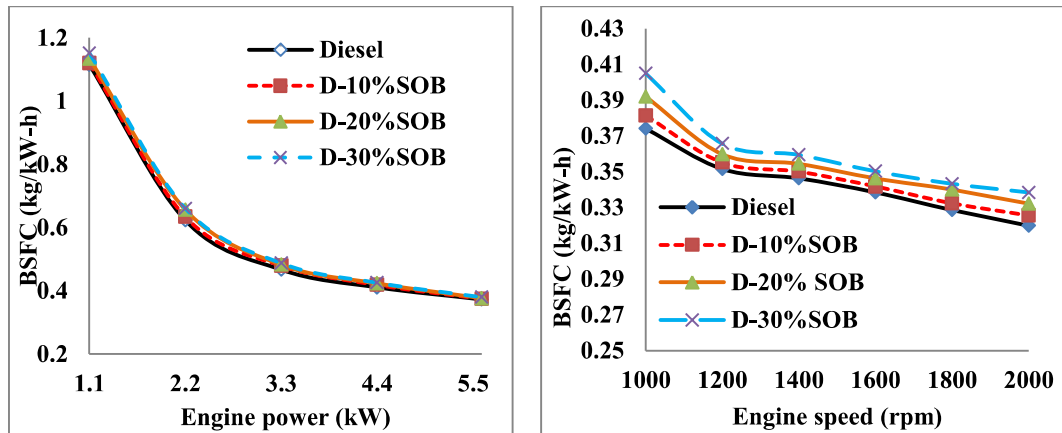


Figure 5.13 BSFC variation versus engine power and speed with SOB blended fuel

Fig 5.14 illustrates the engine BTE variation of different fuel samples with engine power and speed. The engine BTE escalates with increasing engine power and speed. The causes of the growth of BTE have been discussed in 5.1.1. The engine BTE with

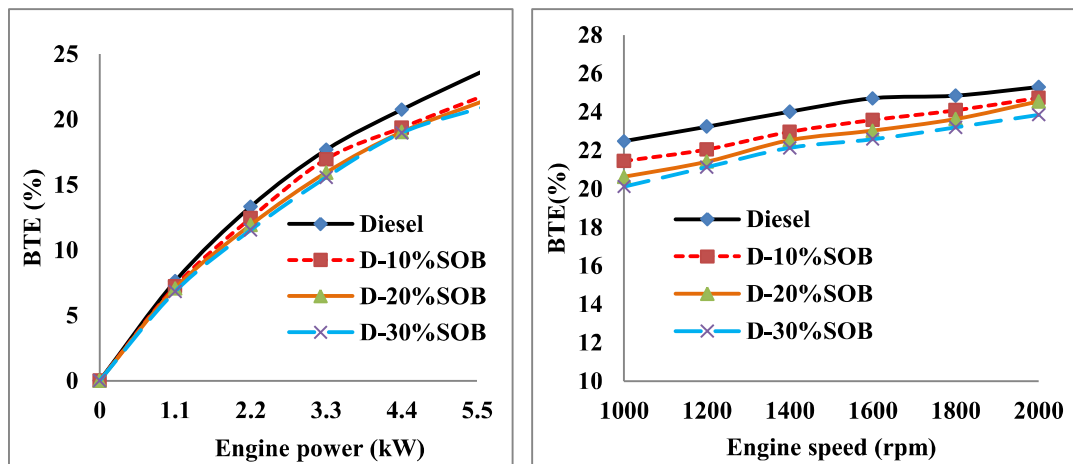


Fig 5.14 BTE variation versus engine power and speed with SOB blended fuel

SOB10, SOB20, and SOB30 diesel blend fuels have been observed to be lower than diesel. The causes of the reduction of BTE with biofuel blending have been discussed in 5.1.1. The BTE of the engine with SOB10, SOB20, and SOB30 diesel blend fuels is 5.50%, 9.75%, and 11.90% lower than diesel fuel, respectively, at 5.5kW engine power and 1500 rpm speed conditions.

5.2.2 Effect of Engine Power, Engine Speed, and SOB Blending on Exergy

Efficiency and Exhaust Gas Temperature

Fig.5.15 illustrates the engine exergy efficiency variation of different fuel samples with engine power and speed. The engine exergy efficiency escalates with increasing engine power and speed. The causes of the enhancement of exergy efficiency have been discussed in 5.1.2. The engine exergy efficiency with SOB10, SOB20, and SOB30-diesel blend fuels has been observed to be lower than the diesel fuel due to the higher fuel viscosity, larger fuel droplet size, and lower fuel atomization rate of biodiesel blended fuel than diesel fuel. The exergy efficiency of the engine with

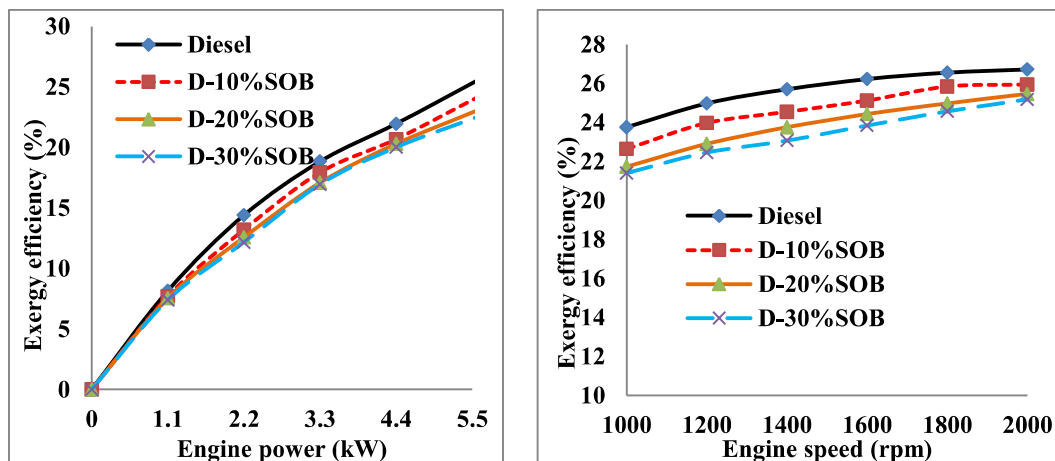


Figure 5.15 Exergy efficiency variation versus engine power and speed with SOB blended fuel

SOB10, SOB20, and SOB30 diesel blend fuels is 8.08%, 9.77%, and 11.33% lower than diesel fuel, respectively, at 5.5kW engine power and 1500 rpm speed condition.

Fig.5.16 illustrates the engine exhaust gas temperature variation of different fuel samples with engine power and speed. The engine exhaust gas temperature with each fuel escalates with engine power and speed. The causes of the increases of exhaust gas temperature with the variation of engine power and speed have been discussed in section 5.1.2. The engine exhaust gas temperature with SOB10, SOB20, and SOB30-diesel blend fuels have been observed to be higher than diesel fuel due to the higher fuel energy rate of SOB blend fuels. The other effects of biofuel blending on exhaust gas temperature have been discussed in section 5.1.2. The engine's exhaust gas temperature with SOB10, SOB20, and SOB30 diesel blend fuels are 1.64%, 5.67%, and 6.46% higher than diesel fuel, respectively, at 5.5kW engine power and 1500 rpm speed conditions.

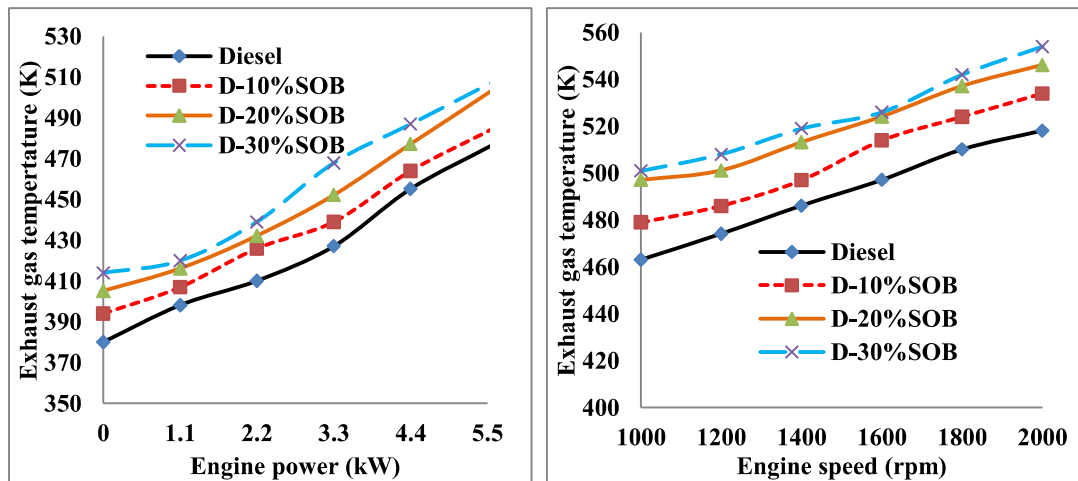


Figure 5.16 Exhaust gas temperature variation versus engine power and speed with SOB fuel

5.2.3 Effect of Engine Power, Engine Speed, and SOB Blending on Exergy

Destruction Rate and Engine Sustainability

The influence of engine power and speed on the exergy destruction rate and engine sustainability has been presented in Fig.5.17 and Fig.5.18, respectively. The exergy destruction enhances with an increase in the engine power and speed; the causes are discussed in section 5.1.3. The fuel burning rate of diesel fuel is lower than SOB blend fuels, due to which the exergy destruction with standard diesel fuel is found to be 19.10%, 17.09%, and 6.91% lower than SOB30, SOB20, and SOB10 at 5.5kW engine power and 1500 rpm speed condition.

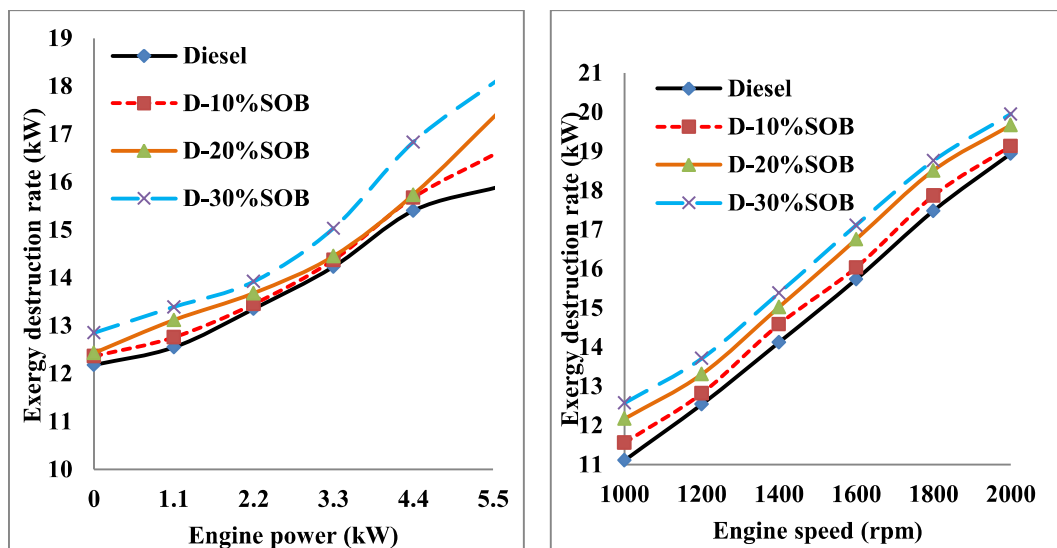


Figure 5.17 Exergy destruction rate variation versus engine power and speed with SOB fuel

Moreover, engine sustainability is a direct function of exergy efficiency. The engine sustainability increases with an increase in engine power due to the exergetic efficiency. The fuel properties, i.e., viscosity and calorific value, affect engine sustainability. However, the calorific value reduces, the viscosity value increases and the engine sustainability reduces with an increase in SOB blend proportion in standard

diesel fuel. The engine sustainability with standard diesel fuel has 3.50%, 2.97%, and 2.44%, higher values than SOB30, SOB20, and SOB10 fuel blends, respectively, at 5.5kW engine power and 1500 rpm speed conditions.

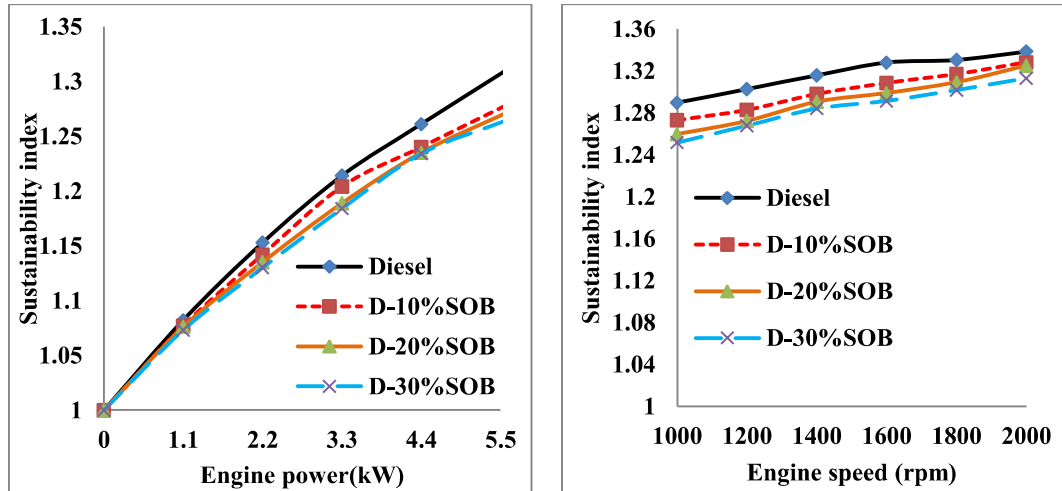


Fig 5.18 Engine sustainability index variation versus engine power and speed with SOB fuel

5.2.4 Effect of Engine Power, Engine Speed, and SOB Blending on Entropy

Generation Rate and HC Emissions

The influence of engine speed and power on the entropy generation rate is illustrated in Fig.5.19. The entropy generation rate increases with increasing engine power and speed because of the exergy destruction rate. The entropy generation rate with standard diesel fuel has 14.21%, 9.93%, and 4.58% higher values than SOB30, SOB20, and SOB10 fuel blends, respectively, at 5.5kW engine power and 1500 rpm speed conditions.

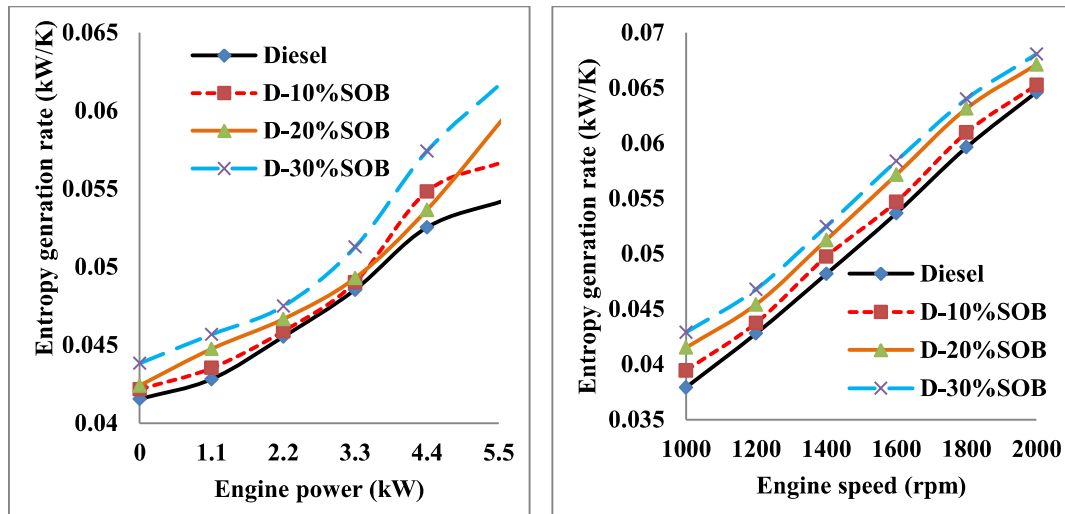


Figure 5.19 Entropy generation rate variation versus engine power and speed with SOB fuel

The effect of engine power and speed on HC emissions has been presented in Fig.5.20. The HC emissions with each fuel sample enhances by escalating the engine power and speed. The causes of enhancement of HC emissions have been discussed in

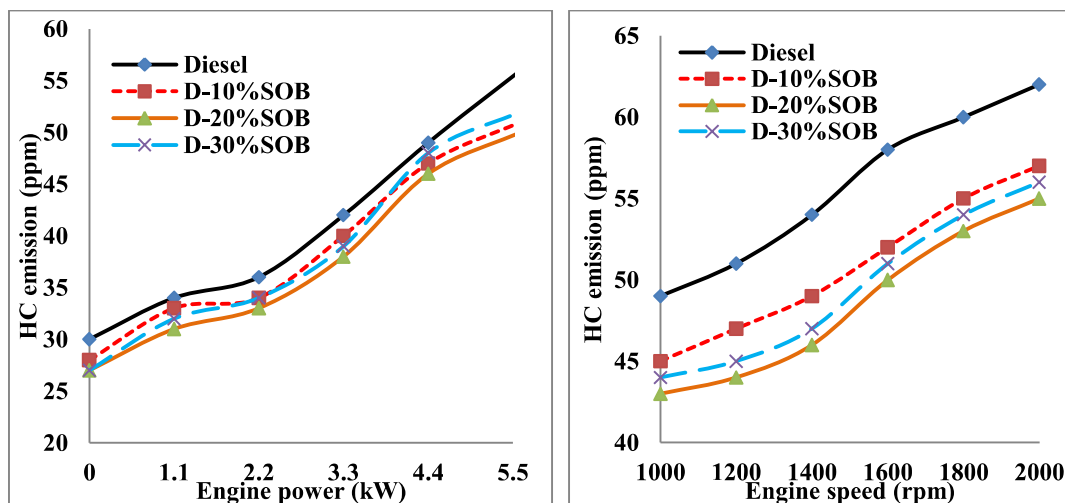


Figure 5.20 HC emissions variation versus engine power and speed with SOB blended fuel

section 5.1.4. The blending of biofuel in diesel reduces the HC emissions due to the higher oxygen level of biofuel. The other causes of the enhancement of HC emissions have been discussed in section 5.1.4. It is observed from the experimental results that HC emissions is reduced by up to 20% of SOB blending in diesel, and beyond this, HC emissions is found to be enhanced. The HC emissions are found lowest for 20% SOB-diesel blend fuel. The HC emissions of the engine with SOB10, SOB20, and SOB30 diesel blend fuels is 8.92%, 10.71%, and 7.14% lower than diesel fuel, respectively, at 5.5kW engine power and 1500 rpm speed condition.

5.2.5 Effect of Engine Power, Engine Speed, and SOB Blending on CO Emissions and CO₂ Emissions

The effect of engine power and speed on CO emissions has been presented in Fig 5.21. The CO emissions with each fuel sample is enhanced by escalating the engine power and speed; the causes are discussed in section 5.1.5. The CO emissions of the engine with SOB diesel blend fuels have been reduced compared to all other fuels at

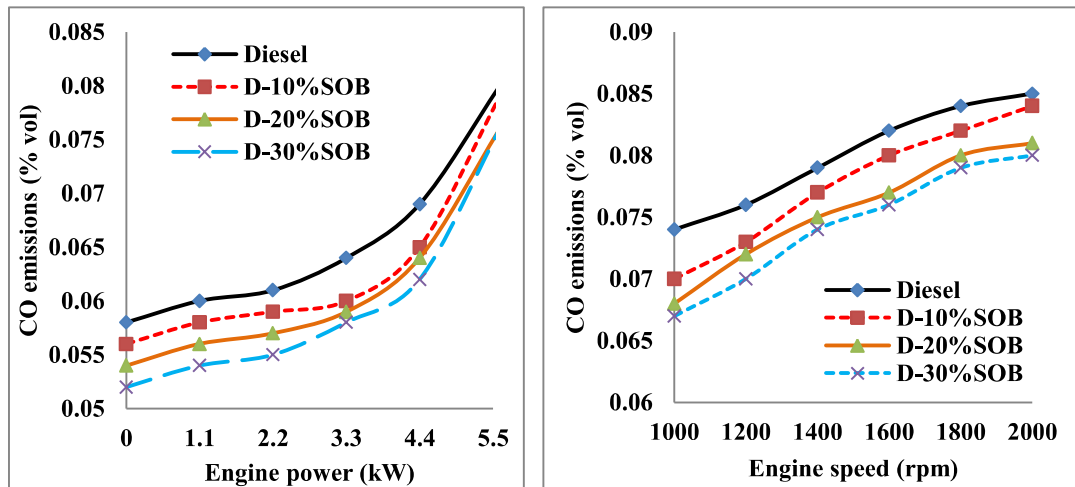


Figure 5.21 CO emissions variation versus engine power and speed with SOB blended fuel

each engine power and speed because of the reduced higher O₂ content of biodiesel fuel. The other causes of CO reduction of emissions have been discussed in section 5.1.5. The CO emissions of the engine with SOB10, SOB20, and SOB30 diesel blend fuels are 1.25%, 5%, and 6.25% lower than diesel fuel, respectively, at 5.5kW engine power and 1500 rpm speed conditions.

The effect of engine power and speed on CO₂ emissions has been presented in Fig.5.22. The CO₂ emissions with each fuel sample increase by escalating the engine power and speed, as discussed in section 5.1.5. The level of CO₂ emissions improves with blends of SOB due to the higher availability of oxygen for combustion, which converts CO into CO₂. However, the level of engine CO₂ emissions with standard diesel fuel has 13.84%, 9.23%, and 6.15% higher values than SOB30, SOB20, and SOB10 fuel blends, respectively, at 5.5kW engine power and 1500 rpm speed conditions.

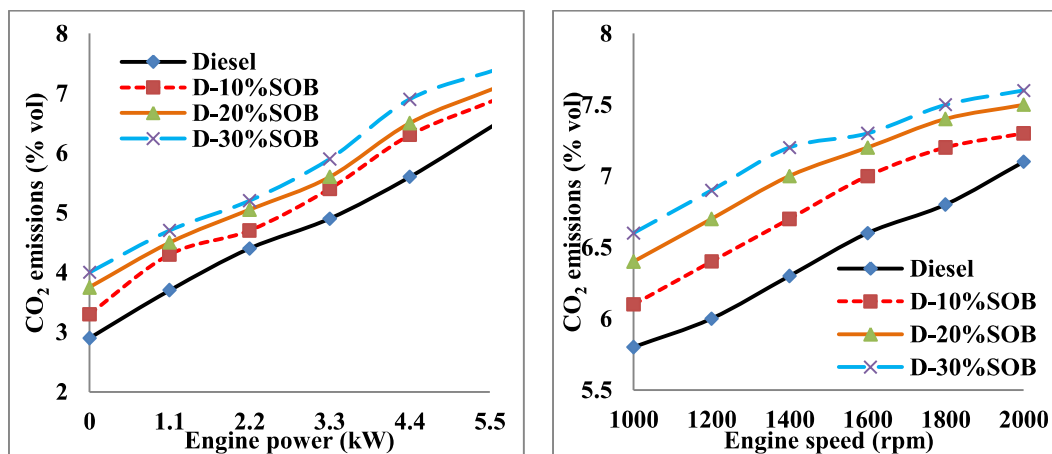


Figure 5.22 CO₂ emissions variation versus engine power and speed with SOB blended fuel

5.2.6 Effect of Engine Power, Engine Speed, and SOB Blending on NO_x and Smoke Emissions

Fig.5.23 illustrates the engine NO emissions variation of different fuel samples with engine power and speed. With the engine power and speed escalating, the NO emissions for each fuel escalated due to higher inside cylinder temperature and pressure. The other causes of the enhancement of NO emissions with engine power and speed have been discussed in section 5.1.6. The NO emissions of the engine with SOB30 fuel are highest compared to all other fuels at each engine power and speed because of reduced ignition lag and higher O₂ content of biodiesel fuel. The other causes of the enhancement of NO emissions with biofuel blending have been discussed in section 5.1.6. The NO emissions of the engine with SOB10, SOB20, and SOB30 diesel blend fuels are 8.98%, 9.58%, and 9.98% higher than diesel fuel, respectively, at 5.5kW engine power and 1500 rpm speed conditions.

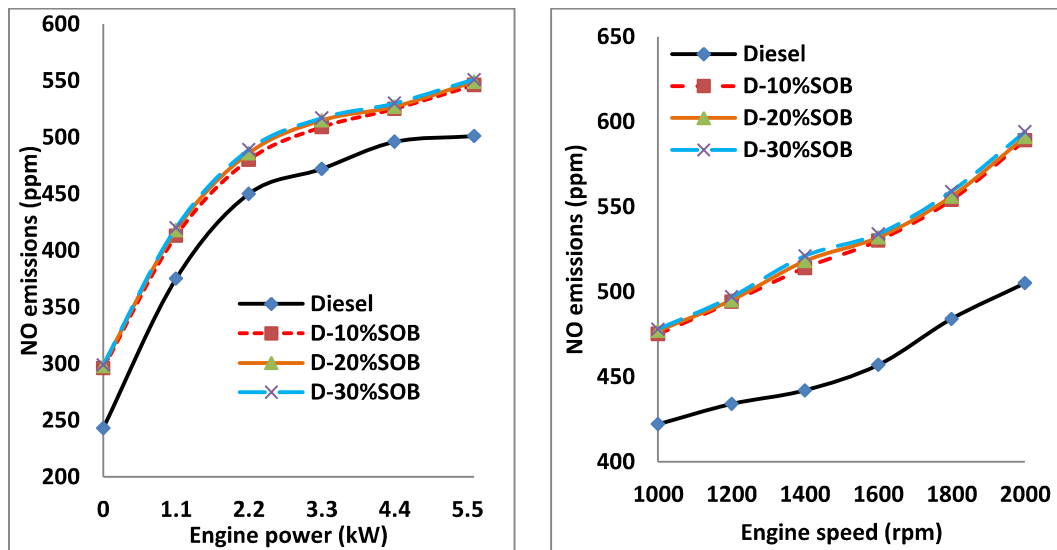


Figure 5.23 NO emissions variation versus engine power and speed with SOB blended fuel

Fig.5.24 illustrates the engine smoke emissions variation of different fuel samples with engine power and speed. The nature of variation of smoke emissions with engine power and speed and its reasons have been discussed in section 5.1.6. The smoke emissions of

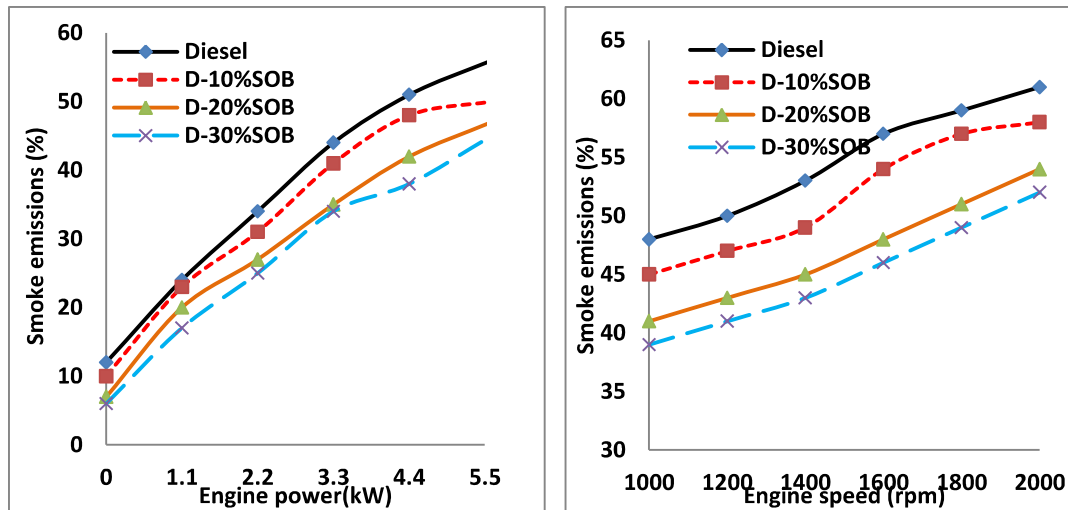


Figure 5.24 Smoke emissions variation versus engine power and speed with SOB blended fuel

the engine with SOB blend fuel has been observed to be lower than standard diesel fuels at each engine power and speed because of reduced ignition lag and higher O_2 content of biodiesel fuel. The other causes of the reduction of smoke emissions with biofuel blending have been discussed in section 5.1.6. The smoke emissions of the engine with SOB10 and SOB20 SOB30 diesel blend fuels are 10.71%, 16.07%, and 19.64% lower than diesel fuel, respectively, at 5.5kW engine power and 1500 rpm speed conditions.

5.3 Analysis of Diesel Engine Performance and Emissions Parameters Fuelled with Water-Emulsified Diesel Fuels

5.3.1 Effect of Engine Power, Engine Speed, and WiDE Fuel on BSFC and BTE

Fig.5.25 illustrates the engine BSFC variation of different fuel samples with engine power and speed. The engine BSFC with each fuel reduces with increasing engine power and speed. The causes of the reduction of BSFC with the variation of engine power and speed have been discussed in 5.1.1. The BSFC of the engine is observed to more with increasing water fraction in diesel because of the increase in the ignition delay period. More fuel is burned during the premixed combustion process. The lower heat content of water-emulsified fuel is a factor for higher BSFC. The engine BSFC is found highest for WiDE15 fuel at each engine power and speed. The BSFC of

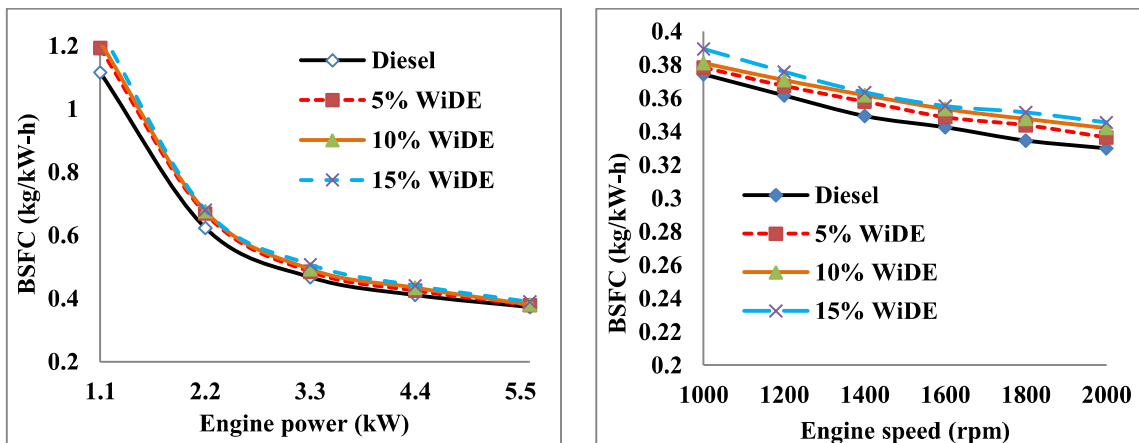


Figure 5.25 BSFC variation versus engine power and speed with water-emulsified fuel

the engine with WiDE5, WiDE10, and WiDE15 is 1.53%, 2.09%, and 4.48% higher than the diesel fuel, respectively, at 5.5kW of engine power and 1500 rpm speed condition.

The BTE of diesel engines for all fuel samples enhances with an increase in engine power and speed, as presented in Fig.5.26. The causes of the increase of BTE with the variation of engine power and speed have been discussed in 5.1.1. The engine BTE increases up to 5% water emulsification due to the lower calorific value of 5%WiDE fuel than diesel fuel and secondary atomization due to micro-explosion. The calorific value of WiDE10 and WiDE15 fuel is lower than WiDE5 fuel but energy absorbed by water for vaporization is higher than WiDE5 fuel, due to which BTE reduces with WiDE10 and WiDE15 fuel. The BTE of the diesel engine at 5.5 kW engine power and 1500 rpm engine speed for WiDE5 fuel has 6.44%, 7.57%, and 3.16% higher values, respectively than WiDE10, WiDE15, and diesel fuel.

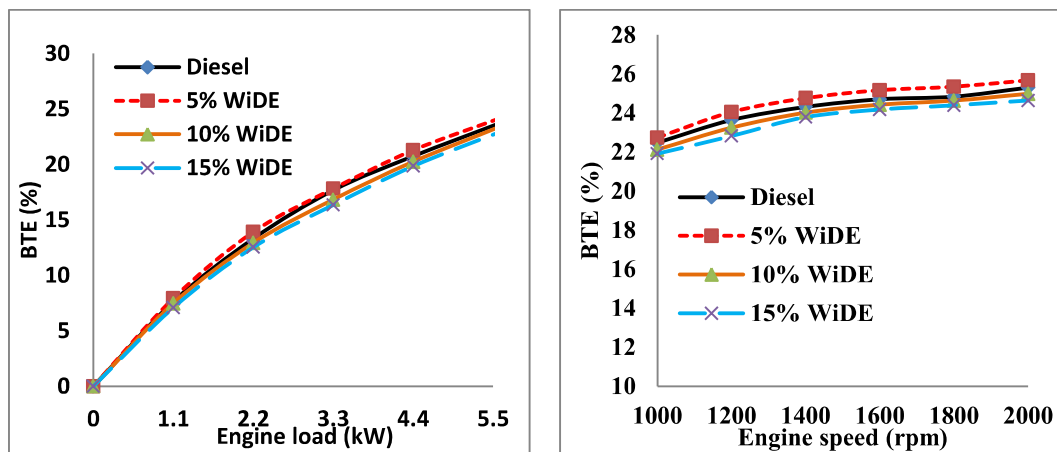


Figure 5.26 BTE variation versus engine power and speed with water-emulsified fuel

5.3.2 Effect of Engine Power, Engine Speed, and WiDE Fuel on Exergy Efficiency and Exhaust Gas Temperature

The effect of engine power and speed on the exergy efficiency has been shown in Fig.5.27. The exergy efficiency of diesel engines for all fuel samples increases with an increase in engine power and speed, as discussed in section 5.1.2. Also, due to a

lower calorific value and secondary atomization, the exergy efficiency is higher for diesel engines with WiDE5 fuel than diesel fuel at all engine power and speeds. The exergy efficiency of WiDE10 and WiDE15 fuel is lower than WiDE5 fuel due higher energy absorption rate for the vaporization of water. The exergy efficiency of the diesel engine with WiDE5 has 4.63%, 5.40%, and 1.89% higher values than WiDE10, WiDE15, and diesel fuel, respectively, at 5.5kW engine power and 1500 rpm engine speed.

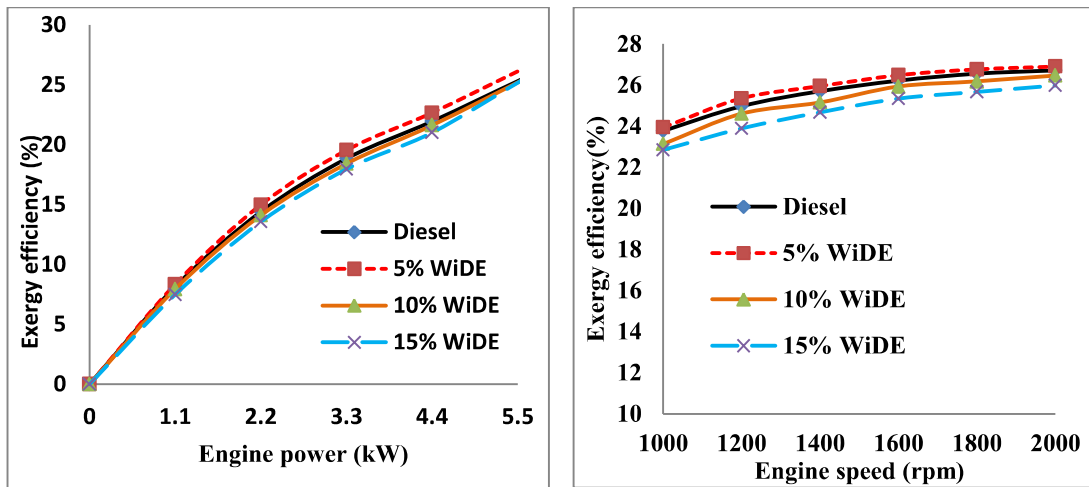


Figure 5.27 Exergy efficiency variation versus engine power and speed with water-emulsified fuel

The exhaust gas temperature of diesel engines for all fuel samples increases with increasing engine power and speed has been shown in Fig.5.28. This may be because, with an increase in engine power and speed, the fuel consumption and energy rate increase for all the fuel samples. The engine exhaust gas temperature reduces by improving the water fraction in water-emulsified diesel fuel due to a higher energy absorption rate by the water particle for evaporation. The exhaust gas temperature of the diesel engine with WiDE5, WiDE10, and WiDE15 fuel has 1.46%, 2.08%, and

3.16% lower values respectively than the diesel fuel at 5.5kW engine power and 1500 rpm engine speed.

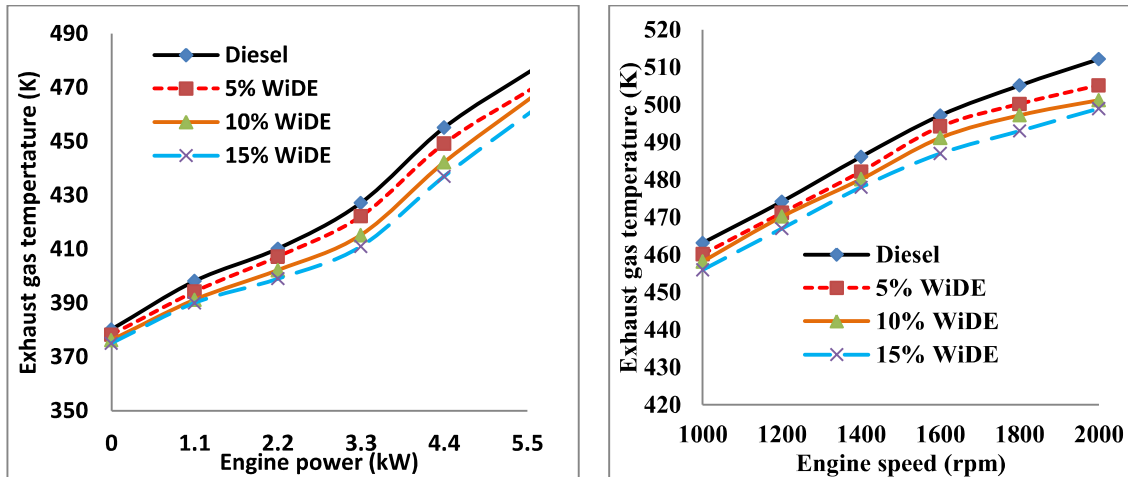


Figure 5.28 Exhaust gas temperature variation versus engine power and speed with water-emulsified fuel

5.3.3 Effect of Engine Power, Engine Speed, and WiDE Fuel On Exergy

Destruction Rate and Engine Sustainability

The exergy destruction rate is the difference between all inlet and outlet exergy rates. The effect of engine power and speed on the engine exergy destruction rate has been shown in Fig.5.29. The exergy destruction rate increases with an increase in engine power and speed, as discussed in section 5.1.3. With an increase in engine power and speed, the fuel consumption rate increase, and due to that fuel energy rate also increases. As a result, the fuel exergy and the exergy destruction rates were also enhanced. The effect of variation of engine speed on exergy destruction rate is more due to higher frictional losses. However, the calorific value of diesel fuel is higher than water-emulsified fuels, due to which the exergy destruction rate with diesel fuel is found to be 1.82%, 3.26%, and 4.65% higher than WiDE5, WiDE10, and WiDE15 fuel, respectively, at 5.5kW engine power and 1500 rpm engine speed.

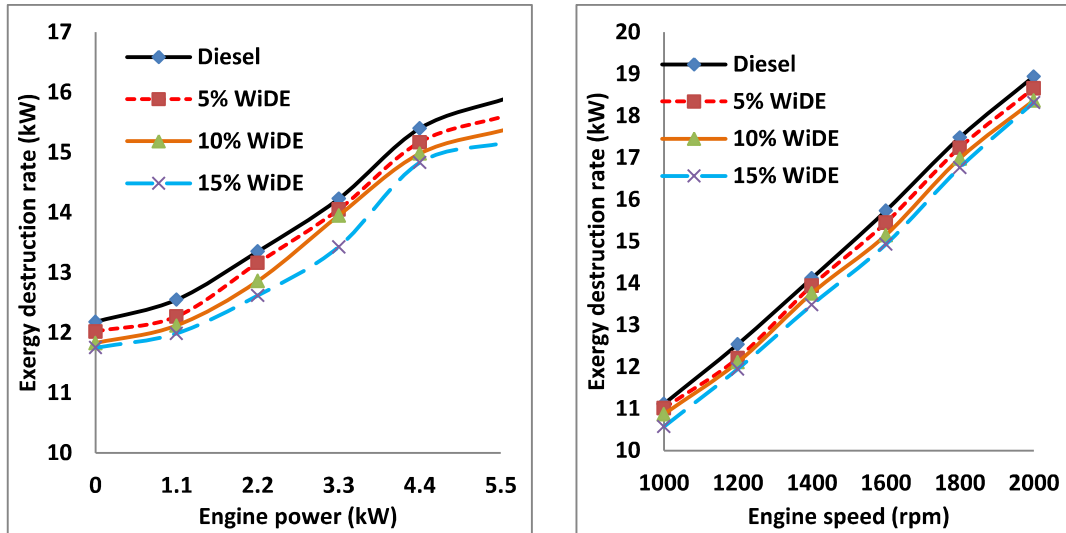


Figure 5.29 Exergy destruction rate variation versus engine power and speed with water-emulsified fuel

Engine sustainability depends on the exergy efficiency of the engine directly. The effect of engine power and speed on the engine sustainability index has been presented in Fig.5.30. However, with an increase in engine power and speed, the engine exergy efficiency increases, which increases the exergy sustainability. The other causes of improvement of the sustainability index with the variation of engine power and speed have been discussed in section 5.1.3. The engine sustainability index is found highest with WiDE5 fuel due to higher exergy efficiency. The exergy sustainability of diesel engines with WiDE5 fuel has 1.44%, 1.59%, and 0.6% higher values than the WiDE10, WiDE15, and diesel fuel, respectively, at 5.5kW engine load and 1500 rpm engine speed.

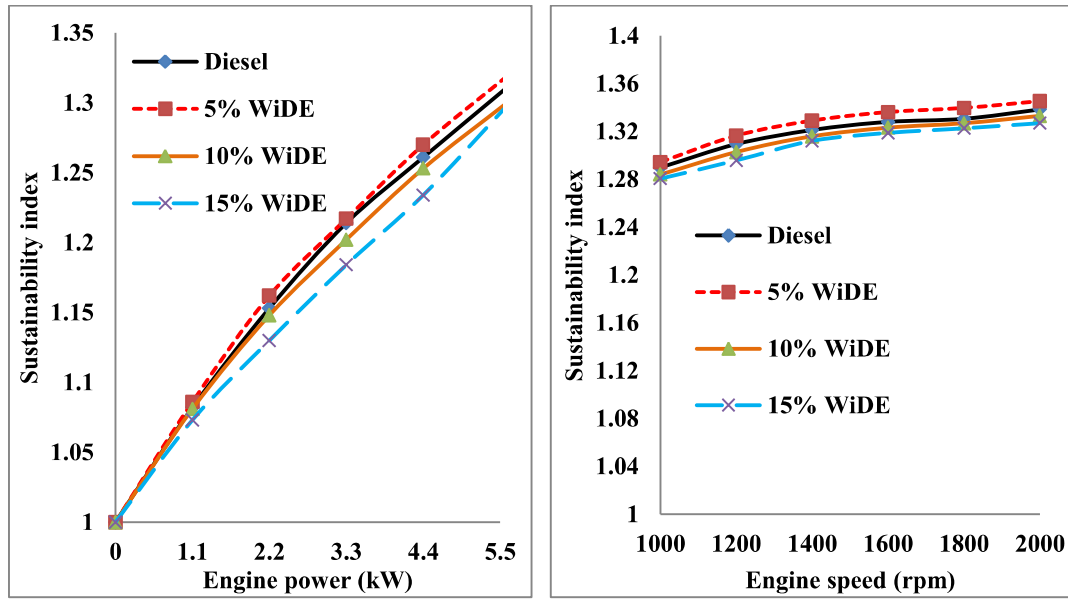


Figure 5.30 Engine sustainability index variation versus engine power and speed with water-emulsified fuel

5.3.4 Effect of Engine Power, Engine Speed, and WiDE Fuel on Entropy

Generation Rate and HC Emissions

The effect of engine power and speed on the entropy generation rate has been shown in Fig.5.31. The entropy generation rate in the engine is directly related to the exergy destruction rate due to irreversibility. Because the exergy destruction rate increases with increasing engine power and speed, the entropy generation rate also increases. The entropy generation rate also depends on the calorific value of the fuel. The calorific value of diesel fuel is greater than water-emulsified fuels, due to which the entropy generation rate for diesel fuel is greater than WiDE5, WiDE10, and WiDE15 fuel by 1.82%, 3.27%, and 4.65%, at 5.5kW engine power and 1500 rpm engine speed.

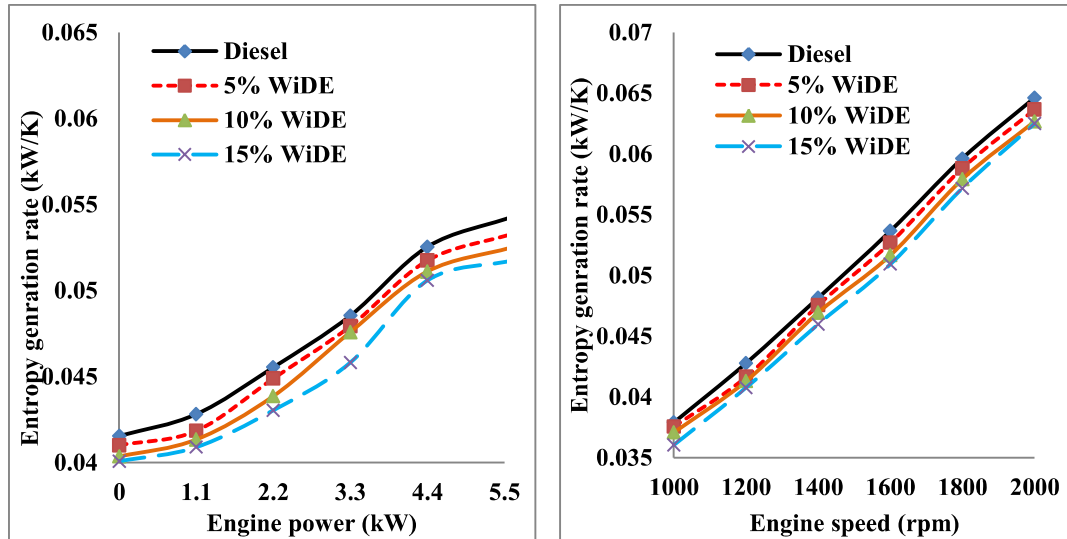


Figure 5.31 Entropy generation rate variation versus engine power and speed with water-emulsified fuel

The effect of engine power and speed on the HC emissions has been shown in Fig.5.32. The HC emissions increase with increasing engine power and speed, the causes of the increase of HC emissions with engine power and speed have been discussed in section 5.1.4. The HC emissions also depend on the combustion quality of the fuel. The combustion quality of water-emulsified fuel is higher than standard diesel fuel due to micro-explosion and secondary atomization of fuel particles. The HC emissions with WiDE5, WiDE10, and WiDE15 fuel is observed lower by 12.5%, 17.85%, and 19.46% compared to diesel fuel, respectively, at 5.5kW engine power and 1500 rpm engine speed.

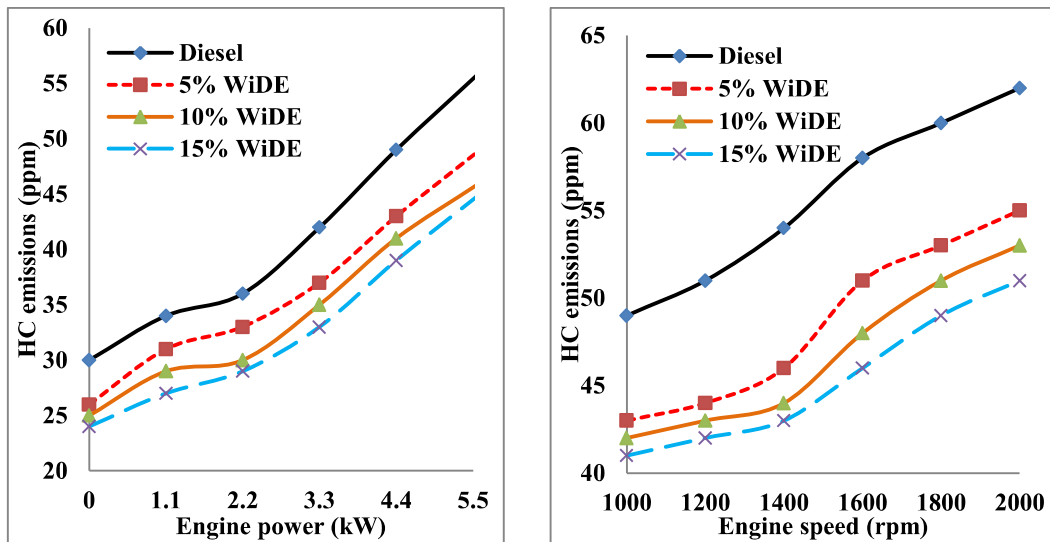


Figure 5.32 HC emissions variation versus engine power and speed with water-emulsified fuel

5.3.5 Effect of Engine Power, Engine Speed, and WiDE Fuel on CO and CO₂

Emissions

The effect of engine power and speed on CO emissions has been shown in Fig.5.33. Due to an enhancement in the fuel consumption rate, the CO emissions revealed an enhanced result with increased engine power and speed. The other causes of the reduction of CO emissions with the variation of engine load and engine speed have been discussed in section 5.1.5. The CO emissions also depend on the combustion quality of the fuel. The combustion quality of water-emulsified fuel is higher than standard diesel fuel due to micro-explosion and secondary atomization of fuel particles. The water-emulsified fuels have higher O₂ levels, which also reduces CO emissions. The CO emissions with WiDE5, WiDE10, and WiDE15 fuel is observed lower by 5%, 8.75%, and 10% compared to diesel fuel, respectively, at 5.5kW engine power and 1500 rpm engine speed.

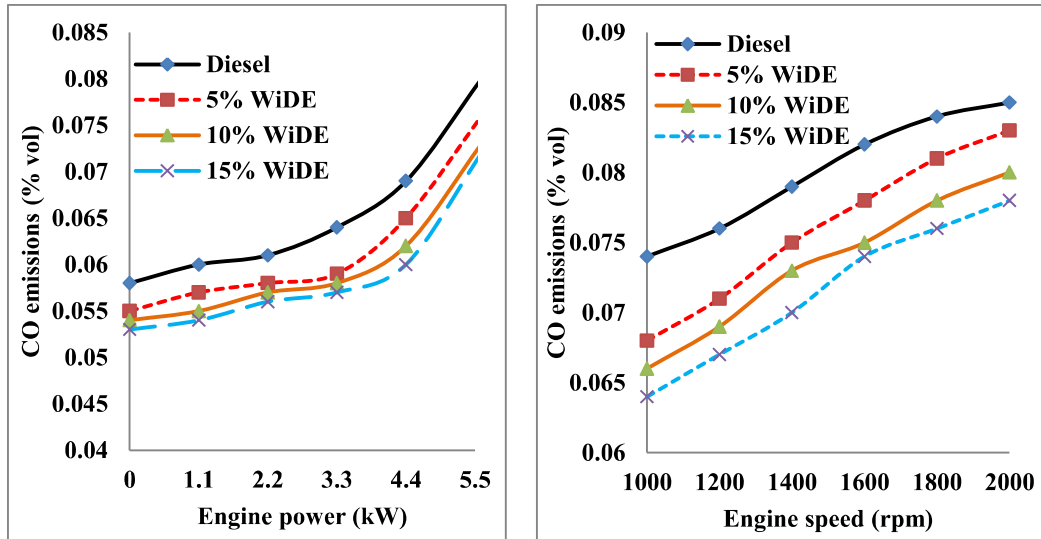


Figure 5.33 CO emission variation versus engine power and speed with water-emulsified fuel

The effect of engine power and speed on CO₂ emissions has been shown in Fig.5.34. Due to an enhancement in the fuel consumption rate, the CO₂ emissions revealed an enhanced result with an increase in engine power and speed. The CO₂ emissions also depend on the combustion quality and availability of O₂ for fuel combustion. The other causes of the enhancement of CO₂ emissions with the variation of engine power and engine speed have been discussed in section 5.1.5. The combustion quality of water-emulsified fuel is higher than standard diesel fuel due to micro-explosion, secondary atomization of fuel particles, and higher availability of O₂. The CO₂ emissions with WiDE5, WiDE10, and WiDE15 fuel is observed to be higher by 3.07%, 4.61%, and 9.23% compared to diesel fuel, respectively, at 5.5kW engine power and 1500 rpm engine speed.

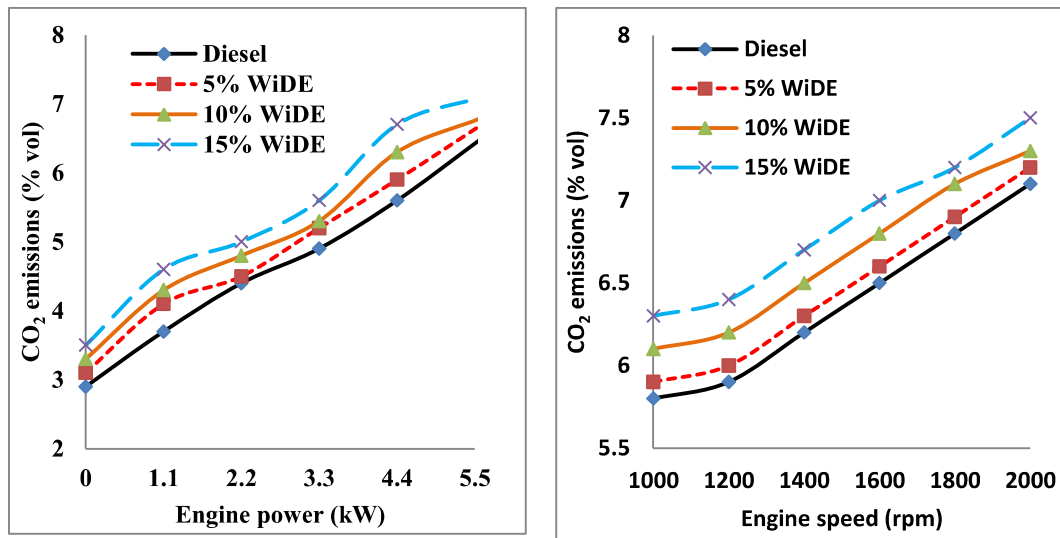


Figure 5.34 CO₂ emissions variation versus engine power and speed with water-emulsified fuel

5.3.6 Effect of Engine Power, Engine Speed, and WiDE Fuel on NO and Smoke

Opacity Emissions

The effect of engine power and speed on the NO emissions has been shown in Fig.5.35. Due to an enhancement in the fuel energy rate, the NO emissions revealed an enhanced result with increased engine power and speed. The NO emissions depend on the in-cylinder temperature and pressure. The other causes of the enhancement of NO emissions with the variation of engine load and engine speed have been discussed in section 5.1.6. The in-cylinder temperature with water-emulsified fuel is lower than standard diesel fuel due to the absorption of in-cylinder energy for the vaporization of water. The water particles in fuel act as a heat sink. The other reason for NO reduction is the inhibition of chemical reactions between N₂ and O₂ to form NO, according to Zeldovich's mechanism. The NO emissions with WiDE5, WiDE10, and WiDE15 fuel is observed lower by 1.79%, 3.79%, and 4.59% compared to diesel fuel, respectively, at 5.5kW engine power and 1500 rpm engine speed.

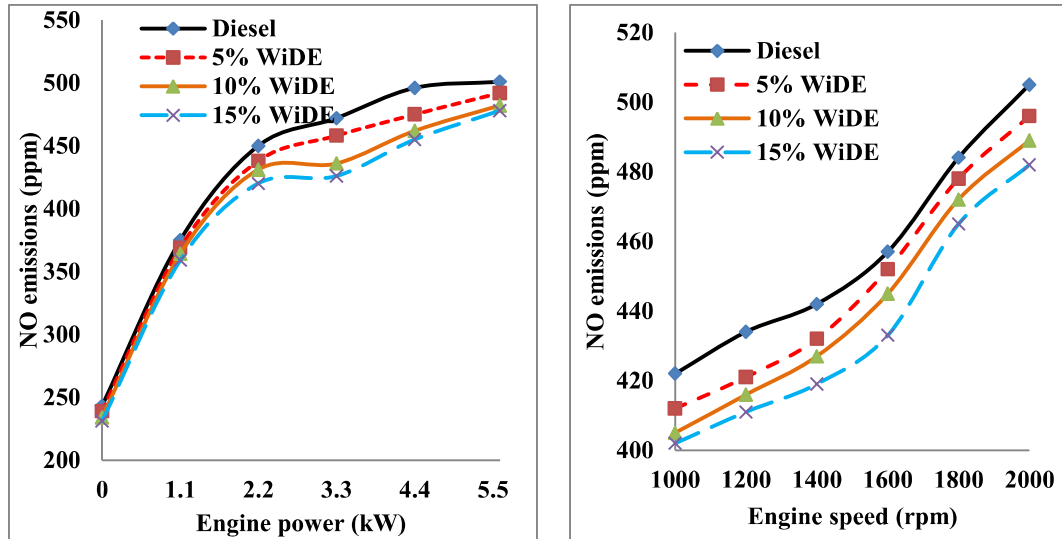


Figure 5.35 NO emissions variation versus engine power and speed with water-emulsified fuel

The effect of engine power and speed on the smoke emissions has been shown in Fig.5.35. Due to an enhancement in the fuel consumption rate, the smoke emission revealed an enhanced result with increased engine power and speed. The other causes of enhanced smoke emissions with engine power and speed variation have been discussed in section 5.1.6. The smoke emissions depend on the combustion quality of the fuel. The combustion quality of water-emulsified fuel is better than diesel fuel, due to which smoke emissions reduce with water emulsification. The other reason for smoke emission with water-emulsified fuel is the higher availability of O_2 . The smoke emission with WiDE5, WiDE10, and WiDE15 fuel is observed lower by 12.5%, 19.64%, and 25% compared to diesel fuel, respectively, at 5.5kW engine power and 1500 rpm engine speed.

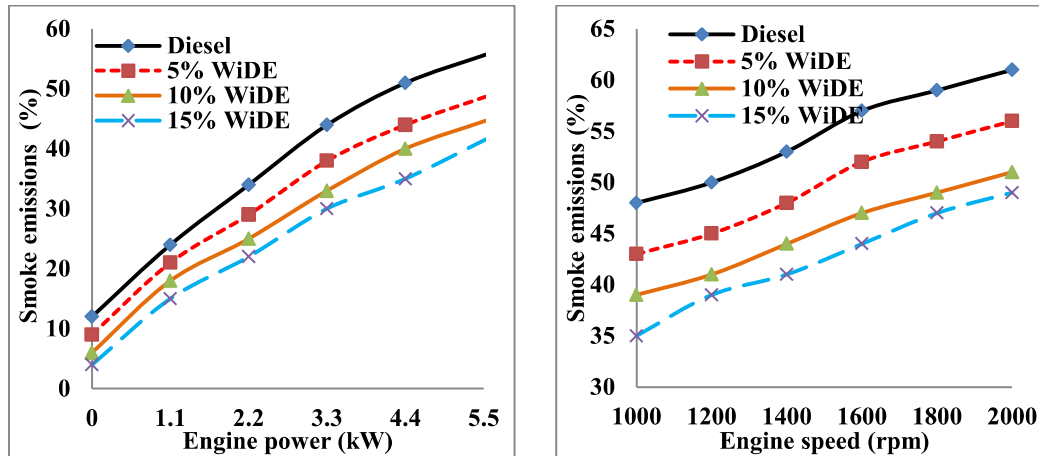


Figure 5.36 Smoke emissions variation versus engine power and speed with water-emulsified fuel

5.4 Analysis of Diesel Engine Performance and Emission Parameters Fuelled with Water-Emulsified OPB Blended Nano Additive Incorporated Fuel

5.4.1 Effect of Engine Power, Engine Speed, and WiDE-Based OPB Nano Fuels Variation on BSFC and BTE

The influence of engine speed and power on diesel engine BSFC is illustrated in Fig.5.37. The effect of engine power and speed variation with OPB20 fuel on engine BSFC has been discussed in section 5.1.1. The emulsification of 5% water in OPB-diesel blended fuel further enhances the density, kinematic viscosity, and BSFC at each engine speed and power. With the incorporation of nano-additive, surface area contact improves which accelerates the chemical reaction rate and shortens the ignition lag period, due to that, the fuel consumption rate reduces, and the BSFC reduces compared to diesel fuel, and 5% water-emulsified OPB-diesel blended fuel at each engine speed and power. It is also noted that the diesel engine BSFC with CNT nano-catalyst is lower than the Al_2O_3 nano-catalyst because the thermal conductivity of CNT nanoparticles is much higher than alumina nanoparticles. The engine BSFC at a speed of 1500 rpm and

5.5kW power with OPB20, 5% water emulsified OPB20, 5% water emulsified CNT incorporated OPB20, and 5% water emulsified Al_2O_3 incorporated OPB20 fuel is found 1.69%, 2.87%, 1.93%, and 1.82% higher compared to diesel fuel. The engine BSFC with 5% water-emulsified CNT incorporated OPB20 and 5% water-emulsified Al_2O_3 incorporated OPB20 fuel is found to be 0.91% and 1.02% lower than 5% water emulsified OPB20 fuel.

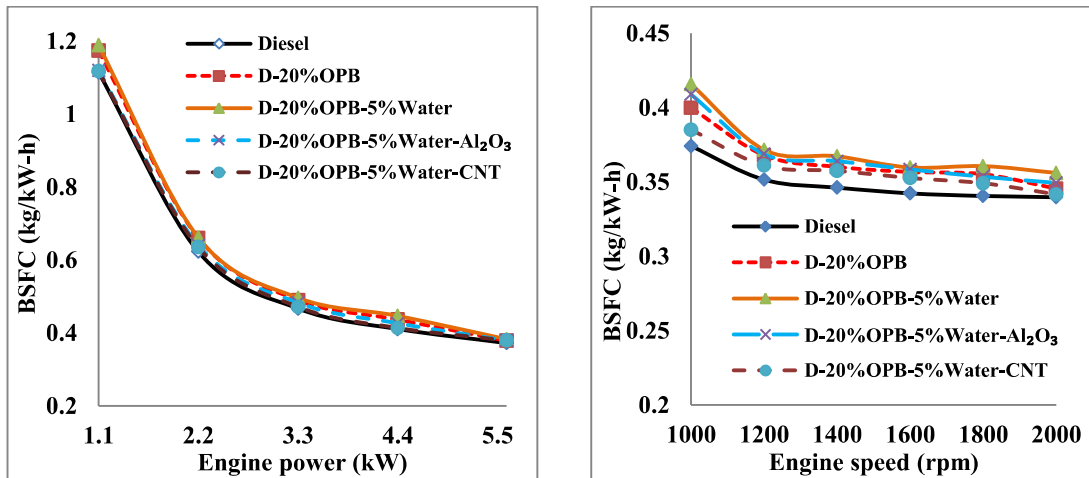


Figure 5.37 BSFC variation versus engine power and speed with OPB blended nano fuel

The effect of engine speed and power on diesel engine BTE is illustrated in Fig.5.38. The effect of engine power variation and speed with OPB20 fuel on engine BTE has been discussed in section 5.1.1. The engine BTE at each engine speed and power with 5% water emulsified OPB20 fuel is found to be higher than OPB20 fuel because of the lower calorific value of the fuel and secondary atomization of fuel particles due to micro-explosion. With the incorporation of CNT and Al_2O_3 nano-catalyst, the fuel utilization rate was reduced due to a shorter period of ignition lag, and reduced short ignition lag improved the combustion efficiency of the fuel, which enhances the BTE of the engine compared to 5% water emulsified OPB20. The fuel

utilization rate with the CNT catalyst is lower than the Al_2O_3 catalyst, due to which the engine BTE with the CNT catalyst is higher than the Al_2O_3 catalyst. The engine BTE at a speed of 1500 rpm and power 5.5kW with OPB20, 5% water emulsified OPB20, and 5% water emulsified Al_2O_3 incorporated OPB20 fuel is found to be 7.25%, 5.23%, and 1.99% lower and with 5% water emulsified CNT incorporated OPB20 fuel is found to be 1.29% higher than the diesel fuel, respectively.

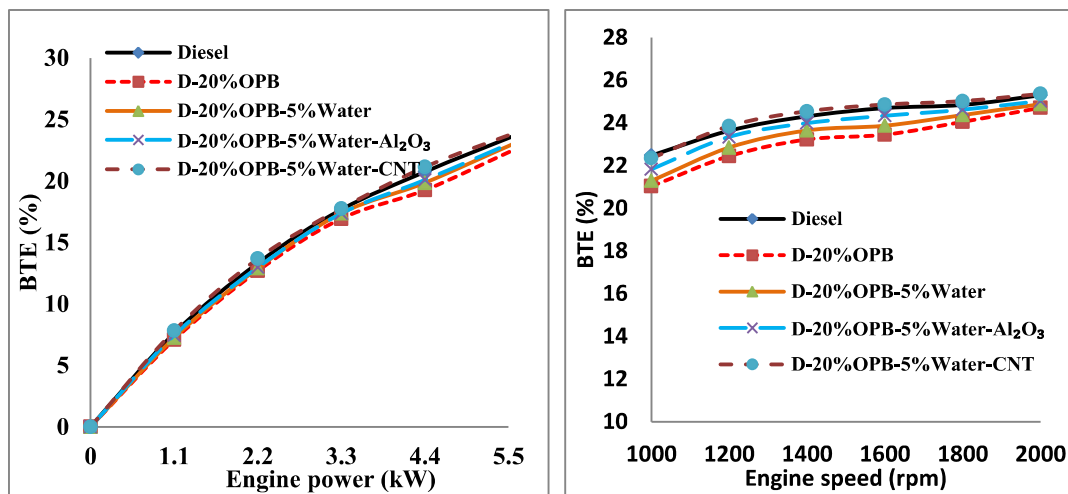


Figure 5.38 BTE variation versus engine power and speed with OPB blended nano fuel

5.4.2 Effect of Engine Power, Engine Speed, and WiDE Based OPB Nano Fuels

Variation on Exergy Efficiency and Exhaust Gas Temperature

The effect of engine power and speed on the exergy efficiency is illustrated in Fig.5.39. The effect of variation of engine power and speed with OPB20 fuel on engine exergy efficiency has been discussed in section 5.1.2. The engine exergy efficiency at each engine speed and power with 5% water emulsified OPB20 fuel are higher than OPB20 fuel because of the lower calorific value of the fuel and secondary atomization of fuel particles due to micro-explosion. With the incorporation of CNT and Al_2O_3

nano-catalyst, the fuel utilization rate reduces due to a shorter period of ignition lag, which enhances the exergy efficiency of the diesel engine compared to 5% water emulsified OPB20. The fuel utilization rate with the CNT catalyst is lower than the Al_2O_3 catalyst, due to which the engine exergy efficiency with the CNT catalyst is higher than the Al_2O_3 catalyst. The engine exergy efficiency at a speed of 1500 rpm and power of 5.5kW with OPB20, 5% water emulsified OPB20, and 5% water emulsified Al_2O_3 incorporated OPB20 fuel is found to be 4.76%, 2.61%, and 2.06% lower and with 5% water emulsified CNT incorporated OPB20 fuel is found to be 1.31% higher than the diesel fuel, respectively.

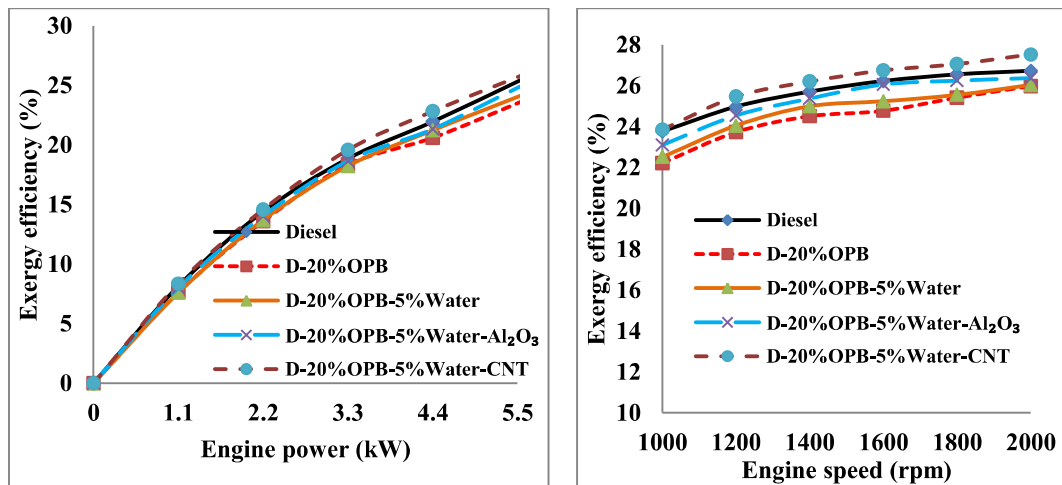


Figure 5.39 Exergy efficiency variation versus engine power and speed with OPB blended nano fuel

The effect of engine speed and power on the exhaust gas temperature is illustrated in Fig.5.40. The effect of engine power and speed variation with OPB20 fuel on engine exhaust gas temperature has been discussed in section 5.1.2. The engine provides a lower exhaust gas temperature with 5% water emulsified OPB20 fuel than OPB20 fuel on account of the lower calorific value of fuel and absorption of energy to vaporize water particles. The exhaust gas temperature with CNT nano additive is lower

than Al_2O_3 nano additive at each engine speed and power, due to a lower fuel consumption rate with CNT fuel. The engine exhaust gas temperature at a speed of 1500 rpm and power of 5.5kW with OPB20 fuel, 5% water emulsified OPB20 fuel, 5% water emulsified Al_2O_3 incorporated OPB20 fuel, and 5% water emulsified CNT incorporated OPB20 fuel is found to be 5.02%, 4.20%, 3.98%, and 1.02% higher than the diesel fuel, respectively.

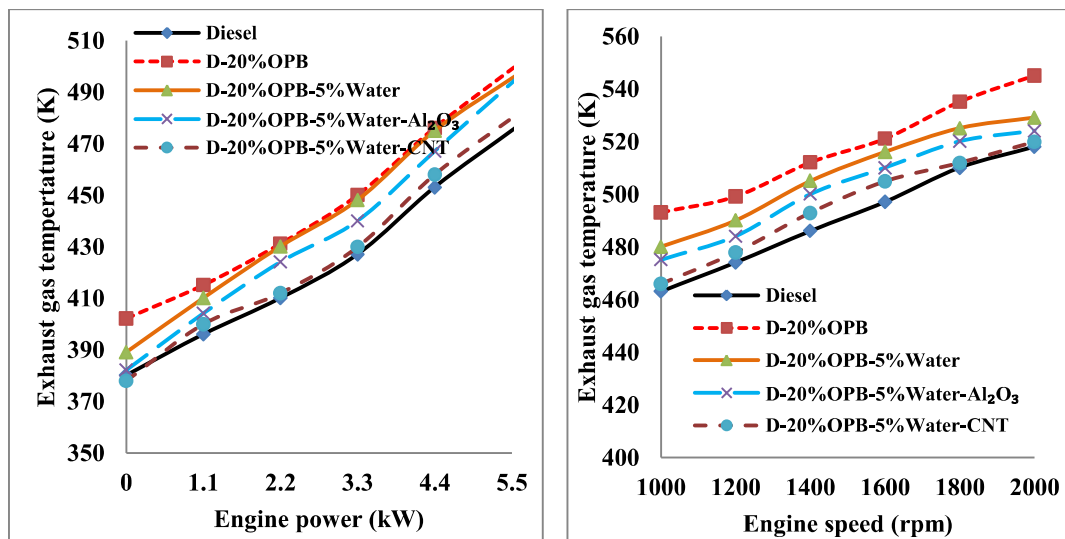


Figure 5.40 Exhaust gas temperature variation versus engine power and speed with OPB blended nano fuel

5.4.3 Effect of Engine Power, Engine Speed, and WiDE Based OPB Nano Fuels Variation on Exergy Destruction Rate and Engine Sustainability Index

The influence of engine speed and power on the engine EDR is illustrated in Fig.5.41. The effect of engine power variation and speed with OPB20 fuel on engine EDR has been discussed in section 5.1.3. The engine provides lower EDR with 5% water emulsified OPB20 fuel than OPB20 fuel due to the lower calorific value of the fuel. The engine EDR at a speed of 1500 rpm and power of 5.5kW with OPB20 fuel, 5% water emulsified OPB20 fuel, 5% water emulsified Al_2O_3 incorporated OPB20 fuel,

and 5% water emulsified CNT incorporated OPB20 fuel is found to be 17.09%, 14.45%, 15.59%, and 16.35% higher than the diesel fuel, respectively.

The influence of engine speed and power on the sustainability index of the engine is illustrated in Fig.5.42. The effect of engine power variation and speed with OPB20 fuel on the engine sustainability index has been discussed in section 5.1.3. The

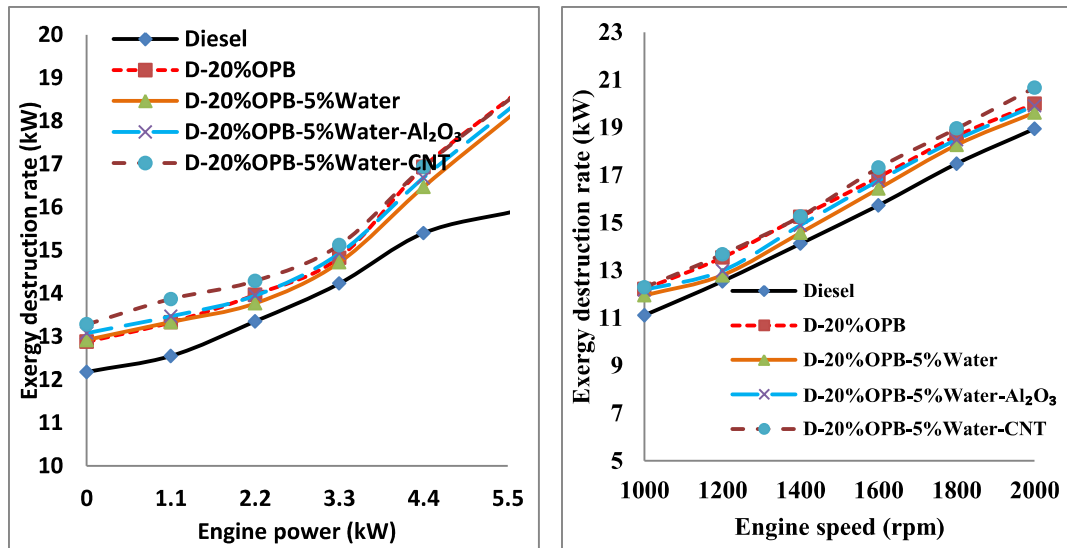


Figure 5.41 Exergy destruction rate variation versus engine power and speed with OPB blended nano fuel

engine sustainability index with 5% water emulsified OPB20 fuel has been observed to be higher than OPB20 fuel due to higher exergy efficiency. With the incorporation of CNT and Al₂O₃ nano-additive, the engine exergy efficiency is higher compared to 5% water emulsified OPB20 fuel; the engine sustainability index has also been found higher with nano-fuel compared to 5% water emulsified OPB20 fuel at each engine speed and power. The engine exergy efficiency with the CNT incorporated fuel is found to be higher compared to Al₂O₃ incorporated fuel due to that engine sustainability with the CNT nano additive fuel is higher than with Al₂O₃ nano additive

fuel. The sustainability index of the engines at a speed of 1500 rpm and power 5.5kW with OPB20 fuel, 5% water emulsified OPB20 fuel, and 5% water emulsified Al_2O_3 incorporated OPB20 fuel is found to be 1.44%, 0.84%, and 0.61% lower and 5% water emulsified CNT incorporated OPB20 fuel is found to be 1.07% higher than the diesel fuel, respectively.

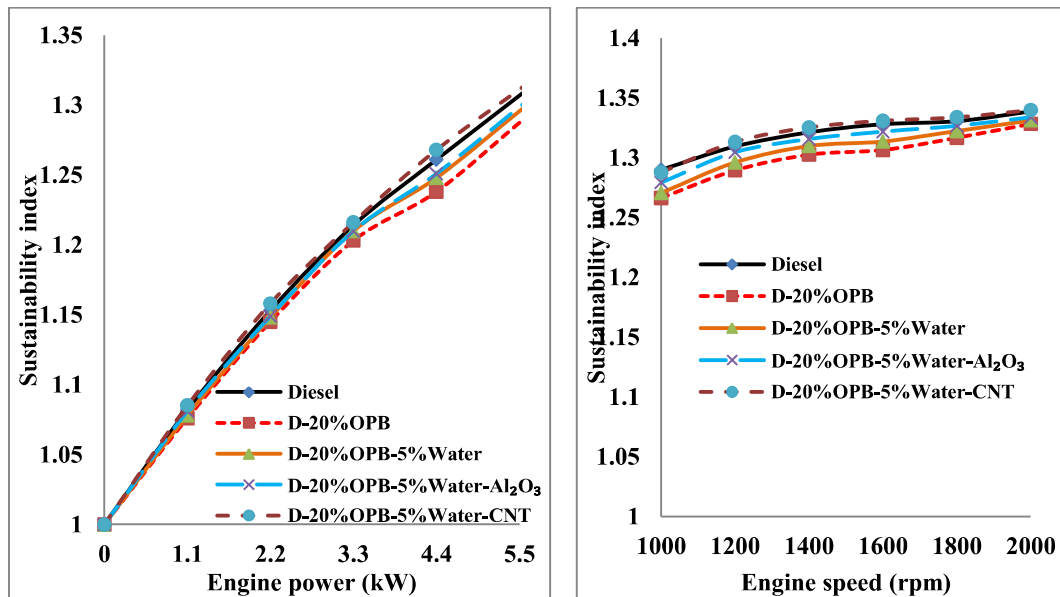


Figure 5.42 Engine sustainability index variation versus engine power and speed with OPB blended nano fuel

5.4.4 Effect of Engine Power, Engine Speed, and WiDE Based OPB Nano Fuels Variation on Entropy Generation Rate and HC Emissions

The effect of engine speed and power on the EGR is illustrated in Fig.5.43. The effect of variation of engine power and speed with OPB20 fuel on engine EGR has been discussed in section 5.1.4. The engine provides lower EGR with 5% water emulsified OPB20 fuel than OPB20 fuel due to lower LHV. The engine EDR with the CNT incorporated fuel is found to be higher compared to Al_2O_3 incorporated fuel due to that engine EGR with the CNT nano additive fuel is higher than with Al_2O_3 nano

additive fuel. The engine EGR at a speed of 1500 rpm and power of 5.5kW with OPB20 fuel, 5% water emulsified OPB20 fuel, 5% water emulsified Al_2O_3 incorporated OPB20 fuel, and 5% water emulsified CNT incorporated OPB20 fuel is found to be 17.09%, 14.45%, 15.59%, and 16.97% higher than the diesel fuel, respectively.

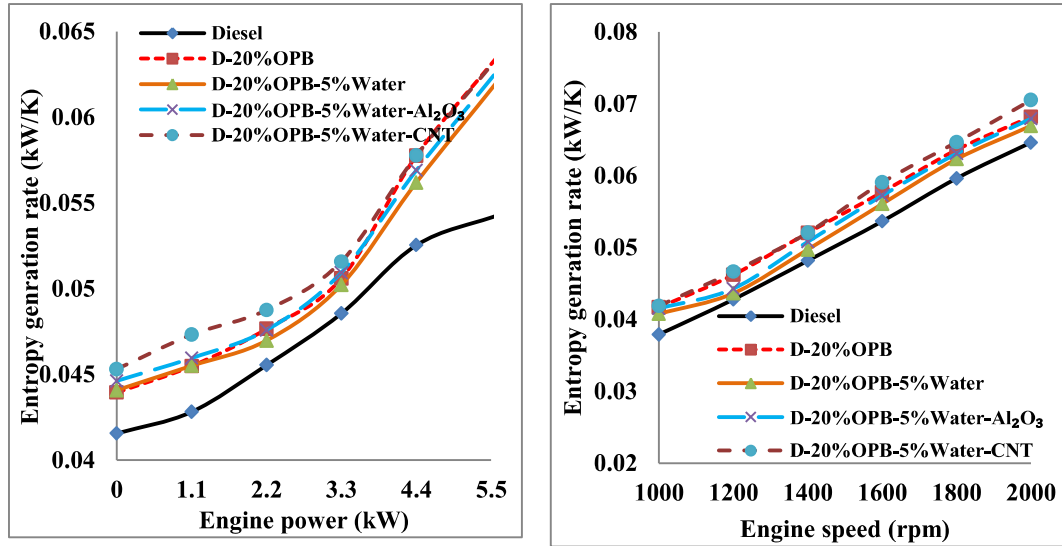


Figure 5.43 Entropy generation rate variation versus engine power and speed with OPB blended nano fuel

The effect of engine speed and power on the HC emissions of the engine is illustrated in Fig.5.44. The effect of engine power variation and speed with OPB20 fuel on engine HC emissions has been discussed in section 5.1.4. The HC emissions of the engine with 5% water emulsified OPB20 fuel is observed to be lower than OPB20 fuel due to micro-explosion and secondary atomization of fuel particles. With the incorporation of CNT and Al_2O_3 nano-additive, the HC emission of the engine is found to be lower compared to 5% water emulsified OPB20 fuel due to the higher rate of secondary atomization and improved combustion quality. The fuel combustion rate with the CNT nano additive fuel is lower compared to Al_2O_3 nano additive fuel because

the HC emissions of the engine with the CNT incorporated fuel are lower than Al_2O_3 incorporated fuel. The HC emissions of the engines at a speed of 1500 rpm and power 5.5kW with OPB20 fuel, 5% water emulsified OPB20 fuel, 5% water emulsified Al_2O_3 incorporated OPB20, and 5% water emulsified CNT incorporated OPB20 fuel is found to be 7.14%, 12.5%, 42.85%, and 46.43% lower than the diesel fuel, respectively.

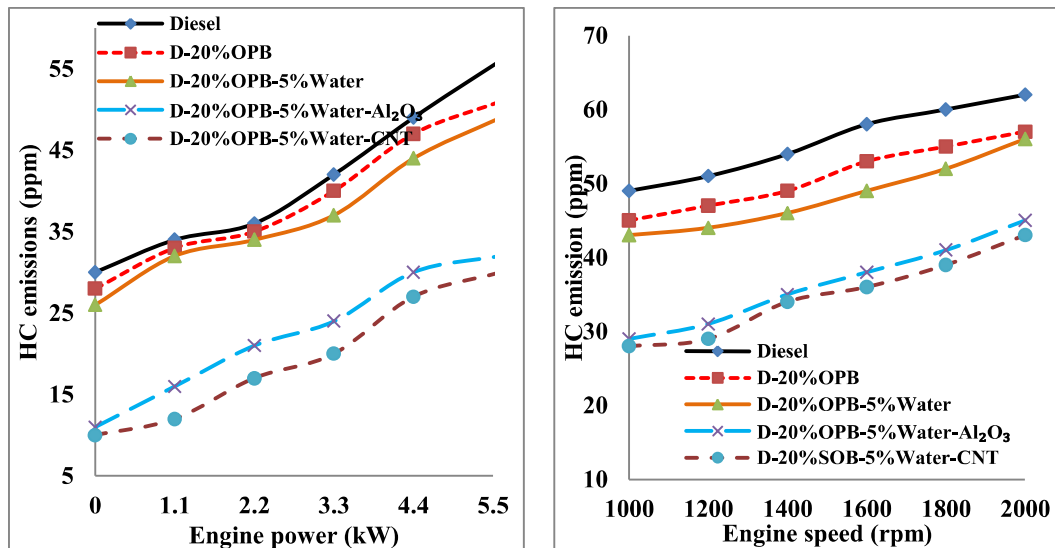


Figure 5.44 HC emissions variation versus engine power and speed with OPB blended nano fuel

5.4.5 Effect of Engine Power, Engine Speed, and WiDE Based OPB Nano Fuels Variation on CO Emissions and CO₂ Emissions

The influence of engine speed and power on the CO emission of the engine is illustrated in Fig.5.45. The effect of engine power and speed variation with OPB20 fuel on engine CO emissions has been discussed in section 5.1.5. The CO emissions of the engine with 5% water emulsified OPB20 fuel is observed to be lower than OPB20 fuel due to superior combustion quality and higher O₂ availability. With the incorporation of CNT and Al_2O_3 nano-additive, the CO emission of the engine is found to reduce further compared to 5% water emulsified OPB20 fuel due to the higher rate of secondary

atomization, improved combustion quality, and shorter ignition delay period. The ignition delay period with the CNT nano additive fuel is lower than Al_2O_3 nano additive fuel due to the fuel consumption rate with the CNT nano additive fuel is also lower than the Al_2O_3 nano additive fuel, and the CO emissions of the engine with the CNT incorporated fuel is found lower compared to Al_2O_3 incorporated fuel. The CO emissions of the engines at a speed of 1500 rpm and power 5.5kW with OPB20 fuel, 5% water emulsified OPB20 fuel, 5% water emulsified Al_2O_3 incorporated OPB20, and 5% water emulsified CNT incorporated OPB20 fuel is found to be 3.75%, 6.25%, 10%, and 15% lower than the diesel fuel, respectively.

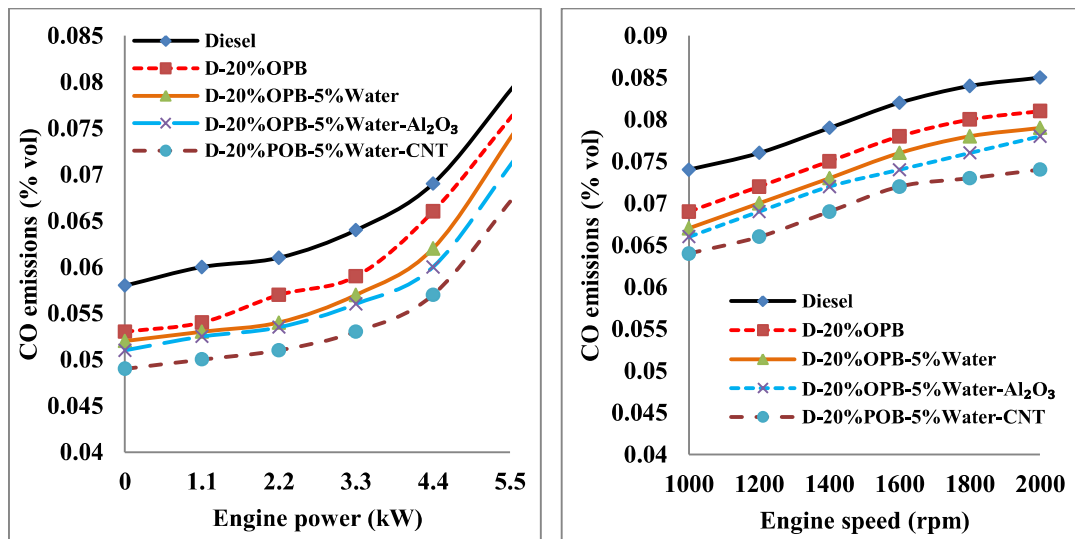


Figure 5.45 CO emissions variation versus engine power and speed with OPB blended nano fuel

The effect of engine speed and power on the CO_2 emissions of the engine is illustrated in Fig.5.46. The effect of engine power and speed variation with OPB20 fuel on engine CO_2 emissions has been discussed in section 5.1.5. The CO_2 emissions of the engine with 5% water emulsified OPB20 fuel and nano additive incorporated water emulsified fuels is observed to be higher than OPB20 fuel due to superior combustion

quality. The fuel combustion quality with the CNT nano additive fuel is superior to Al_2O_3 nano additive fuel due to the lower fuel consumption rate and higher oxygen availability; on account of that, the CO_2 emissions of the engine with the CNT incorporated fuel is found to be higher compared to Al_2O_3 incorporated fuel. The CO_2 emissions of the engines at a speed of 1500 rpm and power 5.5kW with OPB20 fuel, 5% water emulsified OPB20 fuel, 5% water emulsified Al_2O_3 incorporated OPB20, and 5% water emulsified CNT incorporated OPB20 fuel is found to be 7.65%, 4.61%, 10.77%, and 12.31% higher than the diesel fuel, respectively.

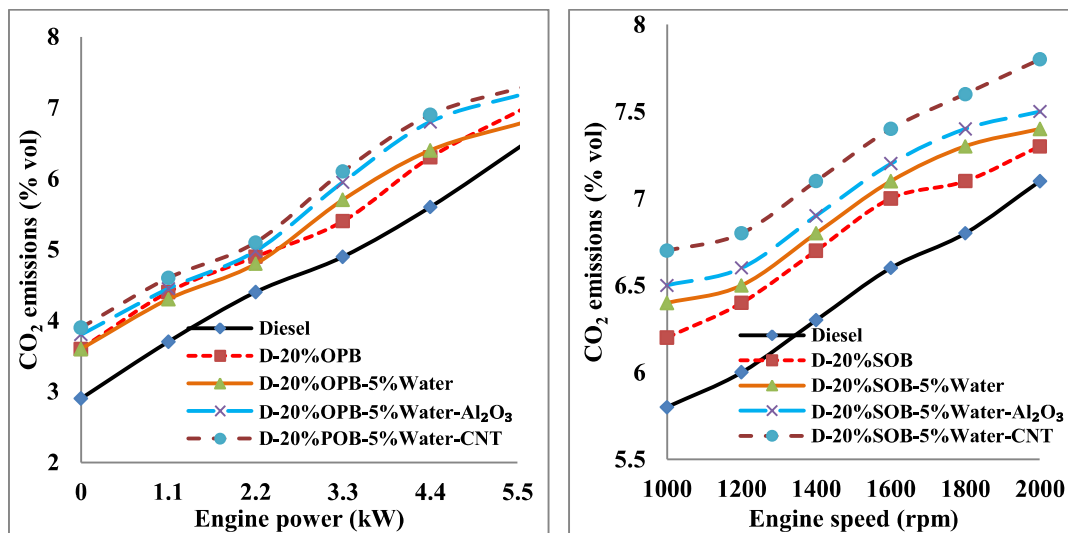


Figure 5.46 CO₂ emissions variation versus engine power and speed with OPB

blended nano fuel

5.4.6 Effect of Engine Power, Engine Speed, and WiDE Based OPB Nano Fuels

Variation on NO Emissions and Smoke Opacity Emissions

The effect of engine speed and power on the NO emissions of the engine is illustrated in Fig.5.47. The effect of engine power variation and speed with OPB20 fuel on engine NO emissions has been discussed in section 5.1.6. The NO emissions of the engine with 5% water emulsified OPB20 fuel and nano additive incorporated water

emulsified fuels are observed to be lower than OPB20 fuel due to lower in-cylinder temperature. The NO emissions of the engine with the CNT incorporated fuel are lower than Al_2O_3 incorporated fuel because the CNT nano additive absorbed more heat than the Al_2O_3 nano additive due to higher thermal conductivity. The NO emission of the engines at a speed of 1500 rpm and power 5.5kW with OPB20 fuel, 5% water emulsified OPB20 fuel, 5% water emulsified Al_2O_3 incorporated OPB20, and 5% water emulsified CNT incorporated OPB20 fuel is found to be 7.78%, 3.79%, 2.59%, and 1.20% higher than the diesel fuel, respectively.

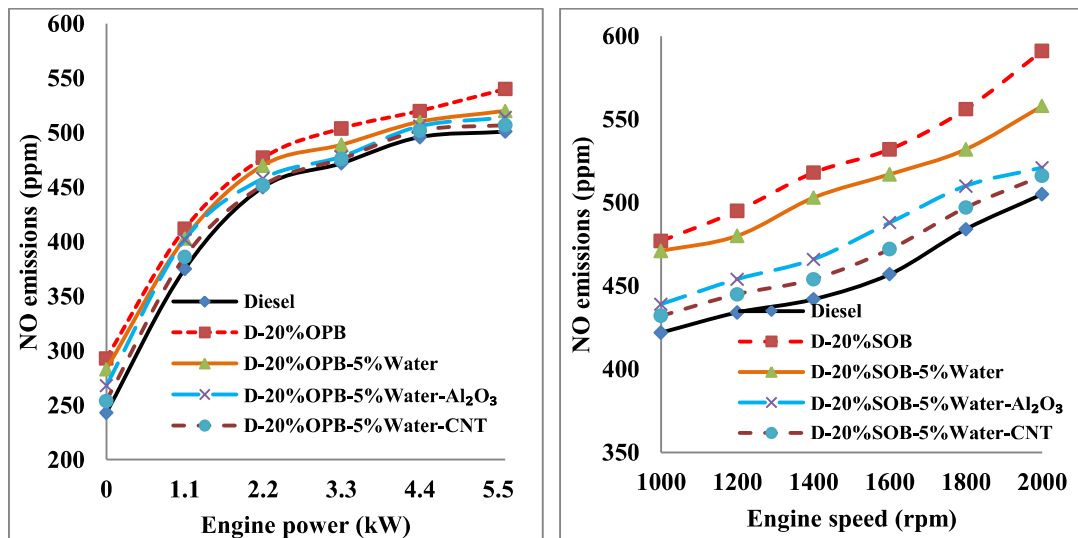


Figure 5.47 NO emissions variation versus engine power and speed with OPB blended nano fuel

The effect of engine speed and power on the smoke emissions of the engine is illustrated in Fig.5.48. The effect of engine power and speed variation with OPB20 fuel on engine smoke emissions has been discussed in section 5.1.6. The smoke emissions of the engine with 5% water emulsified OPB20 fuel and nano additive incorporated water emulsified fuels are observed to be lower than OPB20 fuel due to superior combustion quality. The fuel combustion quality with the CNT nano additive fuel is

superior to Al_2O_3 nano additive fuel that the smoke emissions of the engine with the CNT incorporated fuel are lower than Al_2O_3 incorporated fuel. The smoke emissions of the CI engines at a speed of 1500 rpm and power 5.5kW with OPB20 fuel, 5% water emulsified OPB20 fuel, 5% water emulsified Al_2O_3 incorporated OPB20, and 5% water emulsified CNT incorporated OPB20 fuel is found to be 21.42%, 26.79%, 39.29%, and 41.07% lower than the diesel fuel, respectively.

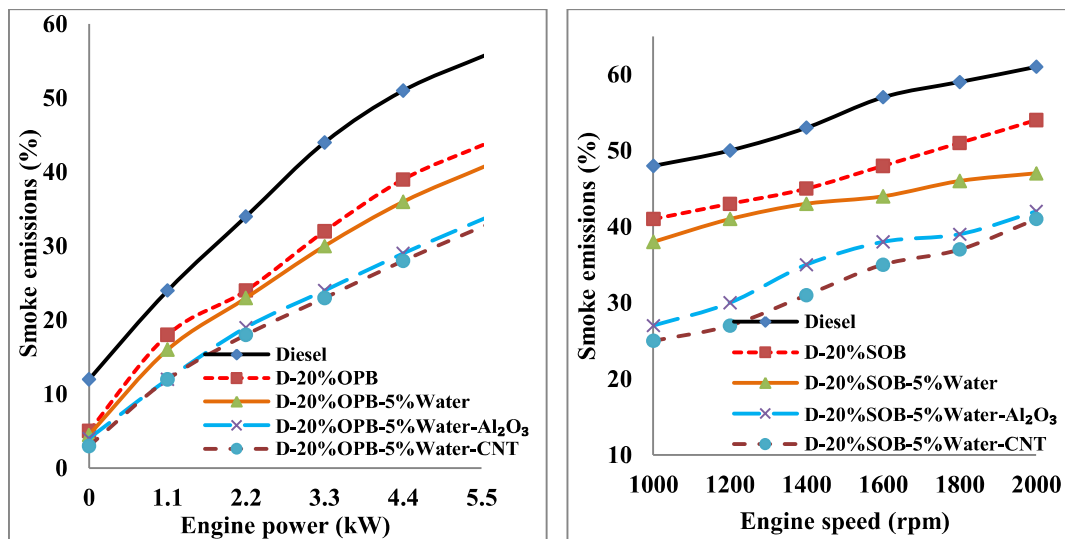


Figure 5.48 Smoke emissions variation versus engine power and speed with OPB blended nano fuel

5.5 Analysis of Diesel Engine Performance and Emission Parameters Fuelled with Water Emulsified SOB Blended Nano Additive Incorporated Fuel

5.5.1 Effect of Engine Power, Engine Speed, and WiDE Based SOB Nano Fuels Variation on BSFC and BTE

The effect of engine speed and power on engine BSFC with SOB20 blended nano fuel is illustrated in Fig.5.49. The effect of variation of engine power and speed with SOB20 fuel on engine BSFC has been discussed in section 5.1.1. The emulsification of 5% water in SOB-diesel blended fuel further enhances the density,

kinematic viscosity, and BSFC at each engine speed and power. The effect of the incorporation of nano-additives has been discussed in section 5.4.1. It is also noted that the diesel engine BSFC with CNT nano-catalyst is higher than the Al_2O_3 nano-catalyst. The engine BSFC at speed 1500 rpm and 5.5kW power with SOB20, 5% water emulsified SOB20, 5% water emulsified CNT incorporated SOB20 and 5% water emulsified Al_2O_3 incorporated SOB20 fuel is found 1.02%, 2.07%, 0.93%, and 0.88% higher compared to diesel fuel. The engine BSFC with 5% water emulsified CNT incorporated SOB20 and 5% water emulsified Al_2O_3 incorporated SOB20 fuel is found to be 1.08% and 1.16% lower than 5% water emulsified SOB20 fuel.

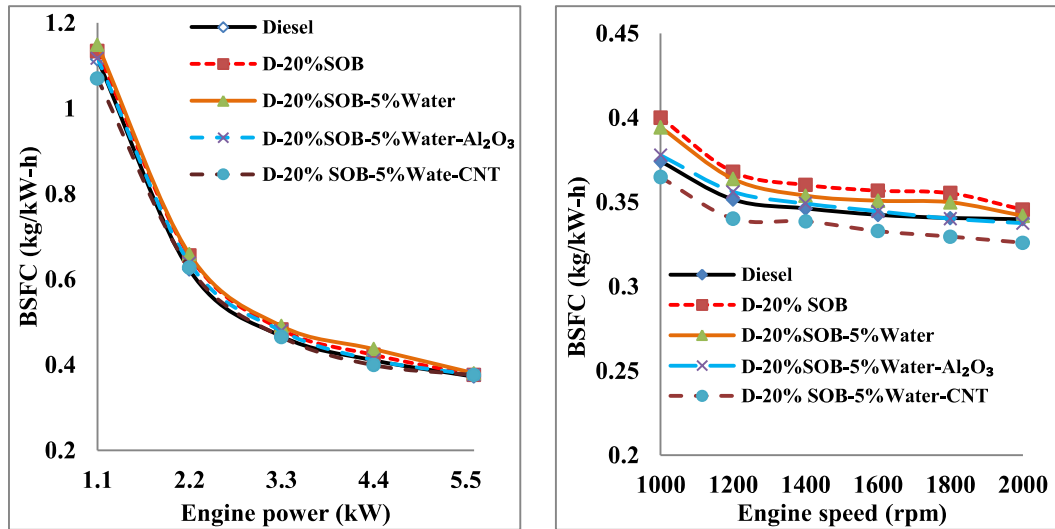


Figure 5.49 BSFC variation versus engine power and speed with SOB blended nano fuel

The effect of engine speed and power on engine BTE with SOB20 blended nano fuel is illustrated in Figure 5.50. The effect of variation of engine power and speed with SOB20 fuel on engine BTE has been discussed in section 5.1.1. The engine BTE at each engine speed and power with 5% water emulsified SOB20 fuel is higher than SOB20 fuel because of the lower calorific value of the fuel and secondary atomization

of fuel particles due to micro-explosion. With the incorporation of CNT and Al_2O_3 nano-catalyst, the fuel utilization rate reduces due to a shorter period of ignition lag, which enhances the BTE of the diesel engine compared to 5% water emulsified SOB20. The fuel utilization rate with the CNT catalyst is lower than the Al_2O_3 catalyst, due to which the engine BTE with the CNT catalyst is higher than the Al_2O_3 catalyst. The engine BTE at a speed of 1500 rpm and power 5.5kW with SOB20, 5% water emulsified SOB20, and 5% water emulsified Al_2O_3 incorporated SOB20 fuel is found to be 9.75%, 6.44%, and 2.61% lower and with 5% water emulsified CNT incorporated SOB20 fuel is found to be 1.37% higher than the diesel fuel, respectively.

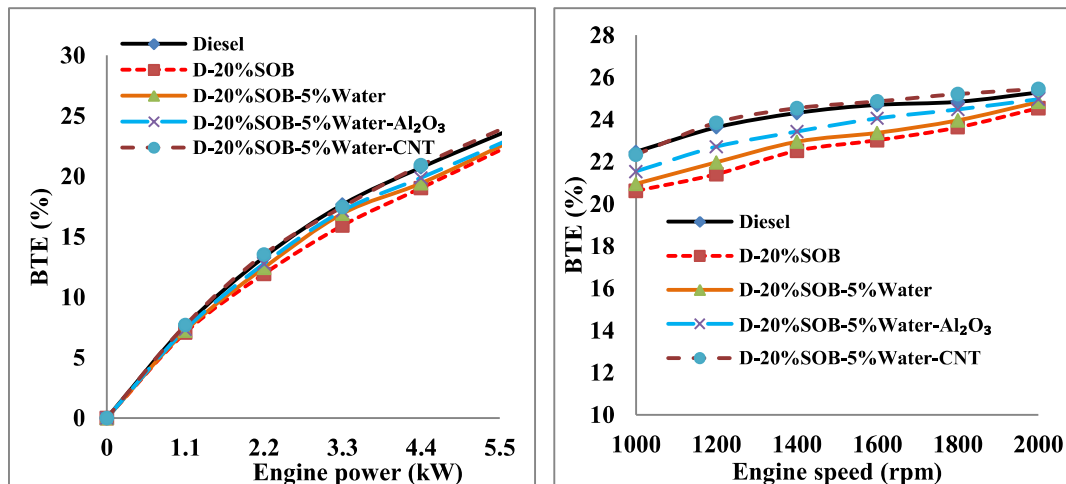


Figure 5.50 BTE variation versus engine power and speed with SOB blended nano fuel

5.5.2 Effect of Engine Power, Engine Speed, and Wide Based SOB Nano Fuels on Exergy Efficiency and Exhaust Gas Temperature

The effect of engine power and speed on the exergy efficiency with SOB20 blended nano fuel is illustrated in Fig.5.51. The effect of variation of engine power and speed with SOB20 fuel on engine exergy efficiency has been discussed in section 5.1.2. The engine exergy efficiency at each engine speed and power with 5% water emulsified

SOB20 fuel are higher than SOB20 fuel because of the lower calorific value of the fuel and secondary atomization of fuel particles due to micro-explosion. The effect of the incorporation of CNT and Al_2O_3 nano-catalyst in blended biodiesel fuel has been discussed in section 5.4.2. The engine exergy efficiency at a speed of 1500 rpm and the power of 5.5kW with SOB20, 5% water emulsified SOB20, and 5% water emulsified Al_2O_3 incorporated SOB20 fuel is found to be 5.56%, 4.21%, and 3.33% lower and with 5% water emulsified CNT incorporated SOB20 fuel is found to be 1.52% higher than the diesel fuel, respectively.

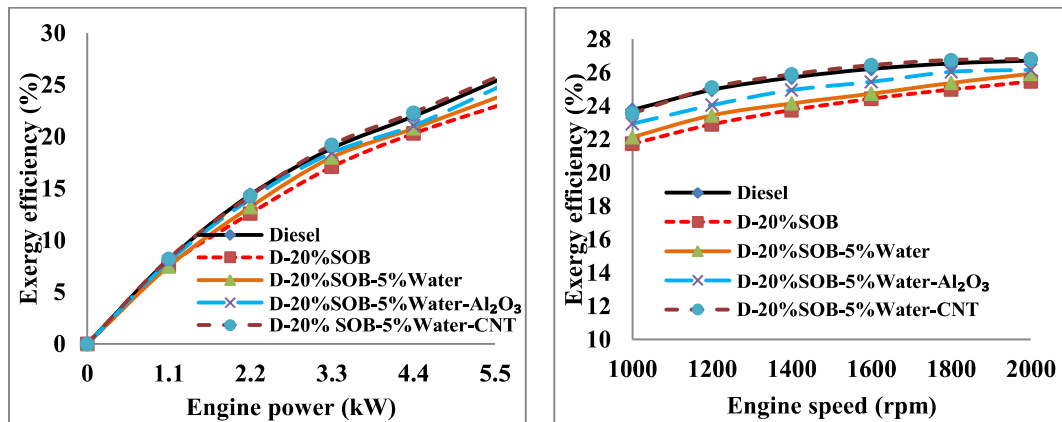


Figure 5.51 Exergy efficiency variation versus engine power and speed with SOB blended nano fuel

The effect of engine speed and power on the exhaust gas temperature with SOB20 blended fuel is illustrated in Fig.5.52. The effect of variation of engine power and speed with SOB20 fuel on engine exhaust gas temperature has been discussed in section 5.1.2. The engine provides a lower exhaust gas temperature with 5% water emulsified SOB20 fuel than SOB20 fuel because of the lower calorific value of fuel and energy absorption to vaporize water particles. The exhaust gas temperature with CNT nano additive is lower than Al_2O_3 nano additive at each engine speed and power

due to a lower fuel consumption rate with CNT fuel. The engine exhaust gas temperature at a speed of 1500 rpm and power of 5.5kW with OPB20 fuel, 5% water emulsified SOB20 fuel, 5% water emulsified Al_2O_3 incorporated SOB20 fuel, and 5% water emulsified CNT incorporated SOB20 fuel is found to be 5.67%, 5.04%, 4.40%, and 1.85% higher than the diesel fuel, respectively.

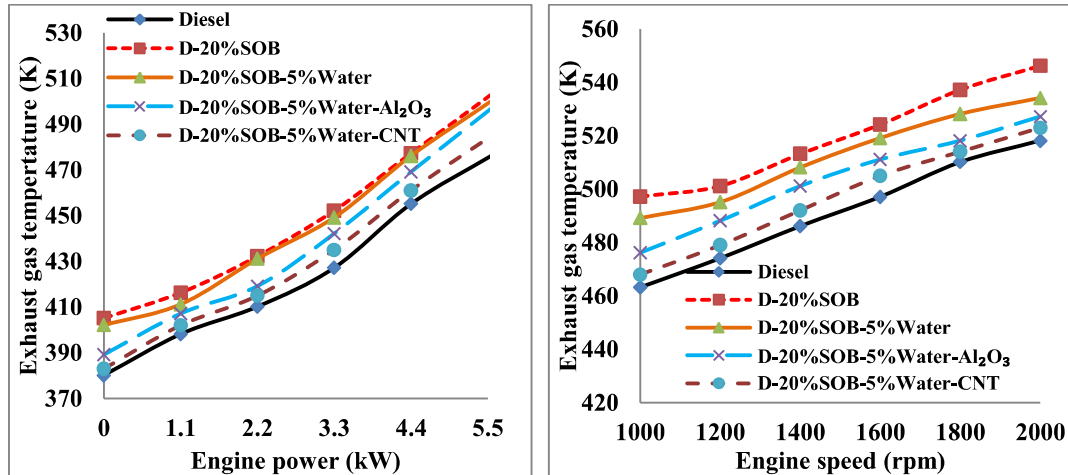


Figure 5.52 Exhaust gas temperature variation versus engine power and speed with SOB blended nano fuel

5.5.3 Effect of Engine Power, Engine Speed, and WiDE Based SOB Nano Fuels on Exergy Destruction Rate and Engine Sustainability Index

The influence of engine speed and power on the engine EDR with SOB20 blended nano is illustrated in Fig.5.53. The effect of engine power and speed variation with SOB20 fuel on engine EDR has been discussed in section 5.1.3. The engine provides lower EDR with 5% water emulsified SOB20 fuel than SOB20 fuel due to the lower calorific value of the fuel. The engine EDR at a speed of 1500 rpm and power of 5.5kW with SOB20 fuel, 5% water emulsified SOB20 fuel, 5% water emulsified Al_2O_3 incorporated SOB20 fuel, and 5% water emulsified CNT incorporated SOB20 fuel is

found to be 9.93%, 9.42%, 12.38%, and 13.83% higher than the diesel fuel, respectively.

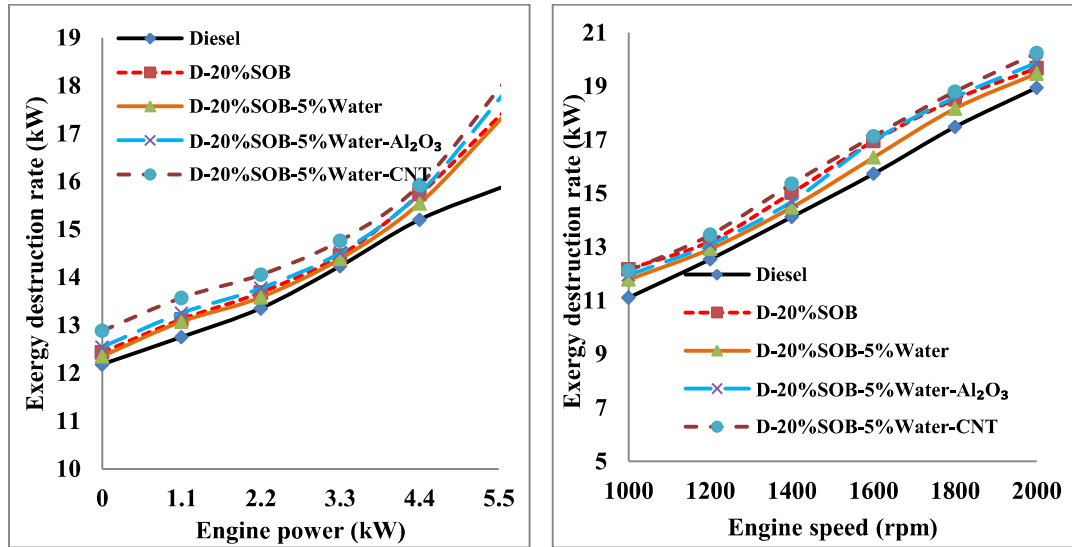


Figure 5.53 Exergy destruction rate variation versus engine power and speed with SOB blended nano fuel

The influence of engine speed and power on the sustainability index of the engine with SOB20 blended nano fuel is illustrated in Fig.5.54. The effect of engine power and speed variation with SOB20 fuel on the engine sustainability index has been discussed in section 5.1.3. The engine sustainability index with 5% water emulsified SOB20 fuel has been observed to be higher than SOB20 fuel due to higher exergy efficiency. With the incorporation of CNT and Al₂O₃ nano-additive, the engine exergy efficiency is higher compared to 5% water emulsified SOB20 fuel; due to that, the engine sustainability index has also been found higher with nano-fuel compared to 5% water emulsified SOB20 fuel at each engine speed and load. The engine exergy efficiency with the CNT incorporated fuel is found to be higher compared to Al₂O₃ incorporated fuel due to that engine sustainability with the CNT nano additive fuel is higher than with Al₂O₃ nano additive fuel. The sustainability index of the engines at a

speed of 1500 rpm and power 5.5kW with OPB20 fuel, 5% water emulsified SOB20 fuel, and 5% water emulsified Al_2O_3 incorporated SOB20 fuel is found to be 1.68%, 1.29%, and 0.99% lower and 5% water emulsified CNT incorporated SOB20 fuel is found to be 0.68% higher than the diesel fuel, respectively.

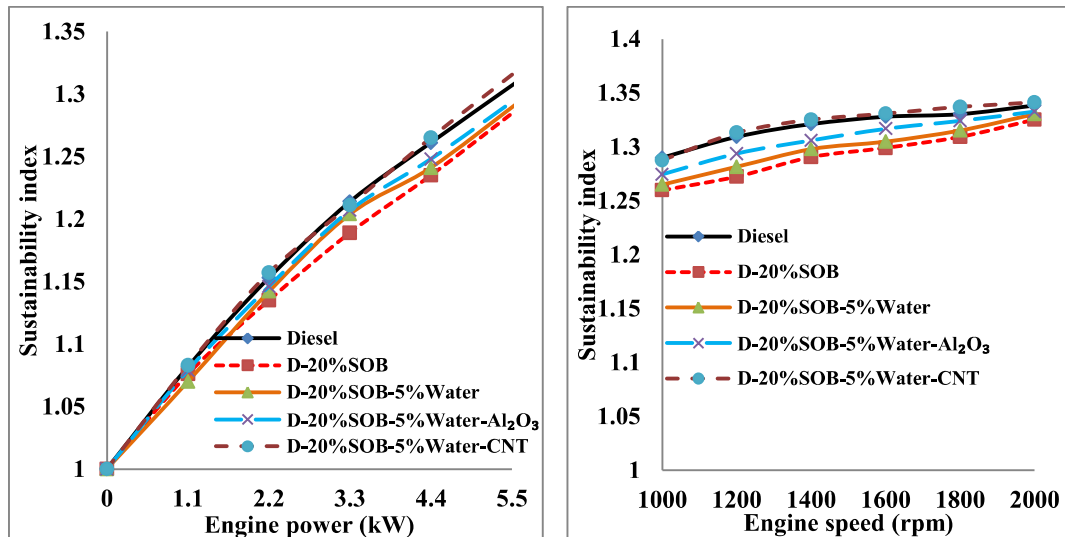


Figure 5.54 Engine sustainability index variation versus engine power and speed with SOB blended nano fuel

5.5.4 Effect of Engine Power, Engine Speed, and WiDE Based SOB Nano Fuels on Entropy Generation Rate and HC Emissions

The effect of engine speed and power on the EGR with SOB20 blended nano fuel is illustrated in Fig.5.55. The effect of variation of engine power and speed with SOB20 fuel on engine EGR has been discussed in section 5.1.4. The engine provides lower EGR with 5% water emulsified SOB20 fuel than SOB20 fuel due to lower calorific value. The diesel engine EDR with the CNT incorporated fuel is found to be higher compared to Al_2O_3 incorporated fuel due to that engine EGR with the CNT nano additive fuel is higher than with Al_2O_3 nano additive fuel. The engine EGR at a speed of 1500 rpm and power of 5.5kW with SOB20 fuel, 5% water emulsified SOB20 fuel,

5% water emulsified Al_2O_3 incorporated SOB20 fuel, and 5% water emulsified CNT incorporated SOB20 fuel is found to be 9.93%, 9.42%, 12.38%, and 13.83% higher than the diesel fuel, respectively.

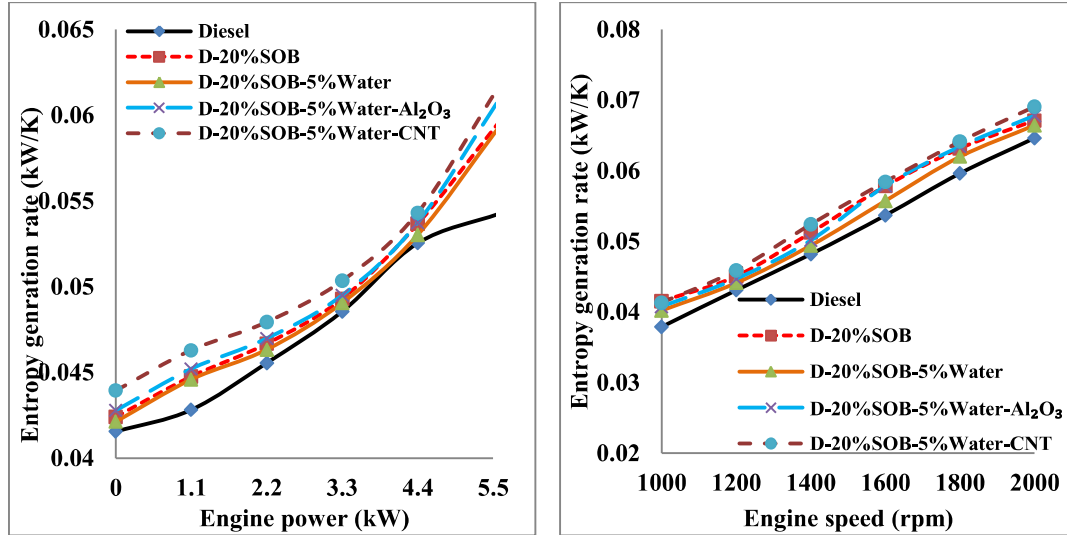


Figure 5.55 Entropy generation rate variation versus engine power and speed with SOB blended nano fuel

The effect of engine speed and power on the HC emissions of the engine with SOB20 blended nano fuel is illustrated in Fig.5.56. The effect of engine power and speed variation with SOB20 fuel on engine HC emissions has been discussed in section 5.1.4. The HC emissions of the engine with 5% water emulsified SOB20 fuel is observed to be lower than SOB20 fuel due to micro-explosion and secondary atomization of fuel particles. With the incorporation of CNT and Al_2O_3 nano-additive, the HC emissions of the engine is found to be lower compared to 5% water emulsified SOB20 fuel due to the higher rate of secondary atomization and improved combustion quality. The fuel combustion quality with the CNT nano additive fuel is superior compared to Al_2O_3 nano additive fuel due to that the HC emissions of the engine with the CNT incorporated fuel is lower than Al_2O_3 incorporated fuel. The HC emissions of

the diesel engines at a speed of 1500 rpm and power 5.5kW with OPB20 fuel, 5% water emulsified SOB20 fuel, 5% water emulsified Al_2O_3 incorporated SOB20, and 5% water emulsified CNT incorporated SOB20 fuel is found to be 10.71%, 12.5%, 46.42%, and 51.78% lower than the diesel fuel, respectively.

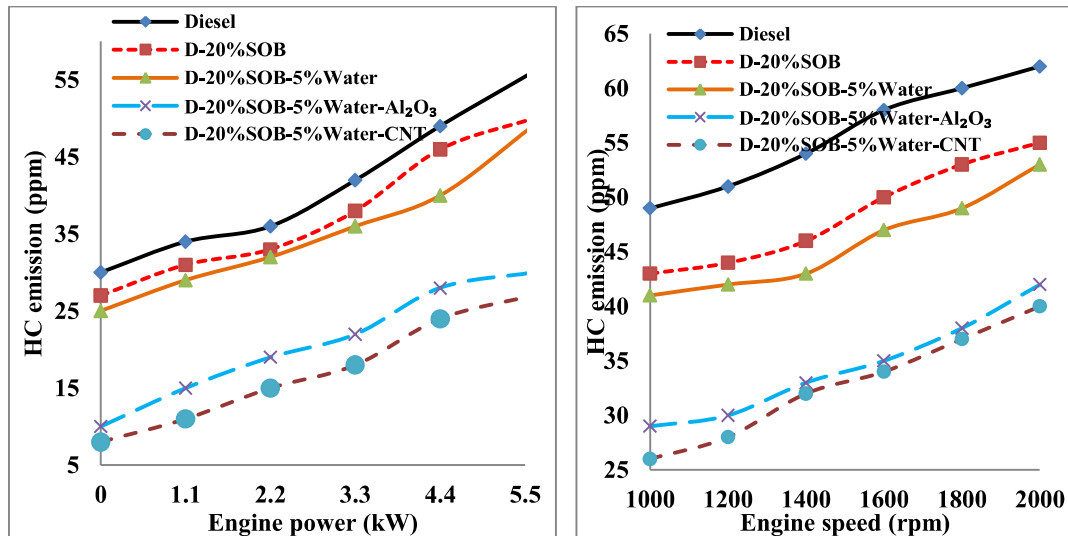


Figure 5.56 HC emissions variation versus engine power and speed with SOB blended nano fuel

5.5.5 Effect of Engine Power, Engine Speed, and WiDE Based SOB Nano Fuels on CO Emissions and CO_2 Emissions

The effect of engine speed and power on the CO emissions of the engine with SOB20 blended nano fuel is illustrated in Fig.5.57. The effect of engine power and speed variation with SOB20 fuel on engine CO emissions has been discussed in section 5.1.5. The CO emissions of the engine with 5% water emulsified SOB20 fuel is observed to be lower than SOB20 fuel due to superior combustion quality. With the incorporation of CNT and Al_2O_3 nano-additive, the CO emissions of the engine are found to further reduce compared to 5% water emulsified SOB20 fuel due to the higher rate of secondary atomization and improved combustion quality. The fuel combustion

quality with the CNT nano additive fuel is superior to Al_2O_3 nano additive fuel due to that the CO emissions of the engine with the CNT incorporated fuel is found to be lower compared to Al_2O_3 incorporated fuel. The CO emissions of the diesel engines at a speed of 1500 rpm and power 5.5kW with SOB20 fuel, 5% water emulsified SOB20 fuel, 5% water emulsified Al_2O_3 incorporated SOB20, and 5% water emulsified CNT incorporated SOB20 fuel is found to be 3.75%, 5.0%, 7.5%, and 12.5% lower than the diesel fuel, respectively.

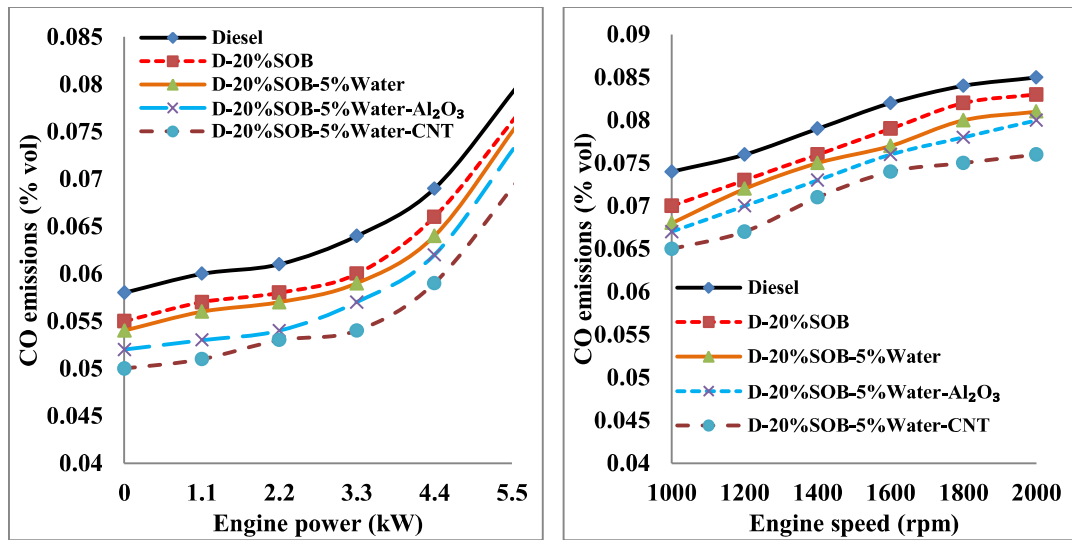


Figure 5.57 CO emissions variation versus engine power and speed with SOB blended nano fuel

The influence of engine speed and power on the CO_2 emissions of the engine with SOB20 blended nano fuel is illustrated in Fig.5.58. The effect of engine power variation and speed with SOB20 fuel on engine CO_2 emissions has been discussed in section 5.1.5. The CO_2 emissions of the engine with 5% water emulsified SOB20 fuel and nano additive incorporated water emulsified fuels are observed to be higher than SOB20 fuel due to superior combustion quality. The CO_2 emissions of the diesel engines at a speed of 1500 rpm and power 5.5kW with SOB20 fuel, 5% water

emulsified SOB20 fuel, 5% water emulsified Al_2O_3 incorporated SOB20, 5% water emulsified CNT incorporated SOB20 fuel is found to be 6.15%, 9.23%, 12.31%, and 15.38% higher than the diesel fuel, respectively.

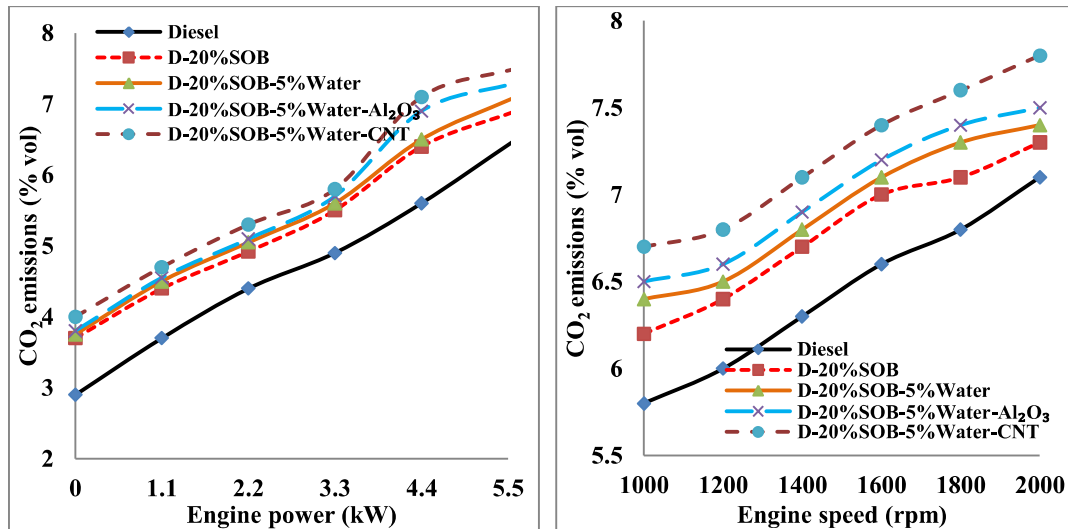


Figure 5.58 CO₂ emissions variation versus engine power and speed with SOB blended nano fuel

5.5.6 Effect of Engine Power, Engine Speed, and WiDE Based SOB Nano Fuels on NO_x and Smoke Emissions

The effect of engine speed and power on the NO emissions of the engine with SOB20 blended nano fuel is illustrated in Fig.5.59. The effect of engine power and speed variation with SOB20 fuel on engine NO emissions has been discussed in section 5.1.6. The NO emissions of the engine with 5% water emulsified SOB20 fuel and nano additive incorporated water emulsified fuels are observed to be lower than SOB20 fuel due to lower in-cylinder temperature. The NO emissions of the engine with the CNT incorporated fuel are lower than Al_2O_3 incorporated fuel. The NO emissions of the diesel engines at a speed of 1500 rpm and power 5.5kW with SOB20 fuel, 5% water emulsified SOB20 fuel, 5% water emulsified Al_2O_3 incorporated SOB20, and 5% water

emulsified CNT incorporated SOB20 fuel is found to be 9.58%, 5.58%, 3.19%, and 2.39% higher than the diesel fuel, respectively.

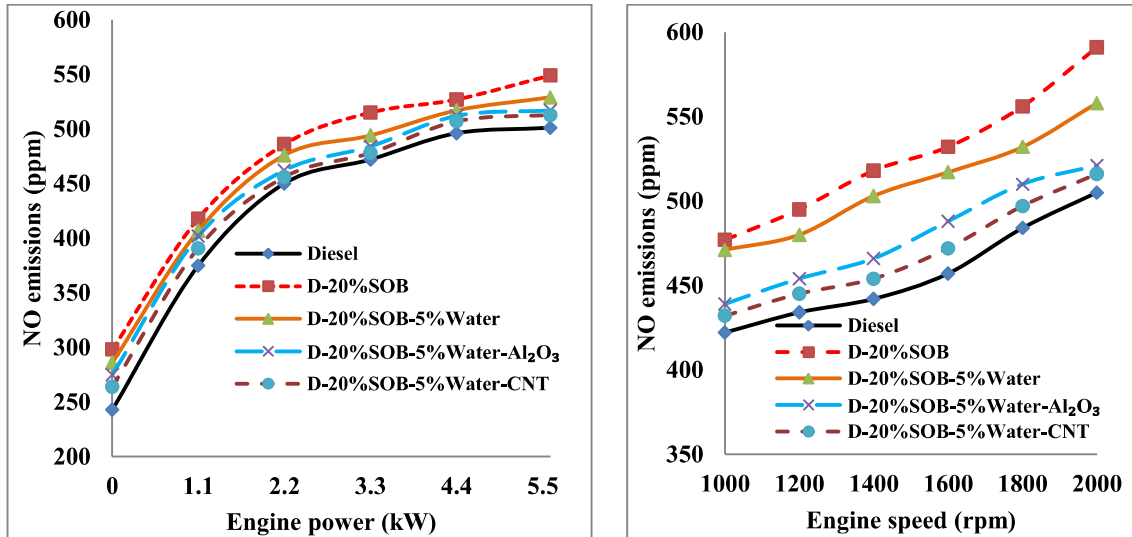


Figure 5.59 NO emissions variation versus engine power and speed with SOB blended nano fuel

The effect of engine speed and power on the smoke emissions of the engine with SOB20 blended nano fuel is illustrated in Fig.5.60. The effect of engine power variation and speed with SOB20 fuel on engine smoke emissions has been discussed in section 5.1.6. The smoke emissions of the engine with 5% water emulsified SOB20 fuel and nano additive incorporated water emulsified fuels are observed to be lower than SOB20 fuel due to superior combustion quality. The smoke emissions of the engines at a speed of 1500 rpm and power 5.5kW with SOB20 fuel, 5% water emulsified SOB20 fuel, 5% water emulsified Al₂O₃ incorporated SOB20, and 5% water emulsified CNT incorporated SOB20 fuel is found to be 16.10%, 23.21%, 32.14%, and 37.5% lower than the diesel fuel, respectively.

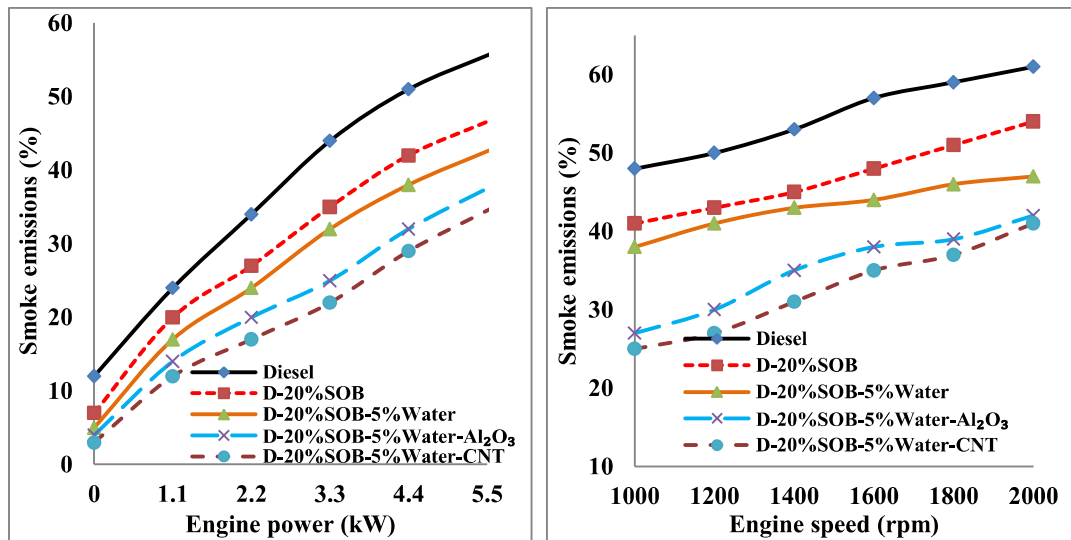


Figure 5.60 Smoke emissions variation versus engine power and speed with SOB blended nano fuel

5.6 Highlights

In this chapter, the effect of variation of engine power and speed on engine performance and emission parameters with OPB blended fuel, SOB blended fuel, and water emulsified fuel have been investigated, and the investigation has also been performed with OPB20 fuel, 5% water emulsified OPB20 fuel, Al₂O₃ and CNT nano additive incorporated 5% water emulsified OPB20 fuel, SOB20 fuel, 5% water emulsified SOB20 fuel, and Al₂O₃ and CNT nano additive incorporated 5% water emulsified SOB20 fuel. Comparative analyses have been performed with the outcomes obtained with diesel fuel. The following observation is taken from the detailed analysis.

- The engine BSFC was reduced, and BTE, exergy efficiency, EDR, EGT, and sustainability index were observed to be increased with an increase in engine power and speed for each fuel sample.
- The engine emission parameters, i.e., NO, CO, CO₂, HC, and smoke emissions, were observed to be increased with increased engine power and speed.

-
- The engine performance parameters, i.e., BSFC, exergy destruction rate, and exhaust gas temperature and emission parameters, i.e., NO and CO₂ emissions, were observed increased with OPB and SOB blended fuel.
 - The engine performance parameters, i.e., BTE, exergy efficiency, sustainability index, and emission parameters, i.e., CO, HC, and smoke emissions, were reduced with OPB and SOB blended fuel.
 - The engine HC emissions was found lowest for OPB20 fuel among all OPB blended fuels and SOB20 blend fuel among all SOB blended fuels.
 - The engine BSFC and CO₂ emissions were observed increased with water emulsified fuel compared to diesel fuel. Further, with an increase in the fraction of water in water emulsification fuel, the engine BSFC and CO₂ emissions were observed to be increased.
 - The engine BTE, exergy efficiency, and sustainability index were observed to increase up to 5% of water emulsification in water emulsified fuel, and with a higher percentage of water emulsification, these parameters were observed to be reduced.
 - The engine BSFC, EDR, EGT, and entropy generation rate were enhanced, and the engine BTE, exergy efficiency, and sustainability index were reduced with a 20% blending of OPB and SOB biodiesel.
 - The engine emission parameters, i.e., NO, and CO₂, were observed increased, and CO, HC, and smoke emissions were observed reduced with a 20% blending of OPB and SOB biodiesel.
 - The engine performance parameters, i.e., BSFC, BTE, exergy efficiency, and sustainability index and emission parameters, i.e., CO₂ emissions, were

observed to be increases with 5% water emulsified OPB20 and SOB20 fuel compared to OPB20 and SOB20 fuels.

- The engine performance parameters, i.e., EDR, EGT, entropy generation rate, and emission parameters, i.e., NO, CO, HC, and smoke emissions, were observed to be reduced with 5% water emulsified OPB20 and SOB20 fuel.
- The engine performance parameters, i.e., BSFC, BTE, exergy efficiency, EGT, and emission parameters, i.e., NO, CO, CO₂, and smoke emissions with OPB fuels are observed to be superior in comparison to with SOB fuels at each engine power and speed. So, OPB fuel is superior to SOB fuel for diesel engine applications.
- The engine BSFC and EGT were observed to be reduced, and BTE, exergy efficiency, EDR, sustainability index, and entropy generation rate was observed to be increased with the incorporation of Al₂O₃ and CNT nano additives. The effect of incorporation of CNT nano additive has been observed to be higher than Al₂O₃ nano additive.
- The engine CO₂ was increased, and HC, CO, NO, and smoke emissions were reduced by incorporating Al₂O₃ and CNT nano additives.

The detailed analysis found that the engine BTE, exergy efficiency, and sustainability index reduce with OPB and SOB blended fuel while increasing WiDE5 fuel. The engine exhaust gas temperature and NO emission were also found increased with OPB and SOB blended fuel while reduced with water emulsified fuel. The experimental result revealed that 5% water emulsified OPB20 fuel and 5% water emulsified SOB20 can be used as fuel for diesel engines for better engine performance and emission characteristics without any engine modification. In this thesis work, further investigation was performed using 5% water emulsified OPB20

and 5% water emulsified SOB20 fuel with and without the incorporation of nano additives (CNT, Al₂O₃).

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