CHAPTER 6

OPTIMIZATION OF DIESEL ENGINE ENERGY, EXERGY, AND EMISSION PARAMETERS WITH OPB, SOB, WIDE & NANO FUELS

In this chapter, the performance parameters, i.e., BTE, exergy efficiency, BSFC, EGT, engine sustainability, EDR, and EGR, and emissions attributes, i.e., HC, CO, CO_2, NO, and smoke opacity, were optimized for different fuel samples, engine power, and engine speed. The various fuel sample used in experimentation are the diesel, OPB diesel blends, SOB diesel blends, water in diesel emulsion fuel, 5% water emulsified Al_2O_3 incorporated OPB20, and 5% water emulsified CNT contained OPB20 fuel. Diesel, 5% water emulsified SOB20, 5% water emulsified Al_2O_3 incorporated SOB20, and 5% water emulsified CNT incorporated SOB20 fuel. The S/N ratio curve and Grey relational analysis for different performance and emission parameters were discussed.

6.1 Optimization for Diesel Engine Performance and Emission Parameters Fuelled with OPB Blended Fuel

6.1.1 S/N Ratio Plot Analysis for BSFC and BTE with OPB Blended Fuel

Fig.6.1 illustrates the S/N ratio curve of engine BSFC and BTE response parameters of OPB blended fuel obtained from the Taguchi method. The S/N ratios of BSFC and BTE have been calculated according to the lower is better and higher is the better-based equation, respectively, using Minitab16 software. Using this S/N curve, the engine operating factors, and their optimum level in engine BSFC and BTE have been obtained. The optimum engine BSFC was obtained with diesel fuel at 35 N-m engine torque, 2000rpm speed. The optimum engine operating condition in terms of BSFC has been found A4-B4-C1. At 35 N-m engine torque, BSFC is lowest due to the lower air-fuel ratio and better combustion quality of fuel inside the cylinder. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 69.67%, and engine speed and fuel type have a contributing factor of 21.36% and 8.97%, respectively, in terms of engine BSFC.

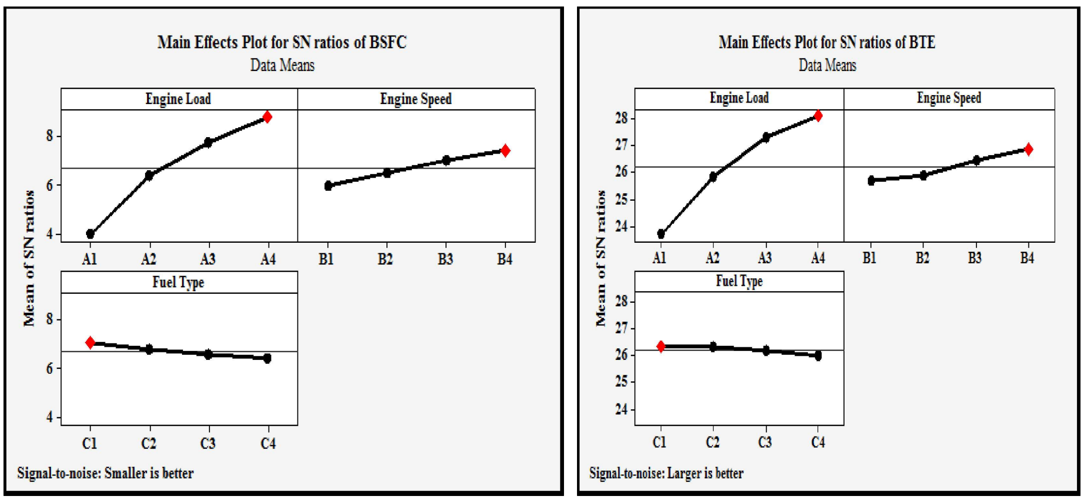

Figure 6.1 S/N ratio variation of BSFC and BTE versus engine torque, speed & OPB fuel

The engine's highest BTE has been obtained at 35 N-m engine torque, 1800rpm speed condition with diesel fuel. The optimum engine operating condition in terms of BTE was found to be A4-B4-C1. At 35 N-m engine torque, BTE has been observed highest due to the higher air-fuel ratio and superior combustion quality of fuel inside the cylinder. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 74.41%, and engine speed and fuel type have a contributing factor of 19.69% and 5.88%, respectively, in terms of engine BTE.

6.1.2 S/N Ratio Plot Analysis for Exergy Efficiency and Exhaust Gas Temperature with OPB Blended Fuel

Fig.6.2 illustrates the S/N ratio curve of engine exergy efficiency and exhaust gas temperature response parameters of OPB fuel obtained from the Taguchi method. The S/N ratio of exergy efficiency and exhaust gas temperature has been calculated according to a higher is better and lower is the better-based equation, respectively, using Minitab16 software. Using this S/N curve, the engine operating factors and their optimum level in engine exergy efficiency and exhaust gas temperature. The engine's highest exergy efficiency has been obtained at 35 N-m engine torque, 2000rpm speed condition with diesel fuel. The optimum engine operating condition for exergy efficiency has been found A4-B4-C1. At 35 N-m engine torque, exergy efficiency has been observed highest due to the higher air-fuel ratio and superior combustion quality of fuel inside the cylinder. The blending of 20% biofuel reduces the engine BTE due to the lower calorific value of the fuel.

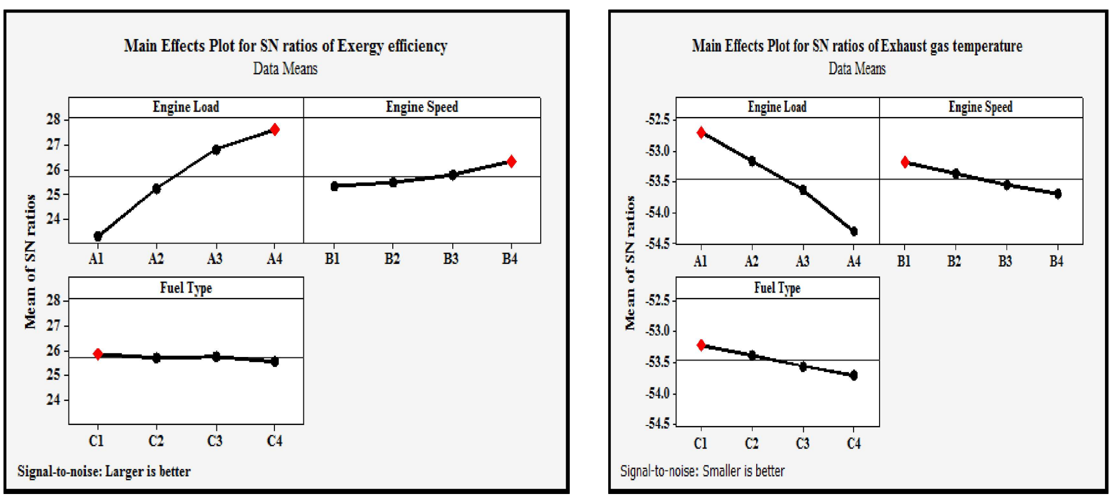

Figure 6.2 S/N ratio variation of exergy efficiency and exhaust gas temperature versus engine torque, speed & OPB fuel

The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 76.73%, and engine speed and fuel type have a contributing factor of 18.47% and 4.79%, respectively, in terms of engine exergy efficiency.

The engine's lowest exhaust gas temperature has been obtained at 14 N-m engine torque, 1400 rpm speed condition with diesel fuel. The optimum engine operating condition for exhaust gas temperature was A1-B1-C1. At 14 N-m engine torque, exhaust gas temperature has been observed to be lowest due to lower fuel energy inside the cylinder. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 61.15%, and engine speed and fuel type have a contributing factor of 20% and 18.85%, respectively in terms of engine exhaust gas temperature.

6.1.3 S/N Ratio Plot Analysis for Exergy Destruction Rate, and HC Emissions with OPB Blended Fuel

Fig.6.3 illustrates the S/N ratio curve of engine exergy destruction rate and HC emissions response parameters of OPB fuel obtained from the Taguchi method. The S/N ratio of exergy destruction rate and HC emissions have been calculated according to the lower is better-based equation using Minitab16 software. Using this S/N curve, the engine operating factors and their optimum level in engine exergy destruction rate and HC emissions have been obtained. The engine's lowest exergy destruction rate has been obtained at 14 N-m engine torque, 1400rpm speed condition with diesel fuel. The optimum engine operating condition for exergy destruction rate is A1-B1-C1. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 52.72%, and engine speed and fuel type have a contributing factor of 36.36% and 10.90%, respectively, in terms of engine exergy destruction rate.

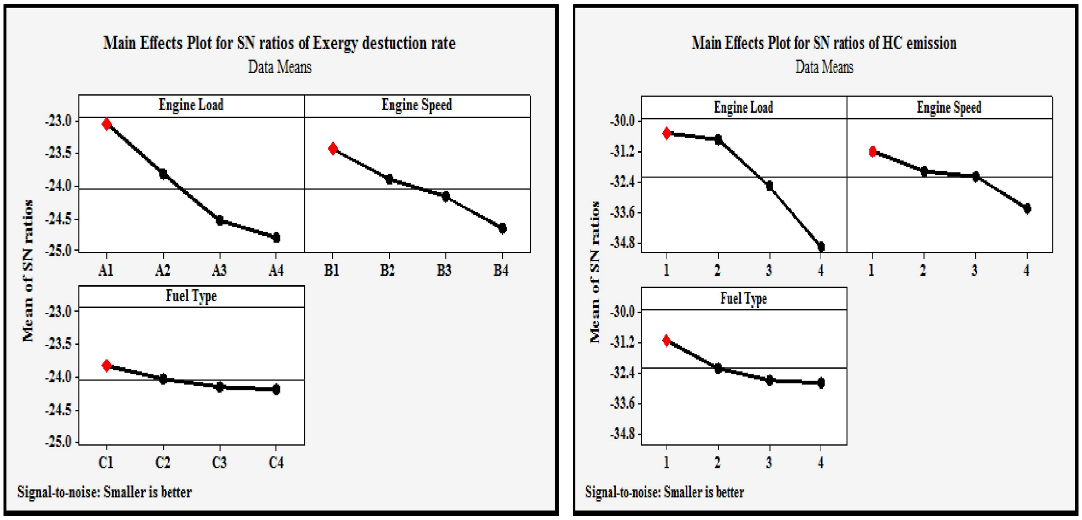

Figure 6.3 S/N ratio variation of exergy destruction rate and HC emissions versus engine torque, speed & OPB fuel

The engine's lowest HC emissions have been obtained at 14 N-m engine torque, 1400rpm speed condition with OPB20 fuel. The optimum engine operating condition in terms of HC emissions was found to be A2-B4-C3. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 53.58%, and the engine speed and fuel type have a contributing factor of 26.73% and 19.69%, respectively, in terms of engine HC emissions.

6.1.4 S/N Ratio Plot Analysis for CO Emissions and CO_2 Emissions with OPB Blended Fuel

Fig.6.4 illustrates the S/N ratio curve of CO, and CO_2 emission response parameters of OPB fuel, obtained from the Taguchi method. The S/N ratio of CO and CO_2 emissions have been calculated according to the lower is better-based equation using Minitab16 software. The engine operating factors and their optimum level in engine CO and CO_2 emission has been obtained using this S/N curve. The engine's lowest CO emissions have been obtained at 14 N-m engine torque, 1400rpm speed condition with OPB30 fuel. The optimum engine operating condition for CO emissions is A1-B1-C4. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 62.94%, and the engine speed and fuel type have a contributing factor of 19.29% and 17.76% in terms of engine CO emission.

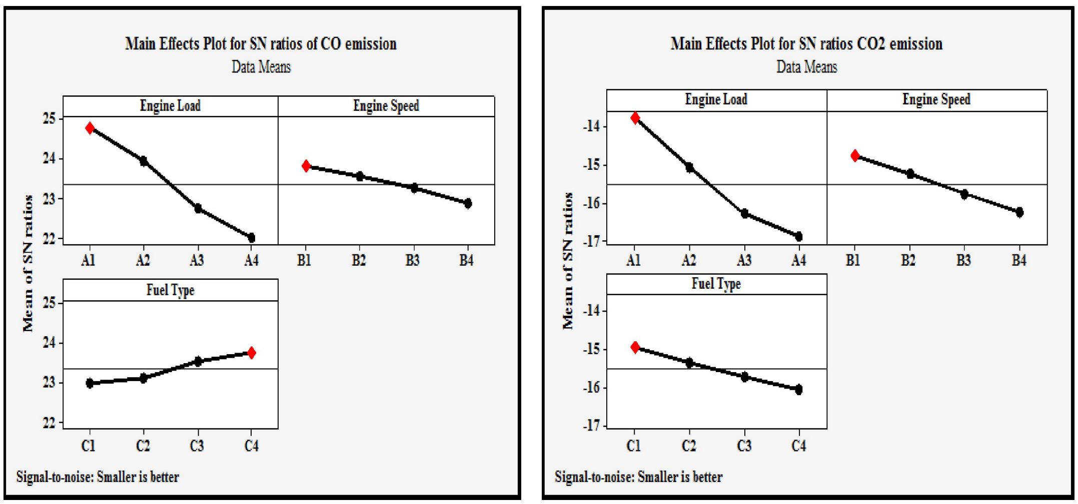

Figure 6.4 S/N ratio variation CO and CO_2 emission versus engine torque, speed & OPB fuel

The engine's lowest CO_2 emissions have been obtained at 14 N-m engine torque, 1400rpm speed condition with diesel fuel. The optimum engine operating condition in terms of CO_2 emissions has been found A1-B1-C1. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 55.12%, and the engine speed and fuel type have a contribution of 25.61% and 19.25% in terms of engine CO_2 emissions.

6.1.5 S/N Ratio Plot Analysis for NO Emission and Smoke Emission with OPB Blended Fuel

Fig.6.5 illustrates the S/N ratio curve of NO, and smoke emissions response parameters of OPB fuel, obtained from the Taguchi method. The S/N ratio of NO and smoke emissions have been calculated according to the lower is better-based equation using Minitab16 software. Using this S/N curve, the engine operating factors and their optimum level in engine NO and smoke emissions have been obtained. The engine's lowest NO emissions have been obtained at 14 N-m engine torque with diesel fuel. The optimum engine operating condition in terms of NO emission was found to be A1-B1-C1. At 14 N-m engine torque, NO emissions have been observed lowest due to the lower temperature and pressure of the cylinder. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 43.14%, and the engine speed and fuel type have a contributing factor of 22.06% and 34.08%, respectively, in engine NO emissions.

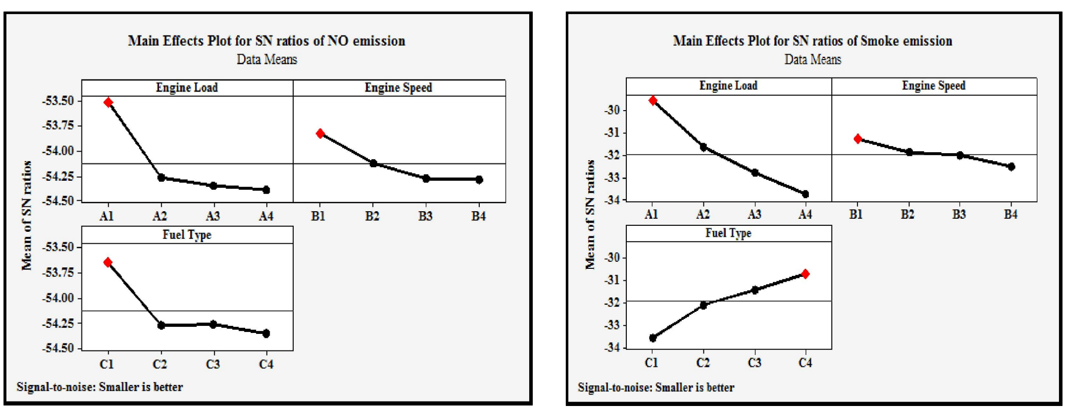

Figure 6.5 S/N ratio variation of NO and smoke emissions versus engine torque, speed & OPB fuel

The engine's lowest smoke emissions have been obtained at 14 N-m engine torque, 1400 rpm speed condition with OPB30 fuel. The optimum engine operating condition in terms of smoke emissions was found to be A1-B1-C4. The Taguchi analysis curve validates the experimental result in section 5.1.6 of smoke emissions. The ANOVA analysis of the S/N ratio concludes that 14 N-m engine torque is the most affecting factor, has a contributing factor of 50.36%, and the engine speed and fuel type have a contributing factor of 14.94% and 34.70%, respectively, in engine smoke emission.

6.1.6 S/N Ratio Plot Analysis for Grey Relational Grade with OPB Blended Fuel

Fig.6.6 illustrates the S/N ratio curve of GRG obtained from the Taguchi method. The S/N ratio of GRG was calculated according to a higher is better-based equation using Minitab16 software. The engine operating factors and their optimum level in engine performance and emission parameters have been obtained using this S/N curve. The engine's lowest emissions and maximum performances have been obtained at 14 N-m engine torque condition and 1400rpm speed with diesel fuel. The optimum engine operating condition in terms of optimum performance characteristics has been found A1-B1-C1. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 44.08%, and engine speed and fuel type have a contributing factor of 28.42% and 27.5% in terms of engine response parameters. The performance and emission parameters of OPB20 fuel are comparable to diesel fuel.

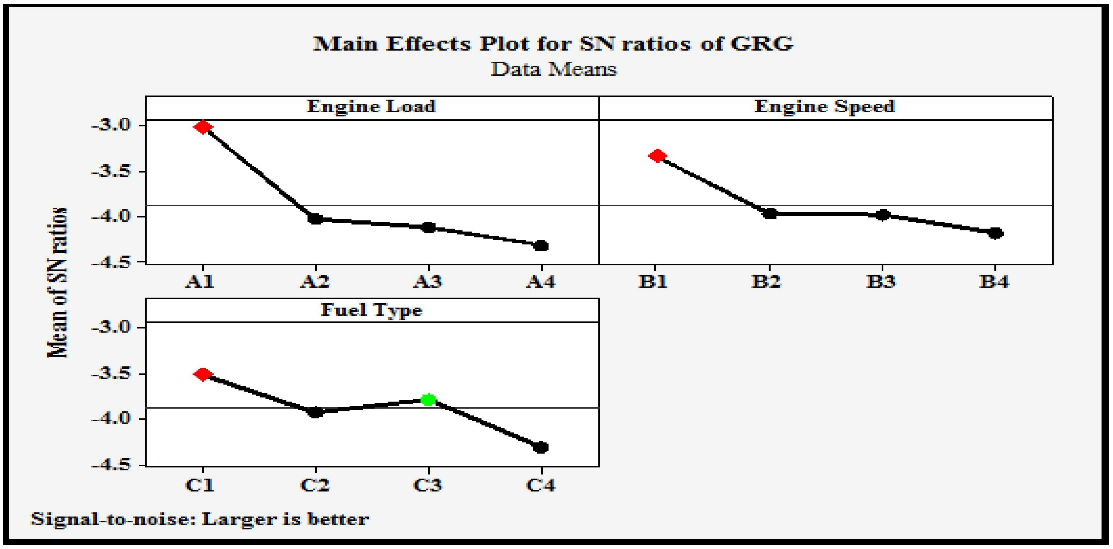

Figure 6.6 S/N ratio variation of GRG versus engine torque, speed & OPB fuel samples

6.1.7 Confirmation Test for OPB Fuels

A confirmation test was conducted with the optimum control parameters, and the predicted GRG (∈) was evaluated using the following equation **(Venkata Ramana et al., 2012)**.

$$\in = Xm + \sum_{i=1}^{q} (Xi - Xm)$$

Xm is the overall mean of GRG, *Xi* is GRG for the optimum level, and *q* is the number of control parameters. The predicted GRG at optimum setting (A1 B1 C1) and experimental value of GRG are 0.7835 and 0.7789, respectively. The error between the predicted and observed value of GRG is found to be .0046 only.

6.2 Optimization for Diesel Engine Performance and Emission Parameters Fuelled with SOB Blended Fuel

6.2.1 S/N Ratio Plot Analysis for BSFC and BTE with SOB Blended Fuel

Fig.6.7 illustrates the S/N ratio curve of engine BSFC and BTE response parameters of SOB blended fuel obtained from the Taguchi method. The S/N ratio calculation method of BSFC and BTE are discussed in section 6.1.1. The optimum engine BSFC was obtained at 35 N-m engine torque, 2000 rpm speed with SOB30 fuel. The optimum engine operating condition in terms of BSFC has been found A4-B4-C4. At 35 N-m engine torque, BSFC is lowest due to the lower air-fuel ratio and better combustion quality of fuel inside the cylinder. The Taguchi analysis curve validates the experimental result in section 5.2.1 of BSFC. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 68.63%, and engine speed and fuel type have a contributing factor of 22.56% and 8.81%, respectively, in terms of engine BSFC.

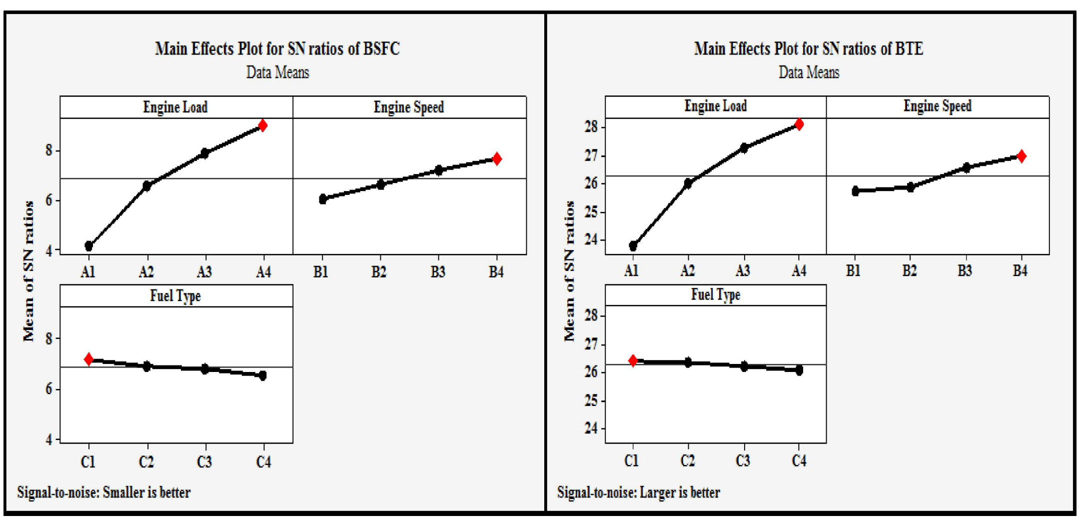

Figure 6.7 S/N ratio variation of BSFC and BTE versus engine torque, speed & SOB fuel

The engine's highest BTE has been obtained at 35 N-m engine torque, 2000 rpm speed condition with SOB20 fuel. The optimum engine operating condition in terms of BTE was found to be A4-B4-C3. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 72.79%, and engine speed and fuel type have a contributing factor of 21.53% and 5.67%, respectively, in terms of engine BTE.

6.2.2 S/N Ratio Plot Analysis for Exergy Efficiency and Exhaust Gas Temperature SOB Blended Fuel

Fig.6.8 illustrates the S/N ratio curve of engine exergy efficiency and exhaust gas temperature response parameters of SOB fuel obtained from the Taguchi method. The S/N ratio calculation method of exergy efficiency and exhaust gas temperature are discussed in section 6.1.2. The engine's highest exergy efficiency has been obtained at 35 N-m engine torque, 2000 rpm speed condition with SOB20 fuel. The optimum engine operating condition for exergy efficiency has been found A4-B4-C3. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 71.08%, and engine speed and fuel type have a contributing factor of 22.29% and 6.62%, respectively, in terms of engine exergy efficiency.

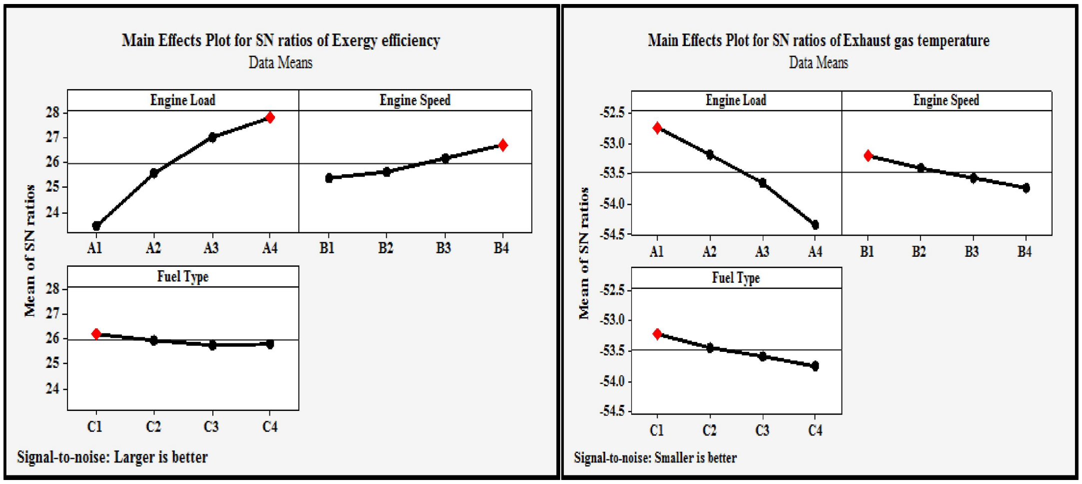

Figure 6.8 S/N ratio variation of exergy efficiency and Exhaust gas temperature versus engine torque, speed & SOB fuel

The engine's lowest exhaust gas temperature has been obtained at 14 N-m engine torque, 1400 rpm speed condition with diesel fuel. The optimum engine operating condition for exhaust gas temperature was A1-B1-C1. At 14 N-m engine torque, exhaust gas temperature has been observed to be lowest due to lower fuel energy inside the cylinder. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 60.38%, and engine speed and fuel type have a contributing factor of 19.62% and 20%, respectively, in terms of engine exhaust gas temperature.

6.2.3 S/N Ratio Plot Analysis for Exergy Destruction Rate and HC Emissions with SOB Blended Fuel

Fig.6.9 illustrates the S/N ratio curve of engine exergy destruction rate and HC emission response parameters of SOB fuel obtained from the Taguchi method. The S/N ratio of exergy destruction rate and HC emission have been calculated according to the lower is better-based equation using Minitab16 software. Using this S/N curve, the engine operating factors and their optimum level in engine exergy destruction rate and

HC emission have been obtained. The engine's lowest exergy destruction rate has been obtained at 14 N-m engine torque, 1400 rpm speed condition with diesel fuel. The optimum engine operating condition for exergy destruction rate is A1-B1-C1. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 59.16%, and engine speed and fuel type have a contributing factor of 36.33% and 4.50%, respectively, in terms of engine exergy destruction rate.

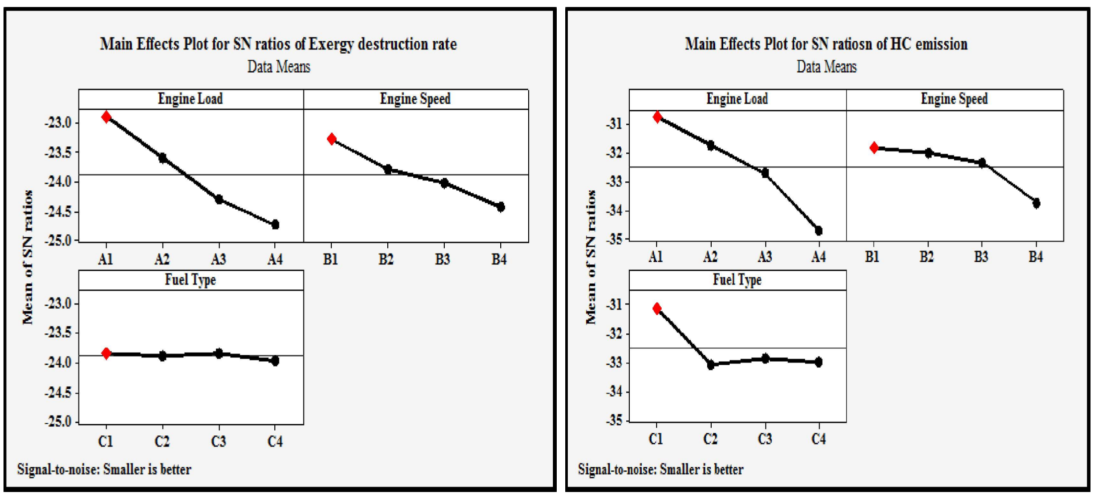

Figure 6.9 S/N ratio variation of exergy destruction rate and HC emissions versus engine torque, speed & SOB fuel

The engine's lowest HC emissions have been obtained at 14 N-m engine torque, 1400 rpm speed condition with diesel fuel. The optimum engine operating condition in terms of HC emissions was found to be A1-B1-C1. The ANOVA analysis of the S/N ratio concludes that engine load is the most affecting factor, has a contributing factor of 50.76%, and the engine speed and fuel type have a contributing factor of 24.24% and 25%, respectively, in terms of engine HC emissions.

6.2.4 S/N Ratio Plot Analysis for CO and CO_2 Emissions with SOB Blended Fuel

Fig.6.10 illustrates the S/N ratio curve of CO, and CO_2 emission response parameters of SOB fuel, obtained from the Taguchi method. The S/N ratio of CO and CO_2 emissions have been calculated according to the lower is better-based equation using Minitab16 software. The engine operating factors and their optimum level in engine CO and CO_2 emissions have been obtained using this S/N curve. The engine's lowest CO emission has been obtained at 14 N-m engine torque, 1400 rpm speed condition with SOB30 fuel. The optimum engine operating condition for CO emissions is A1-B1-C4. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 61.42%, and the engine speed and fuel type have a contribution of 21.06% and 17.52% in terms of engine CO emissions.

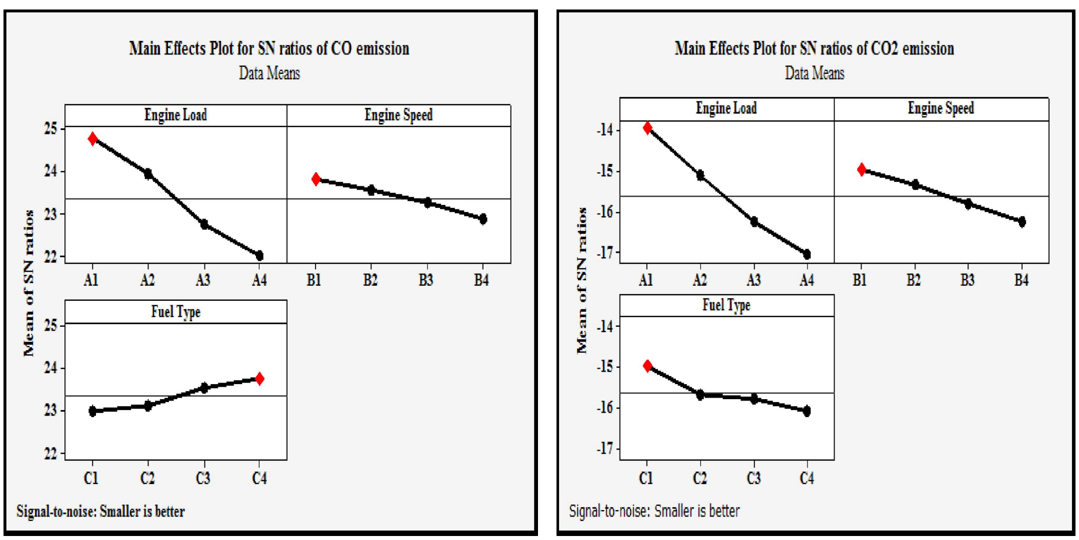

Figure 6.10 S/N ratio variation of CO and CO_2 emissions versus engine torque, speed & SOB fuel

The engine's lowest CO_2 emissions have been obtained at 14 N-m engine torque, 1400 rpm speed condition with diesel fuel. The optimum engine operating condition for CO_2 emissions is A1-B1-C1. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 56.9%, and the engine speed and fuel type have a contribution of 22.9% and 20.12% in terms of engine CO_2 emissions.

6.2.5 S/N Ratio Plot Analysis for NO Emissions and Smoke Opacity Emissions with SOB Blended Fuel

Fig.6.11 illustrates the S/N ratio curve of NO, and smoke emission response parameters of SOB fuel, obtained from the Taguchi method. The S/N ratio of NO and smoke emissions have been calculated according to the lower is better-based equation using Minitab16 software. The engine operating factors and their optimum level in engine NO and smoke emissions have been obtained using this S/N curve. The

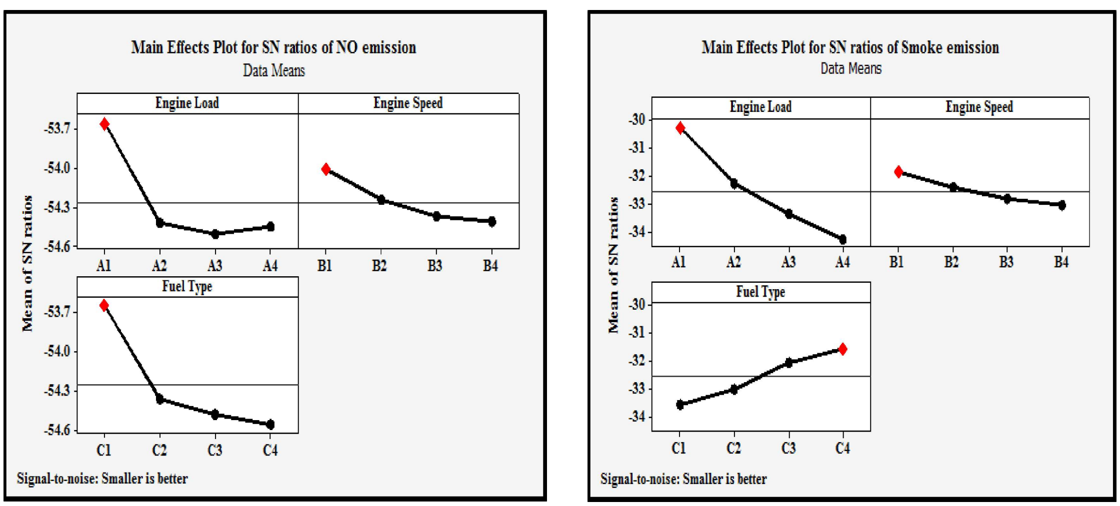

Figure 6.11 S/N ratio variation of NO and smoke emissions versus engine torque, speed & SOB fuel

engine's lowest NO emissions have been obtained at 14 N-m engine torque with diesel fuel. The optimum engine operating condition in terms of NO emissions was found to be A1-B1-C1. At 14 N-m engine torque, NO emissions have been observed lowest due to the lower temperature and pressure of the cylinder. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 39.35%, and the engine speed and fuel type have a contributing factor of 18.52% and 42.13%, respectively, in engine NO emissions.

The engine's lowest smoke emissions have been obtained at 14 N-m engine torque with SOB30 fuel. The optimum engine operating condition in terms of smoke emissions was found to be A1-B1-C4. The ANOVA analysis of the S-N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 55.49%, and the engine speed and fuel type have a contributing factor of 16.76% and 27.75%, respectively, in engine smoke emissions.

6.2.6 S/N Ratio Plot Analysis of Grey Relational Grade with SOB Blended Fuel

The S/N ratio of GRG was calculated according to a higher is better-based equation using Minitab16 software and shown in Fig.6.12. The engine operating factors and their optimum level in engine performance and emission parameters have been obtained using this S/N curve. The engine's lowest emissions and maximum performances have been obtained at 14 N-m engine torque and 1400 rpm speed with diesel fuel. The optimum engine operating condition in terms of optimum performance characteristics has been found A1-B1-C1. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 40.16%, and engine speed and fuel type have a contributing factor of 26.75% and 33.08% in terms of engine response parameters. The performance and emission parameters of SOB20 fuel are comparable to diesel fuel.

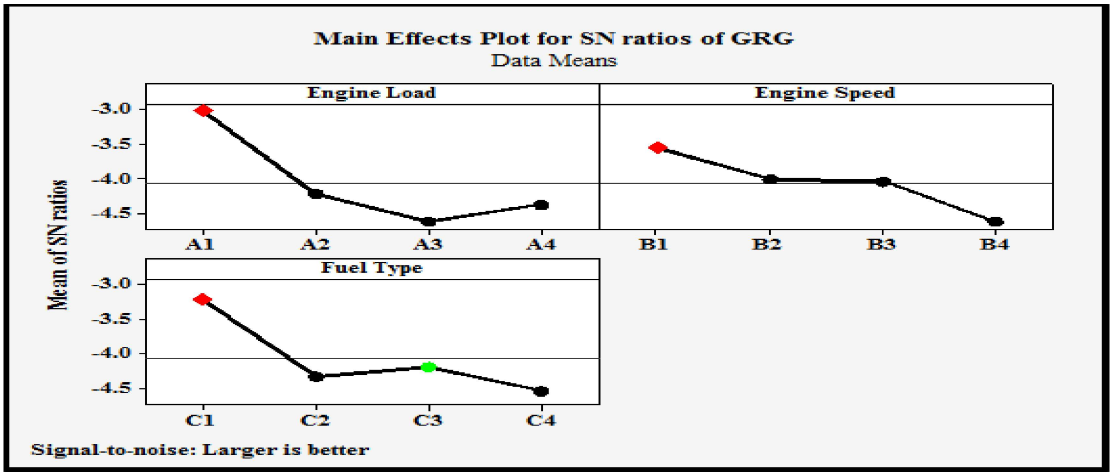

Figure 6.12 S/N ratio variation of GRG versus engine torque, speed & SOB fuel samples

5.5.7 Confirmation Test for SOB Fuels

A confirmation test was conducted with the optimum control parameters, and the predicted GRG (∈) was evaluated using the following equation.

$$\in = Xm + \sum_{i=1}^{q}(Xi - Xm)$$

Xm is the overall mean of GRG, *Xi* is GRG for the optimum level, and *q* is the number of control parameters. The predicted GRG at optimum setting (A1 B1 C1) and experimental value of GRG are 0.8243 and 0.8013, respectively. The error between the predicted and observed value of GRG is found to be 0.023 only.

6.3 Optimization for Diesel Engine Performance and Emission Parameters Fuelled with WiDE Fuel

6.3.1 S/N Ratio Plot Analysis for BSFC and BTE with WiDE Fuel

Fig.6.13 illustrates the S/N ratio curve of engine BSFC and BTE response parameters of water-emulsified fuel obtained from the Taguchi method. The S/N ratio calculation method of BSFC and BTE are discussed in section 6.1.1. The optimum engine BSFC was obtained with diesel fuel at 35 N-m engine torque, 2000 rpm speed. The optimum engine operating condition in terms of BSFC has been found A4-B4-C1. At 14 N-m engine torque, BSFC is lowest due to the lower air-fuel ratio and better combustion quality of fuel inside the cylinder. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 70.74%, and engine speed and fuel type have a contributing factor of 17.84% and 11.42%, respectively, in terms of engine BSFC.

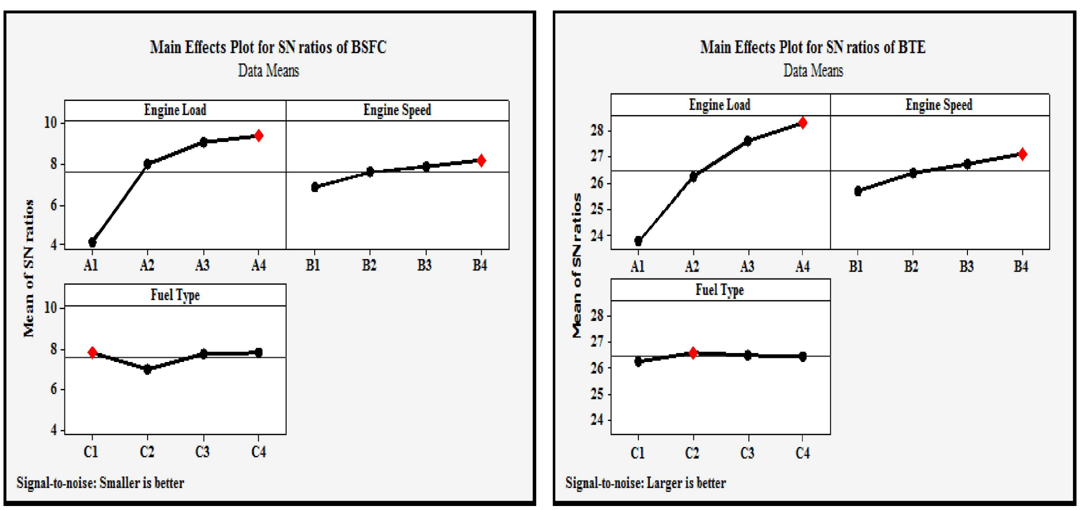

Figure 6.13 S/N ratio variation of BSFC and BTE emissions versus engine torque, speed & water emulsified fuel.

The engine's highest BTE has been obtained at 35 N-m engine torque, 2000 rpm speed condition with WiDE5 fuel. The optimum engine operating condition in terms of BTE was found to be A4-B4-C2. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 72.24%, and engine speed and fuel type have a contributing factor of 22.56% and 5.2%, respectively, in terms of engine BTE.

6.3.2 S/N Ratio Plot Analysis for Exergy Efficiency and Exhaust Gas Temperature with WiDE Fuel

Fig.6.14 illustrates the S/N ratio curve of engine exergy efficiency and exhaust gas temperature response parameters of water-emulsified fuel obtained from the Taguchi method. The S/N ratio calculation method of exergy efficiency and exhaust gas temperature are discussed in section 6.1.2. The engine's highest exergy efficiency has been obtained at 35 N-m engine torque, 2000 rpm speed condition with WiDE5 fuel. The optimum engine operating condition for exergy efficiency has been found A4-B4-C2. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 74.14%, and engine speed and fuel type have a contributing factor of 21.34% and 4.52%, respectively, in terms of engine exergy efficiency.

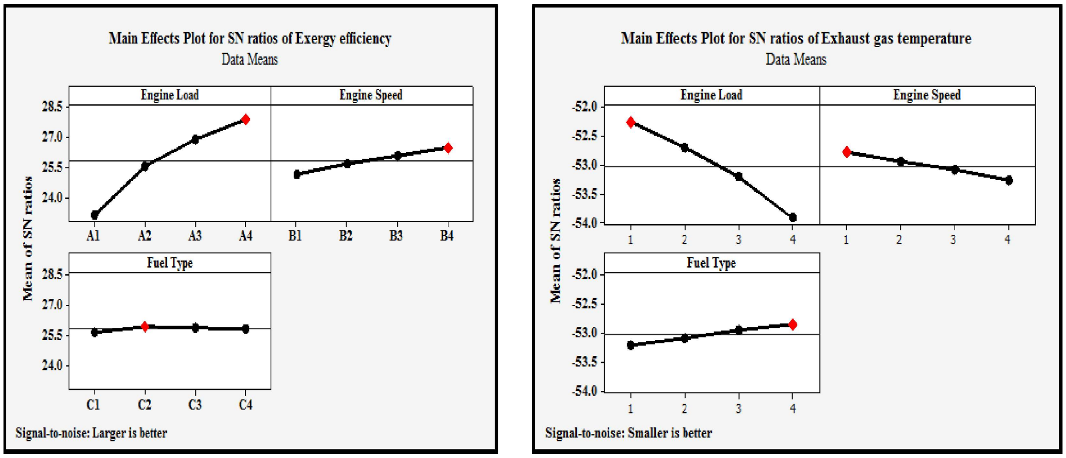

Figure 6.14 S/N ratio variation of exergy efficiency and exhaust gas temperature versus engine torque, speed & SOB fuel samples

The engine's lowest exhaust gas temperature has been obtained at 14 N-m engine torque, 1400 rpm speed condition with WiDE15 fuel. The optimum engine operating condition for exhaust gas temperature was A1-B1-C3. At 14 N-m engine torque, exhaust gas temperature has been observed to be lowest due to lower fuel energy inside the cylinder. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 66.8%, and engine speed and fuel type have a contributing factor of 19.2% and 14%, respectively, in terms of engine exhaust gas temperature.

6.3.3 S/N Ratio Plot Analysis for Exergy Destruction Rate and HC Emissions with WiDE Fuel

Fig.6.15 illustrates the S/N ratio curve of engine exergy destruction rate and HC emission response parameters of water-emulsified fuel obtained from the Taguchi method. The S/N ratio of exergy destruction rate and HC emissions have been calculated according to the lower is better-based equation using Minitab16 software. Using this S/N curve, the engine operating factors and their optimum level in engine exergy destruction rate and HC emissions have been obtained. The engine's lowest exergy destruction rate has been obtained at 14 N-m engine torque, 1400 rpm speed condition with WiDE15 fuel. The optimum engine operating condition for exergy destruction rate is A1-B1-C4. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 43.67%, and engine speed and fuel type have a contributing factor of 28.30% and 28.03%, respectively, in terms of engine exergy destruction rate.

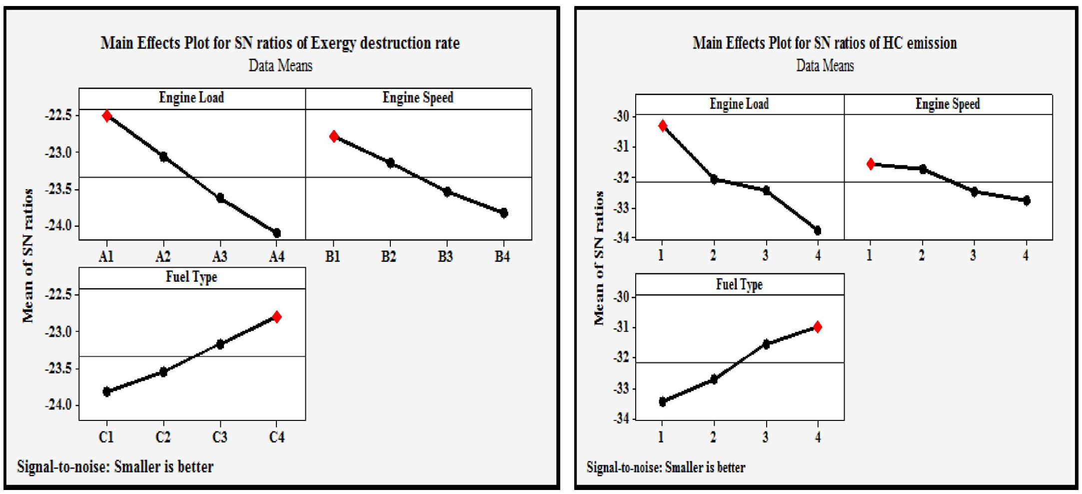

Figure 6.15 S/N ratio variation of exergy destruction rate and HC emissions versus engine torque, speed & emulsion fuel

The engine's lowest HC emissions has been obtained at 14 N-m engine torque, 1400 rpm speed condition with WiDE15 fuel. The optimum engine operating condition in terms of HC emissions was found to be A1-B1-C4. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 48.53%, and the engine speed and fuel type have a contributing factor of 16.68% and 34.77%, respectively, in terms of engine HC emissions.

6.3.4 S/N Ratio Plot Analysis for CO and CO_2 Emissions with WiDE Fuel

Fig.6.16 illustrates the S/N ratio curve of CO and CO_2 emissions response parameters obtained from the Taguchi method. The S/N ratio of CO and CO_2 emissions have been calculated according to the lower is better-based equation using Minitab16 software. The engine operating factors and their optimum level in engine CO and CO_2 emissions have been obtained using this S/N curve. The engine's lowest CO emissions have been obtained at 14 N-m engine torque, 1400 rpm speed condition with WiDE10 fuel. The optimum engine operating condition for smoke emission is A1-B1-C3. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 57.81%, and the engine speed and fuel type have contributed to 21.88% and 20.31% in terms of engine CO emissions.

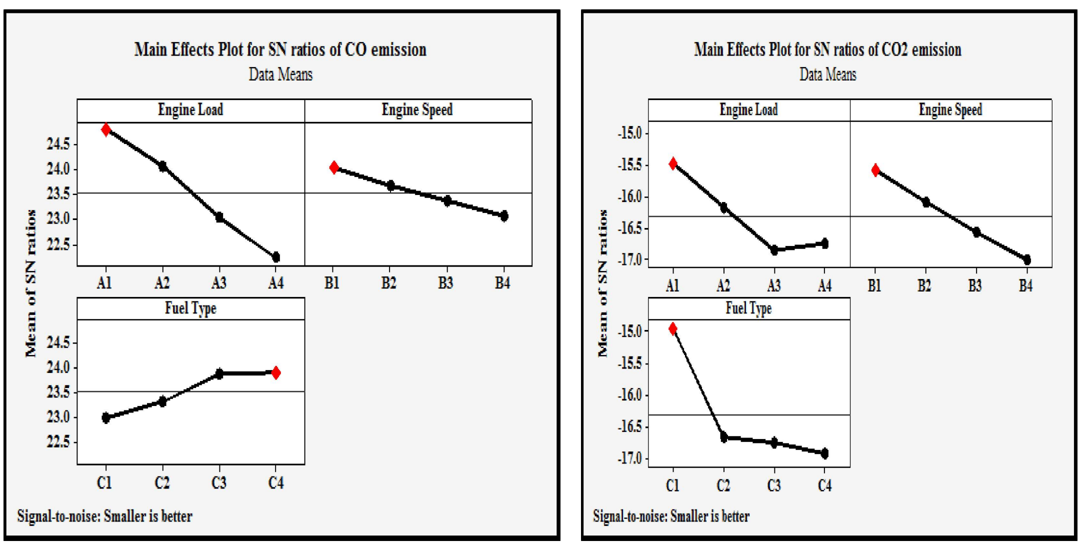

Figure 6.16 S/N ratio variation of CO and CO_2 emissions versus engine torque, speed & water emulsified fuel samples.

The engine's lowest CO_2 emissions has been obtained at 14 N-m engine torque, 1400 rpm speed condition with diesel fuel. The optimum engine operating condition for CO_2 emissions is A1-B1-C1. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 41.44%, and the engine speed and fuel type contribute to 29.9% and 28.75% in terms of engine CO_2 emissions.

6.3.5 S-N Ratio Plot Analysis for NO and Smoke Emissions with WiDE Fuel

Fig.6.17 illustrates the S/N ratio curve of NO, and smoke emissions response parameters of water emulsified fuel, obtained from the Taguchi method. The S/N ratio of NO and smoke emissions have been calculated according to the lower is better-based equation using Minitab16 software. Using this S/N curve, the engine operating factors and their optimum level in engine NO and smoke emissions. The engine's lowest NO emission has been obtained at 14 N-m engine torque, 1400 rpm speed with WiDE15 fuel. The optimum engine operating condition in terms of NO emissions was found to be A1-B1-C4. At 14 N-m engine torque, NO emissions has been observed lowest due to the lower temperature and pressure of the cylinder. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 44.39%, and the engine speed and fuel type have a contributing factor of 22.93% and 32.68%, respectively, in engine NO emissions.

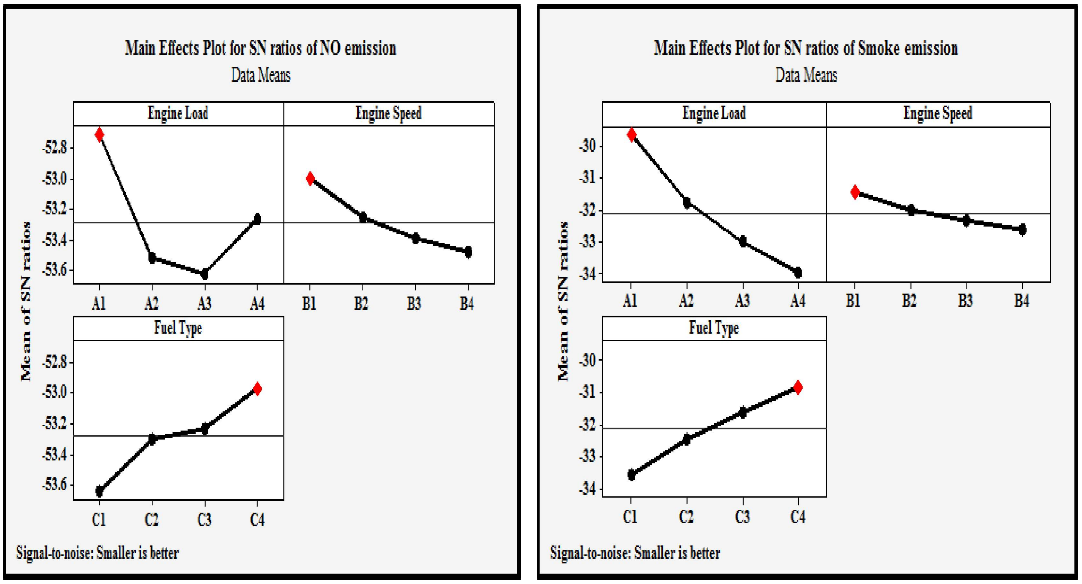

Figure 6.17 S/N ratio variation of NO and smoke emissions versus engine torque, speed & water emulsion fuel samples

The engine's lowest smoke emissions has been obtained at 14 N-m engine torque with WiDE15 fuel. The optimum engine operating condition in terms of smoke emissions was found to be A1-B1-C4. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 52.34%, and the engine speed and fuel type have a contributing factor of 14.52% and 33.13%, respectively, in engine smoke emissions.

6.3.6 S/N Ratio Plot Analysis for Grey Relational Grade with WiDE Fuel

The S/N ratio of GRG was calculated according to a higher is better-based equation using Minitab16 software. The engine operating factors and their optimum level in engine performance and emission parameters have been obtained using this S/N curve. The engine's optimum emissions and performances have been obtained at 14 N-m engine torque and 1400 rpm speed with WiDE5 fuel. The optimum engine operating condition in terms of optimum performance characteristics has been found A1-B1-C2.

The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 66.01%, and engine speed and fuel type have a contributing factor of 17.53% and 16.45% in terms of engine response parameters, as shown in Fig.6.18.

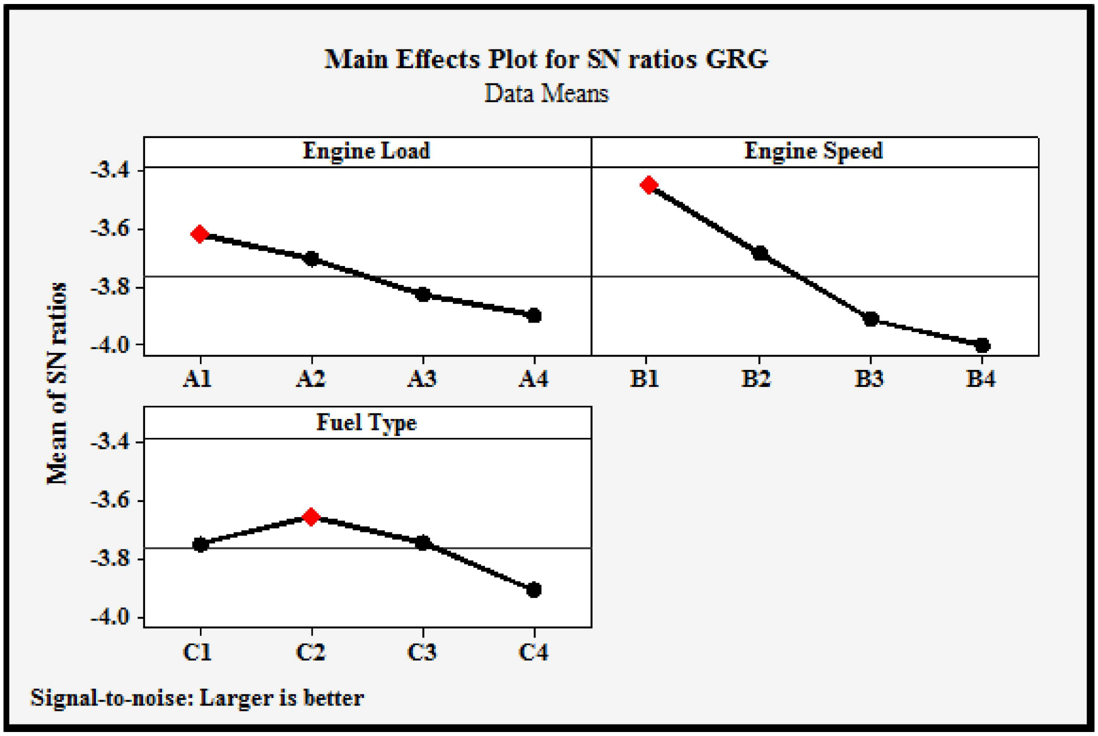

Figure 6.18 S/N ratio variation of GRG versus engine torque, speed & water emulsion fuel samples

6.3.7 Confirmation Test for Water Emulsion Fuels

A confirmation test was conducted with the optimum control parameters, and the predicted GRG (∈) was evaluated using the following equation.

$$\in = Xm + \sum_{i=1}^{q}(Xi - Xm)$$

Xm is the overall mean of GRG, *Xi* is GRG for the optimum level, and *q* is the number of control parameters. The predicted GRG at the optimum setting (A1-B2-C3) and experimental value of GRG are 0.79 and 0.78, respectively. The error between the predicted and observed value of GRG is found to be .01 only.

6.4 Optimization for Diesel Engine Performance and Emission Parameters Fuelled with Water Emulsified OPB Blended Nano Additive Incorporated Fuel

6.4.1 S/N Ratio Plot Analysis for BSFC and BTE with OPB Blended Nano Additive Incorporated Fuel

Fig.6.19 illustrates the S-N ratio curve of engine BSFC and BTE response parameters of OPB blended nano fuel, obtained from the Taguchi method. The S/N ratio calculation method of BSFC and BTE has been discussed in section 6.1.1. Using this S/N curve, the engine operating factors and their optimum level in engine BSFC and BTE have been obtained. The optimum engine BSFC was obtained at 35 N-m engine torque, 2000 rpm speed with 5% water emulsified CNT incorporated OPB20 fuel. The optimum engine operating condition in terms of BSFC has been found A4-B4-C4. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 61.19%, and engine speed and fuel type have a contributing factor of 16.48% and 22.35%, respectively, in terms of engine BSFC.

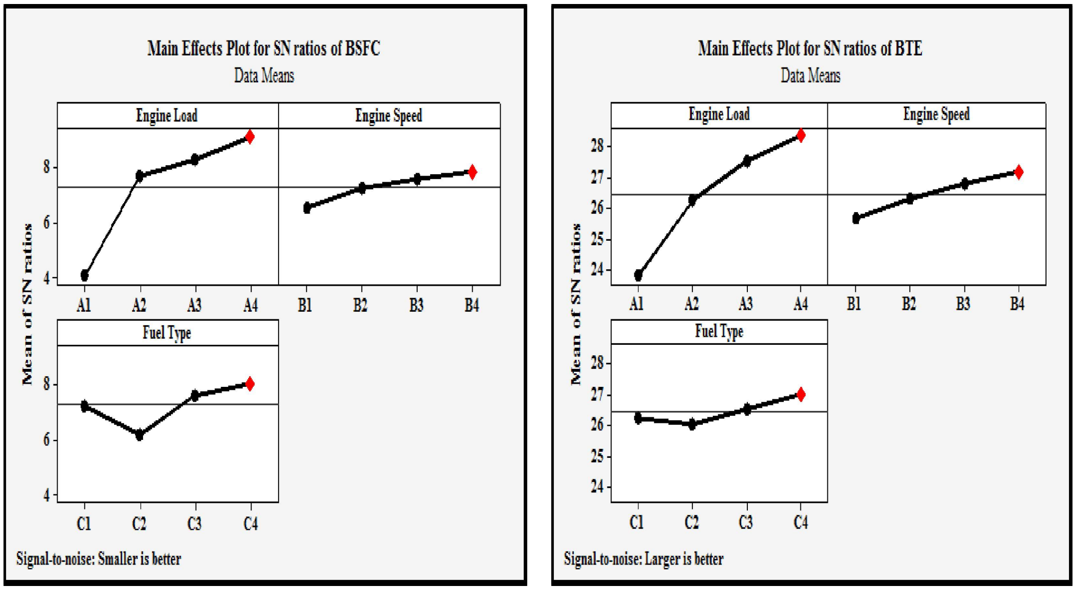

Figure 6.19 S/N ratio variation of BSFC and BTE versus engine torque, speed & OPB blended nano fuel

The engine's highest BTE has been obtained at 35 N-m engine torque, 2000 rpm speed condition with 5% water emulsified CNT incorporated OPB20 fuel. The optimum engine operating condition for BTE is A4-B4-C4. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 64.54%, and engine speed and fuel type have a contributing factor of 21.37% and 14.12%, respectively, in terms of engine BTE.

6.4.2 S/N Ratio Plot Analysis for Exergy Efficiency and Exhaust Gas Temperature with OPB Blended Nano Additive Incorporated Fuel

Fig.6.20 illustrates the S/N ratio curve of engine exergy efficiency and exhaust gas temperature response parameters of OPB blended nano fuel, obtained from the Taguchi method. The S/N ratio calculation method of exergy efficiency and exhaust gas temperature are discussed in section 6.1.2. The engine's highest exergy efficiency has been obtained at 35 N-m engine torque, 2000 rpm speed condition with 5% water emulsified CNT incorporated OPB20 fuel. The optimum engine operating condition for exergy efficiency has been found A4-B4-C4. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 66.57%, and engine speed and fuel type have a contributing factor of 21.34% and 12.09%, respectively, in terms of engine exergy efficiency.

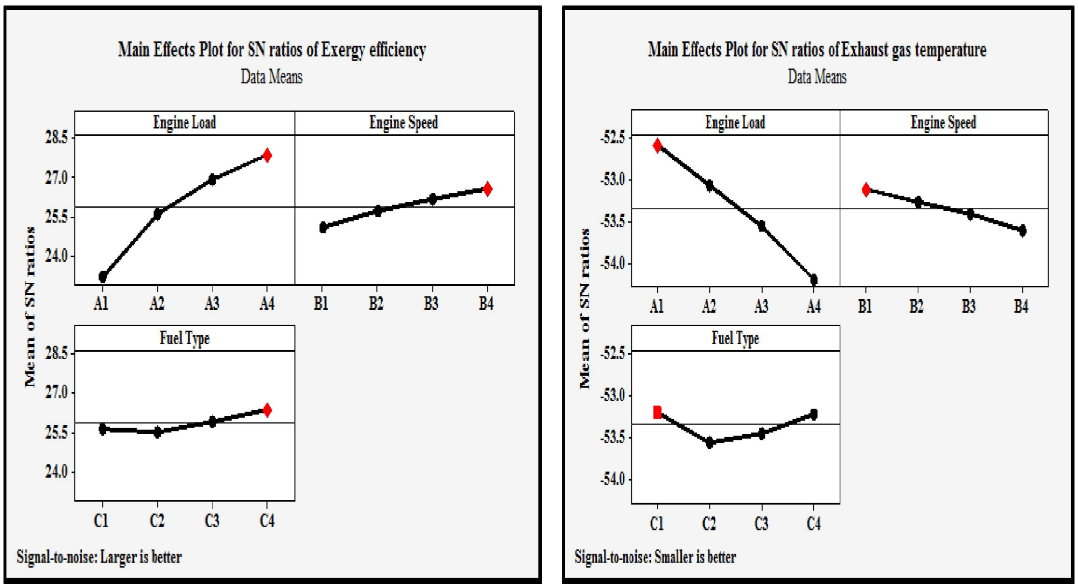

Figure 6.20 S/N ratio variation of exergy efficiency and exhaust gas temperature versus engine torque, speed & OPB blended nano fuel

The engine's lowest exhaust gas temperature has been obtained at 14 N-m engine torque, 1400 rpm speed condition with diesel fuel. The optimum engine operating condition for exhaust gas temperature is A1-B1-C1. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 65.45%, and engine speed and fuel type have a contributing factor of 19.92% and 14.63%, respectively, in terms of engine exhaust gas temperature.

6.4.3 S/N Ratio Plot Analysis for Exergy Destruction Rate and HC Emissions with OPB Blended Nano Additive Incorporated Fuel

Fig.6.21 illustrates the S/N ratio curve of engine EDR and HC emissions response parameters of OPB20 blended nano fuel, obtained from the Taguchi method. The S/N ratio calculation method of EDR and HC emissions has been discussed in section 6.1.3. The engine operating factors and their optimum level in engine EDR and HC emissions have been obtained using this S/N curve. The engine's lowest EDR has been obtained at 14 N-m engine torque, 1400 rpm speed condition with diesel fuel. The optimum engine operating condition in EDR is A1-B1-C4. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 48.84%, and engine speed and fuel type have a contributing factor of 37.57% and 6.35%, respectively, in terms of engine EDR.

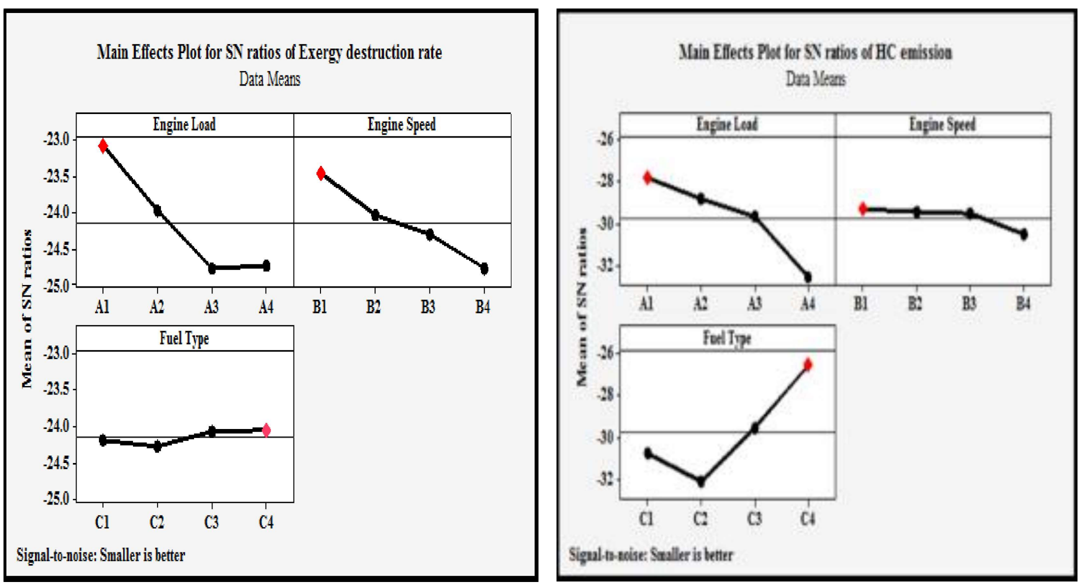

Figure 6.21 S/N ratio variation of exergy destruction rate, and HC emissions versus engine torque, speed & OPB blended nano fuel

The engine's lowest HC emissions have been obtained at 14 N-m engine torque, 1800 rpm speed condition with 5% water emulsified CNT incorporated OPB20 fuel. The optimum engine operating condition in HC emissions is A1-B1-C4. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 38.87%, and the engine speed and fuel type have a contributing factor of 15.34% and 45.79%, respectively, in terms of engine HC emissions.

6.4.4 S/N Ratio Plot Analysis for CO and CO_2 Emissions with OPB Blended Nano Additive Incorporated Fuel

Fig. 6.22 illustrates the S/N ratio curve of CO, and CO_2 emission response parameters of OPB blended fuel, obtained from the Taguchi method. The S/N ratio calculation method of CO and CO_2 emissions has been discussed in section 6.1.4. The engine operating factors and their optimum level in engine CO and CO_2 emissions have been obtained using this S/N curve. The engine's lowest CO emission has been obtained at 14 N-m engine torque, 1400 rpm speed condition with 5% water emulsified CNT incorporated SOB20 fuel. The optimum engine operating condition for CO emissions is A1-B1-C4. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 53.69%, and the engine speed and fuel type contribute to 18.76% and 27.54% in terms of engine CO emissions.

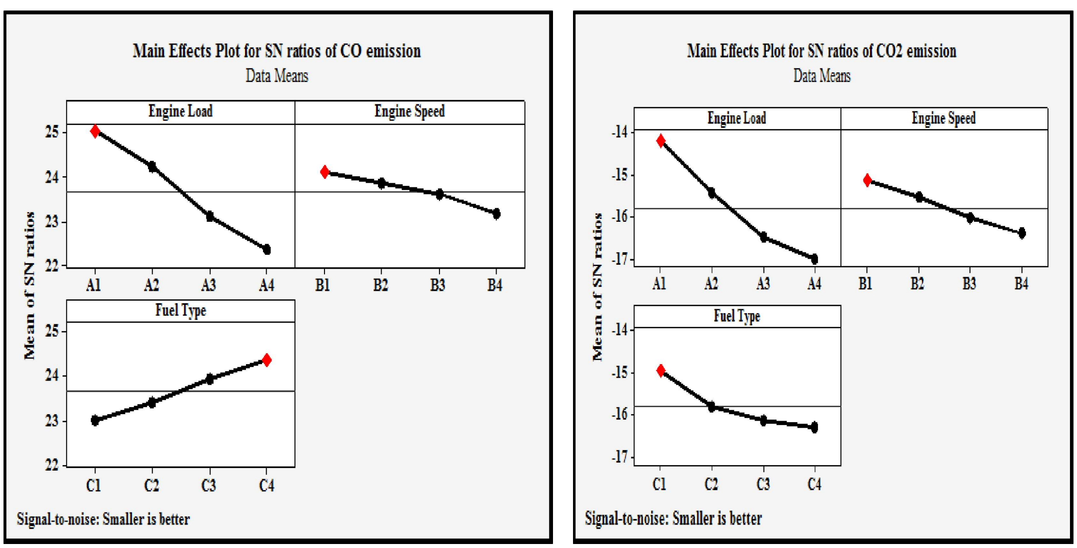

Figure 6.22 S/N ratio variation of CO and CO_2 emissions versus engine torque, speed & OPB blended nano fuel

The engine's lowest CO_2 emissions has been obtained at 14 N-m engine torque, 1400 rpm speed condition with diesel fuel. The optimum engine operating condition for CO_2 emissions is A1-B1-C1. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 52.11%, and the engine speed and fuel type have contributed to 23.3% and 24.58% in terms of engine CO_2 emissions.

6.4.5 S/N Ratio Plot Analysis for NO and Smoke Emissions with OPB Blended Nano Additive Incorporated Fuel

Fig.6.23 illustrates the S/N ratio curve of NO, and smoke emissions response parameters of OPB20 blended nano fuel, obtained from the Taguchi method. The S/N ratio calculation method for NO and smoke emissions have been discussed in section 6.1.5. Using this S/N curve, the engine operating factors and their optimum level in engine NO and smoke emissions. The engine's lowest NO emissions has been obtained at 14 N-m engine torque, 1400 rpm speed with diesel fuel. The optimum engine operating condition for NO emissions is A1-B1-C1. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 49.40%, and the engine speed and fuel type have a contributing factor of 34.34% and 16.26%, respectively, in engine NO emissions.

The engine's lowest smoke emissions have been obtained at 14 N-m engine torque, 1400 rpm speed condition with 5% water emulsified CNT incorporated OPB20 fuel. The optimum engine operating condition for smoke emissions is A1-B1-C4. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 43.09%, and the engine speed and fuel type have a contributing factor of 11.93% and 44.98%, respectively, in engine smoke emissions.

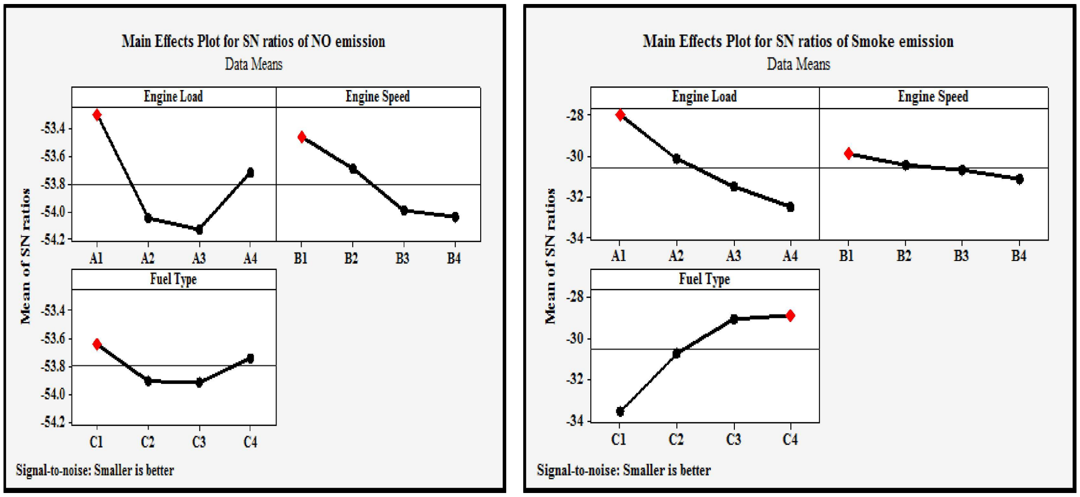

Figure 6.23 S/N ratio variation of NO and smoke emissions versus engine torque, speed & OPB blended nano fuel

6.4.6 S/N Ratio Plot Analysis for Grey Relational Grade with OPB Blended Nano Additive Incorporated Fuel

Fig.6.24 illustrates the S/N ratio curve of GRG of OPB20 blended nano fuel, obtained from the Taguchi method. The S/N ratio of GRG has been calculated according to a higher is better-based equation using Minitab16 software. The engine operating factors and their optimum level in engine performance and emission parameters have been obtained using this S/N curve. The engine's optimum emissions and performances have been obtained at 14 N-m engine torque and 1400 rpm speed with diesel fuel. The optimum engine operating condition in terms of optimum performance characteristics has been found A1-B1-C1. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 53.94%, and engine speed and fuel type have a contributing factor of 22.63% and 23.43% in terms of engine response parameters. The performance and emission parameters of 5% water-emulsified CNT incorporated OPB20 fuel is comparable to diesel fuel.

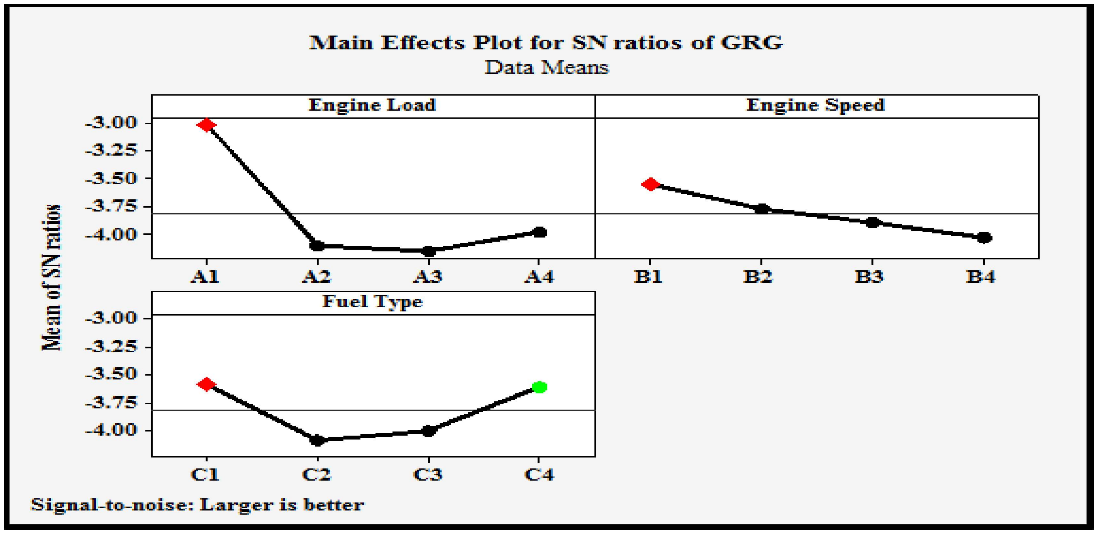

Figure 6.24 S/N ratio variation of GRG versus engine torque, speed & OPB blended nano fuel

6.4.7 Confirmation Test for OPB Blended Nano Fuel with OPB Blended Nano Additive Incorporated Fuel

A confirmation test was conducted with the optimum control parameters, and the predicted GRG (∈) was evaluated using the following equation.

$$\in = Xm + \sum_{i=1}^{q}(Xi - Xm)$$

Xm is the overall mean of GRG, *Xi* is GRG for the optimum level, and **q** is the number of control parameters. The predicted GRG at the optimum setting (A1-B1-C1) and experimental value of GRG are 0.7730 and 0.7473, respectively. The error between the predicted and observed value of GRG is found to be .026 only.

6.5 Optimization for Diesel Engine Performance and Emission Parameters Fuelled with Water Emulsified SOB Blended Nano Additive Incorporated Fuel

6.5.1 S/N Ratio Plot Analysis for BSFC and BTE with SOB Blended Nano Additive Incorporated Fuel

Fig.6.25 illustrates the S/N ratio curve of engine BSFC and BTE response parameters of SOB blended nano fuel, obtained from the Taguchi method. The S/N ratio calculation method of BSFC and BTE has been discussed in section 6.1.2. Using this S/N curve, the engine operating factors and their optimum level in engine BSFC and BTE have been obtained. The optimum engine BSFC was obtained at 35 N-m engine torque, 2000 rpm speed condition with 5% water emulsified CNT incorporated SOB20 fuel. The optimum engine operating condition in terms of BSFC has been found A4-B4-C4. The ANOVA analysis of the S-N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 62.75%, and engine speed and fuel type have a contributing factor of 14.98% and 22.26%, respectively, in terms of engine BSFC.

The engine highest BTE has been obtained at 35 N-m engine torque, 2000 rpm speed condition with 5% water emulsified CNT incorporated SOB20 fuel. The optimum engine operating condition in BTE is A4-B4-C4. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 64.39%, and engine speed and fuel type have a contributing factor of 21% and 14.6%, respectively, in terms of engine BTE.

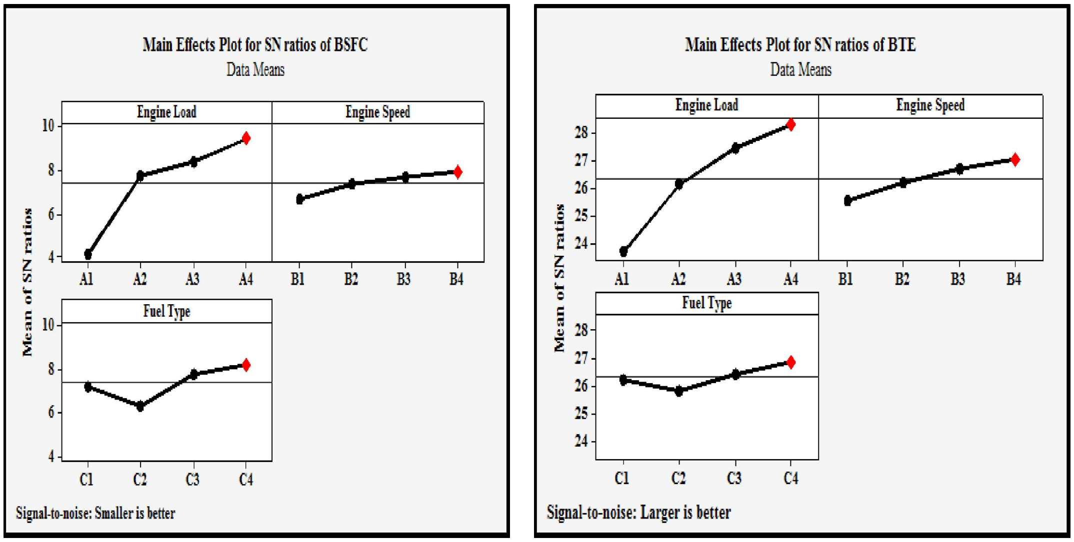

Figure 6.25 S/N ratio variation of BSFC and BTE versus engine torque, speed & SOB blended nano fuel

6.5.2 S/N Ratio Plot Analysis for Exergy Efficiency and Exhaust Gas Temperature with SOB Blended Nano Additive Incorporated Fuel

Fig.6.26 illustrates the S/N ratio curve of engine exergy efficiency and exhaust gas temperature response parameters of SOB blended nano fuel, obtained from the Taguchi method. The S/N ratio calculation method of exergy efficiency and exhaust gas temperature are discussed in section 6.1.2. The engine's highest exergy efficiency has been obtained at 35 N-m engine torque, 2000 rpm speed condition with 5% water emulsified CNT incorporated SOB20 fuel. The optimum engine operating condition for exergy efficiency has been found A4-B4-C4. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 65.73%, and engine speed and fuel type have a contributing factor of 20.89% and 13.37%, respectively, in terms of engine exergy efficiency.

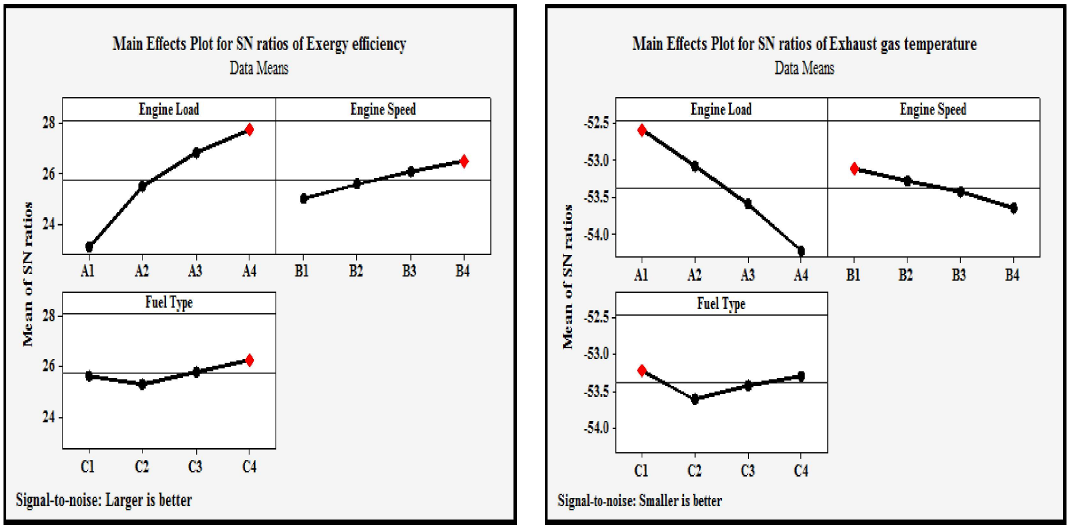

Figure 6.26 S/N ratio variation of exergy efficiency and exhaust gas temperature versus engine torque, speed & SOB blended nano fuel

The engine's lowest exhaust gas temperature has been obtained at 14 N-m engine torque, 1400 rpm speed condition with diesel fuel. The optimum engine operating condition for exhaust gas temperature is A1-B1-C1. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 64.06%, and engine speed and fuel type have a contributing factor of 20.7% and 15.23%, respectively, in terms of engine exhaust gas temperature.

6.5.3 S/N Ratio Plot Analysis for Exergy Destruction Rate and HC Emissions with SOB Blended Nano Additive Incorporated Fuel

Fig.6.27 illustrates the S/N ratio curve of engine EDR and HC emission response parameters of SOB20 blended nano fuel, obtained from the Taguchi method. The S/N ratio calculation method of EDR and HC emissions has been discussed in section 6.1.3. The engine operating factors and their optimum level in engine EDR and HC emissions have been obtained using this S/N curve. The engine's lowest EDR has been obtained at 14 N-m engine torque, 1400 rpm speed condition with 5% water emulsified CNT incorporated SOB20 fuel. The optimum engine operating condition in EDR is A1-B1-C4. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 55.12%, and engine speed and fuel type have a contributing factor of 37.65% and 7.22%, respectively, in terms of engine EDR.

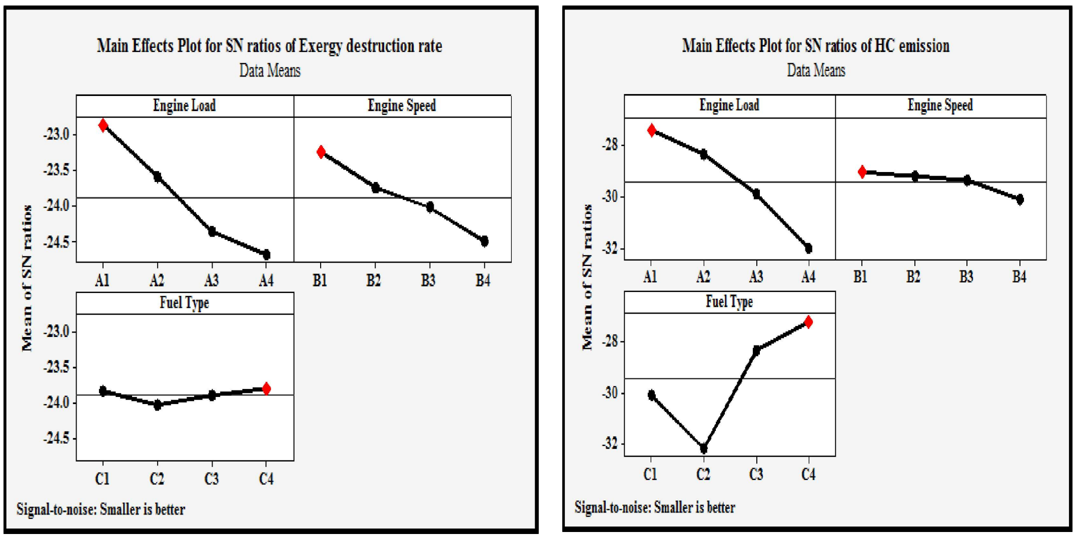

Figure 6.27 S/N ratio variation of exergy destruction rate, and HC emission versus engine torque, speed & SOB blended nano fuel

The engine's lowest HC emission has been obtained at 14 N-m engine torque, 1400 rpm speed condition with 5% water emulsified CNT incorporated SOB20 fuel. The optimum engine operating condition in HC emissions is A1-B1-C4. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 43.11%, and the engine speed and fuel type have a contributing factor of 13.70% and 43.19%, respectively, in terms of engine HC emissions.

6.5.4 S/N Ratio Plot Analysis for CO and CO_2 Emissions with SOB Blended Nano Additive Incorporated Fuel

Fig.6.28 illustrates the S/N ratio curve of CO and CO_2 emissions response parameters of SOB blended nano fuel obtained from the Taguchi method. The S/N ratios of CO and CO_2 emissions have been calculated according to the lower is better-based equation using Minitab16 software. The engine operating factors and their optimum level in engine CO and CO_2 emissions has been obtained using this S/N curve. The engine's lowest CO emissions have been obtained at 14 N-m engine torque, 1400 rpm speed condition with 5% water emulsified CNT incorporated SOB20 fuel. The optimum engine operating condition for CO emissions is A1-B1-C4. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 56.26%, and the engine speed and fuel type have contributed to 17.69% and 26.04% in terms of engine CO emissions.

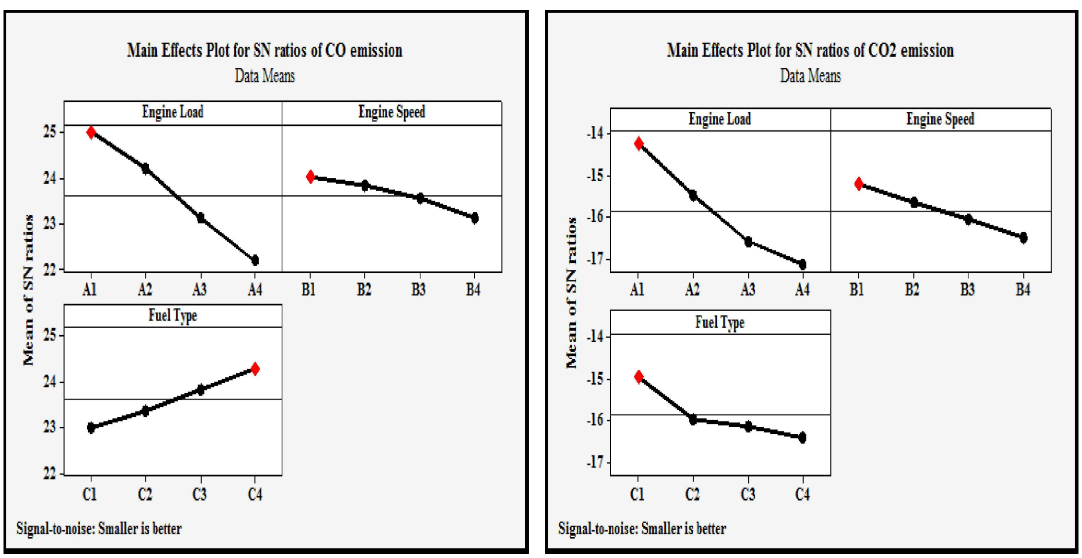

Figure 6.28 S/N ratio variation of CO and CO_2 emissions versus engine torque, speed & SOB blended nano fuel

The engine's lowest CO_2 emissions have been obtained at 14 N-m engine torque, 1400 rpm speed condition with diesel fuel. The optimum engine operating condition for CO_2 emissions is A1-B1-C1. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 51.49%, and the engine speed and fuel type have a contribution of 23.02% and 25.48% in terms of engine CO_2 emissions.

6.5.5 S/N Ratio Plot Analysis for NO Emissions and Smoke Emissions with SOB Blended Nano Additive Incorporated Fuel

Fig.6.29 illustrates the S/N ratio curve of NO, and smoke emission response parameters of SOB20 blended nano fuel, obtained from the Taguchi method. The S/N ratio calculation method for NO and smoke emissions have been discussed in section 6.1.5. Using this S/N curve, the engine operating factors and their optimum level in engine NO and smoke emissions. The engine's lowest NO emissions have been obtained at 14 N-m engine torque, 1400 rpm speed with diesel fuel. The optimum engine operating condition for NO emissions is A1-B1-C1. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 46.29%, and the engine speed and fuel type have a contributing factor of 29.71% and 24%, respectively, in engine NO emissions.

The engine's lowest smoke emissions have been obtained at 14 N-m engine torque, 1400 rpm speed condition with 5% water emulsified CNT incorporated SOB20 fuel. The optimum engine operating condition for smoke emissions is A1-B1-C4. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 41.76%, and the engine speed and fuel type have a contributing factor of 12.55% and 45.69%, respectively, in engine smoke emissions.

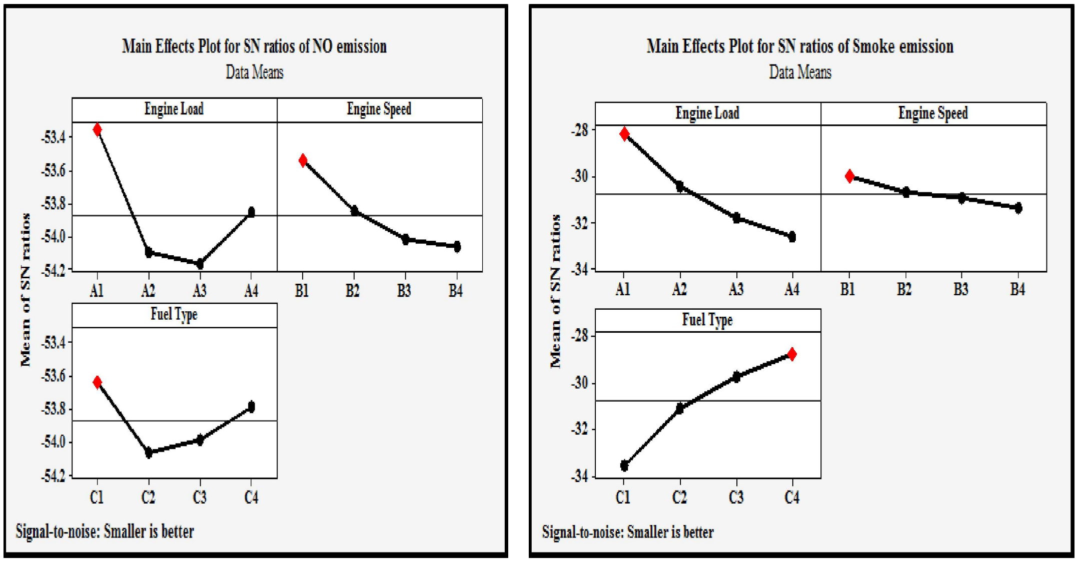

Figure 6.29 S/N ratio variation of NO and smoke emissions versus engine torque, speed & SOB blended nano fuel

6.5.6 S/N Ratio Plot Analysis for Grey Relational Grade with SOB Blended Nano Additive Incorporated Fuel

Fig 6.30 illustrates the S/N ratio curve of GRG of SOB20 blended nano fuel obtained from the Taguchi method. The S/N ratio of GRG has been calculated according to a higher is better-based equation using Minitab16 software. The engine operating factors and their optimum level in engine performance and emission parameters have been obtained using this S/N curve. The engine's optimum emissions and performances have been obtained at 14 N-m engine torque and 1400 rpm speed with diesel fuel. The optimum engine operating condition in terms of optimum performance characteristics has been found A1-B1-C1. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 53.31%, and engine speed and fuel type have a contributing factor of 21.28% and 25.41% in terms of engine response parameters. The performance and emission parameters of 5% water-emulsified CNT incorporated SOB20 fuel are comparable to diesel fuel.

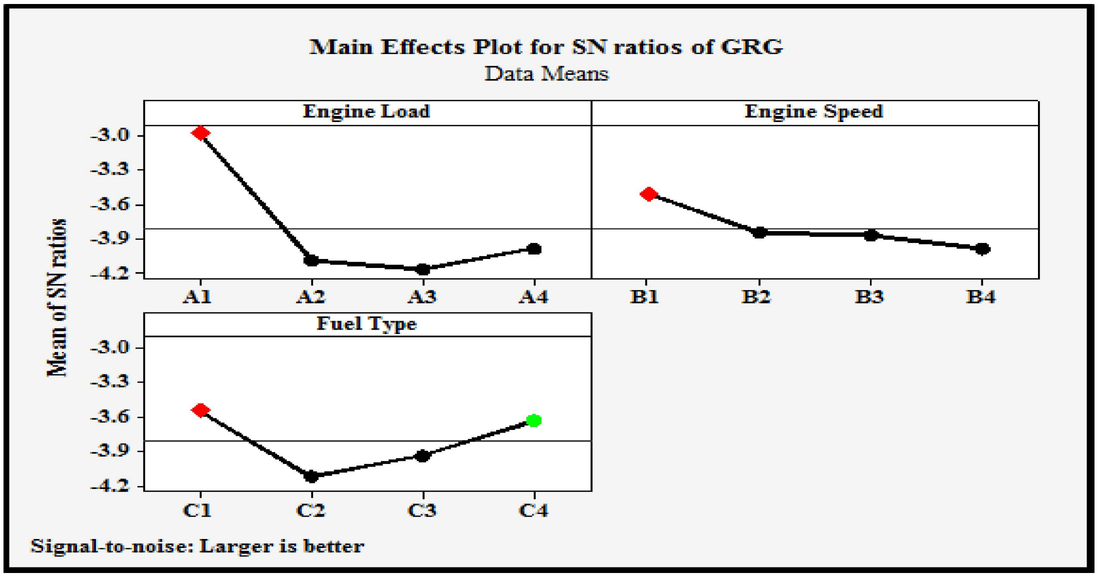

Figure 6.30 S/N ratio variation of GRG versus engine torque, speed & SOB blended nano fuel

6.5.7 Confirmation Test for SOB Blended Nano Fuel

A confirmation test was conducted with the optimum control parameters, and the predicted GRG (∈) was evaluated using the following equation.

$$\in = Xm + \sum_{i=1}^{q}(Xi - Xm)$$

Xm is the overall mean of GRG, *Xi* is GRG for the optimum level, and *q* is the number of control parameters. The predicted GRG at optimum setting (A1 B1 C1) and experimental value of GRG are 0.7738 and 0.7557, respectively. The error between the predicted and observed value of GRG is found to be .0182only.

6.6 Optimization for Diesel Engine Performance and Emission Parameters Fuelled with Water Emulsified OPB Blended and SOB Blended CNT Nano Additive Incorporated Fuel

6.6.1 S/N Ratio Plot Analysis for BSFC and BTE with CNT Nano Additive Incorporated Fuels

Fig.6.31 illustrates the S/N ratio curve of engine BSFC and BTE response parameters of CNT nano additive incorporated OPB, and SOB blended fuel, obtained from the Taguchi method. The S/N ratio calculation method of BSFC and BTE has been discussed in section 6.1.2. Using this S-N curve, the engine operating factors, and their optimum level in engine BSFC and BTE, the optimum engine BSFC was obtained at 35 N-m engine torque, 2000 rpm speed condition with 5% water emulsified CNT incorporated SOB20 fuel. The optimum engine operating condition in BSFC is A4-B4-C2. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 68.00%,

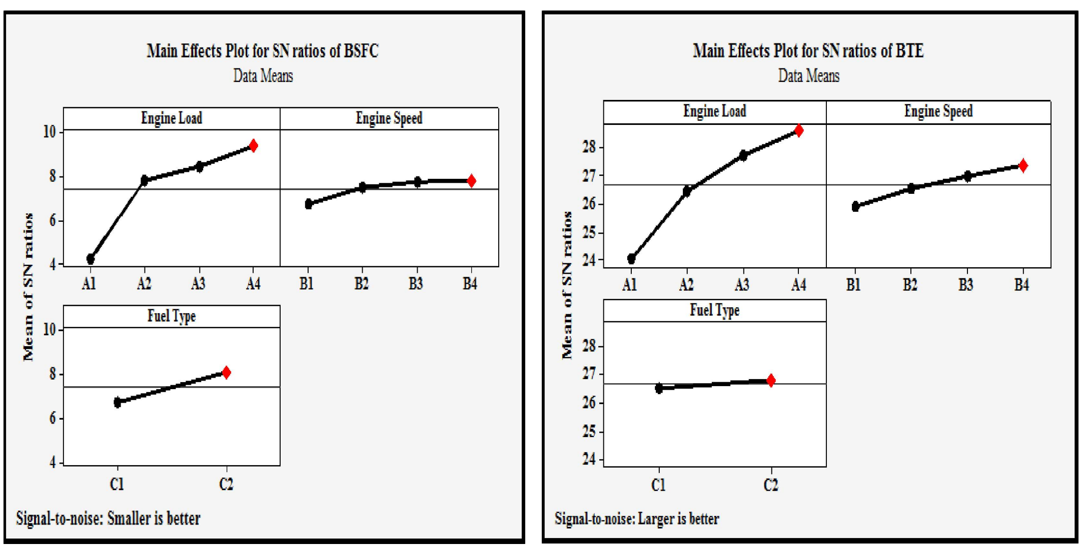

Figure 6.31 S/N ratio variation of BSFC and BTE versus engine torque, speed & CNT nano additive incorporated biodiesel blended fuel

and engine speed and fuel type have a contributing factor of 14.10% and 17.89%, respectively, in terms of engine BSFC.

The engine highest BTE has been obtained at 35 N-m engine torque, 2000 rpm speed condition with 5% water emulsified CNT incorporated SOB20 fuel. The optimum engine operating condition in BTE is A4-B4-C2. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 72.45%, and engine speed and fuel type have a contributing factor of 23.25% and 4.30%, respectively, in terms of engine BTE

6.6.2 S/N Ratio Plot Analysis for Exergy Efficiency and Exhaust Gas Temperature with CNT Nano Additive Incorporated Fuels

Fig 6.32 illustrates the S/N ratio curve of engine exergy efficiency and exhaust gas temperature response parameters of CNT nano additive incorporated OPB and SOB blended fuel, obtained from the Taguchi method. The S/N ratio calculation method of exergy efficiency and exhaust gas temperature are discussed in section 6.1.2. The engine's highest exergy efficiency has been obtained at 35 N-m engine torque, 2000 rpm speed condition with 5% water emulsified CNT incorporated SOB20 fuel. The optimum engine operating condition for exergy efficiency has been found A4-B4-C2. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 72.21%, and engine speed and fuel type have a contributing factor of 21.82% and 5.97%, respectively, in terms of engine exergy efficiency.

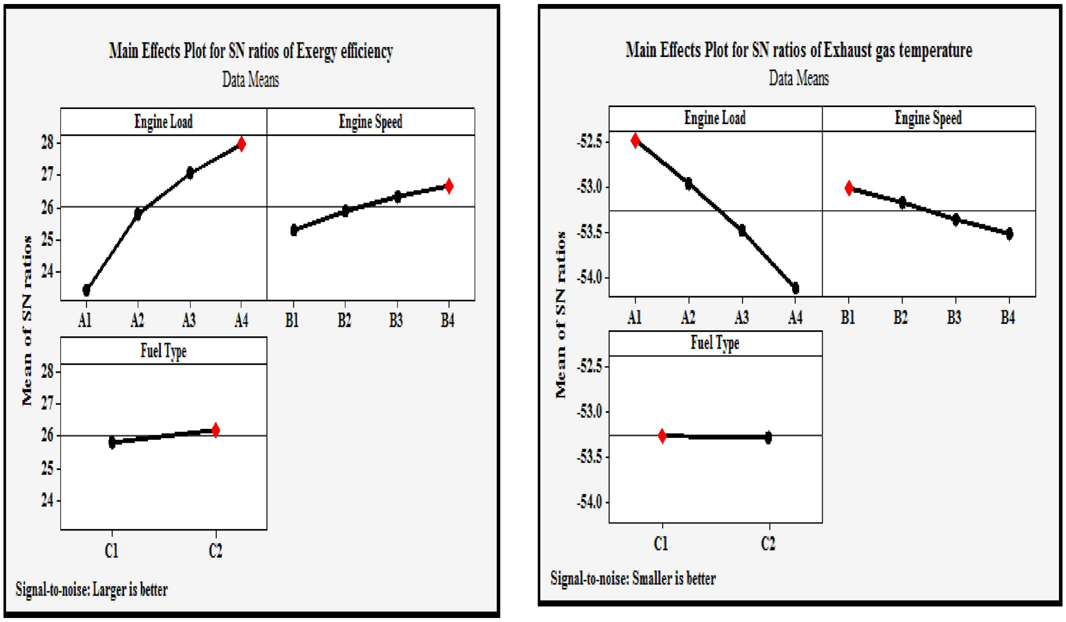

Figure 6.32 S/N ratio variation of exergy efficiency and exhaust gas temperature versus engine torque, speed & CNT nano additive incorporated biodiesel blended fuel

The engine's lowest exhaust gas temperature has been obtained at 14 N-m engine torque, 1400 rpm speed condition with 5% water emulsified CNT incorporated OPB20 fuel. The optimum engine operating condition for exhaust gas temperature is A1-B1-C1. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 75%, and engine speed and fuel type have a contributing factor of 23.18% and 1.8%, respectively, in terms of engine exhaust gas temperature.

6.6.3 S/N Ratio Plot Analysis for Exergy Destruction Rate and HC Emissions with CNT Nano Additive Incorporated Fuels

Fig.6.33 illustrates the S/N ratio curve of engine EDR and HC emission response parameters of CNT nano additive incorporated OPB and SOB blended fuel, obtained from the Taguchi method. The S/N ratio calculation method of EDR and HC emissions has been discussed in section 6.1.3. The engine operating factors and their optimum level in engine EDR and HC emissions have been obtained using this S/N curve. The engine's lowest EDR has been obtained at 14 N-m engine torque, 1400 rpm speed condition with 5% water emulsified CNT incorporated SOB20 fuel. The optimum engine operating condition in EDR is A1-B1-C2. The ANOVA analysis of the S/N curve concludes that engine torque is the most affecting factor, has a contributing factor of 46.61%, and engine speed and fuel type have a contributing factor of 35.17% and 18.23%, respectively, in terms of engine EDR.

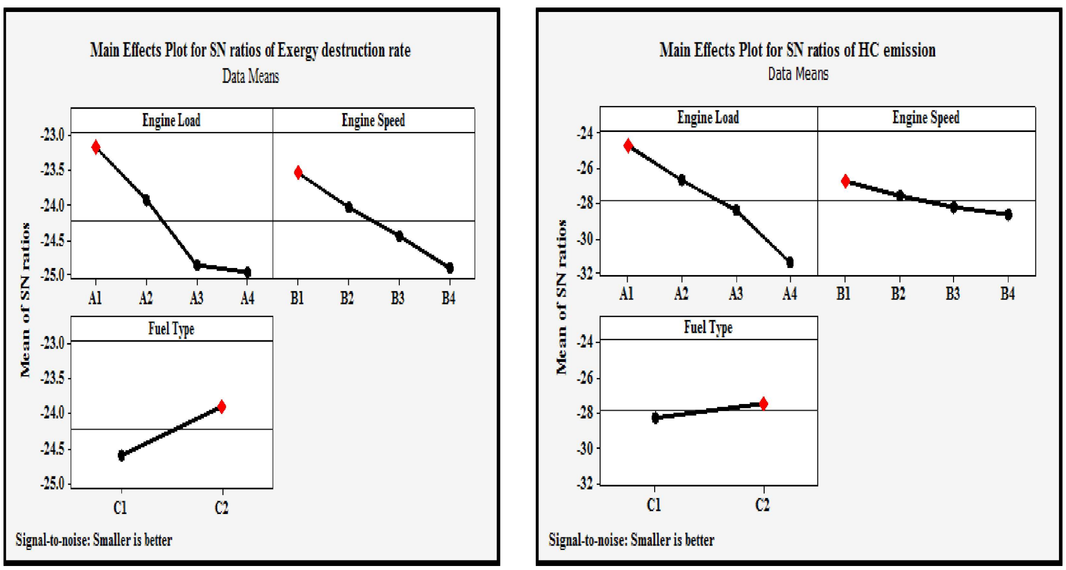

Figure 6.33 S/N ratio variation of exergy destruction rate, and HC emissions versus engine torque, speed & CNT nano additive incorporated biodiesel blended fuel

The engine's lowest HC emissions have been obtained at 14 N-m engine torque, 1400 rpm speed condition with 5% water emulsified CNT incorporated SOB20 fuel. The optimum engine operating condition in HC emissions is A1-B1-C2. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 70.45%, and the engine speed and fuel type have a contributing factor of 20.5% and 9.04%, respectively, in terms of engine HC emissions.

6.6.4 S/N Ratio Plot Analysis for CO and CO_2 Emissions with CNT Nano Additive Incorporated Fuels

Fig.6.34 illustrates the S/N ratio curve of CO and CO_2 emission response parameters of CNT nano additive incorporated OPB, and SOB blended fuel obtained from the Taguchi method. The S/N ratio of CO and CO_2 emissions have been calculated according to the lower is better-based equation using Minitab16 software. The engine operating factors and their optimum level in engine CO and CO_2 emissions have been obtained using this S/N curve. The engine's lowest CO emissions have been obtained at 14 N-m engine torque, 1400 rpm speed condition with 5% water emulsified CNT incorporated SOB20 fuel. The optimum engine operating condition for CO emissions is A1-B1-C2. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 44.41%, and the engine speed and fuel type have a contribution of 37.76% and 17.82% in terms of engine CO emissions.

The engine's lowest CO_2 emission has been obtained at 14 N-m engine torque, 1400 rpm speed condition with 5% water emulsified CNT incorporated OPB20 fuel. The optimum engine operating condition for CO_2 emissions is A1-B1-C1. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 67.87%, and the engine speed and fuel type have a contribution of 31% and 1.11% in terms of engine CO_2 emissions.

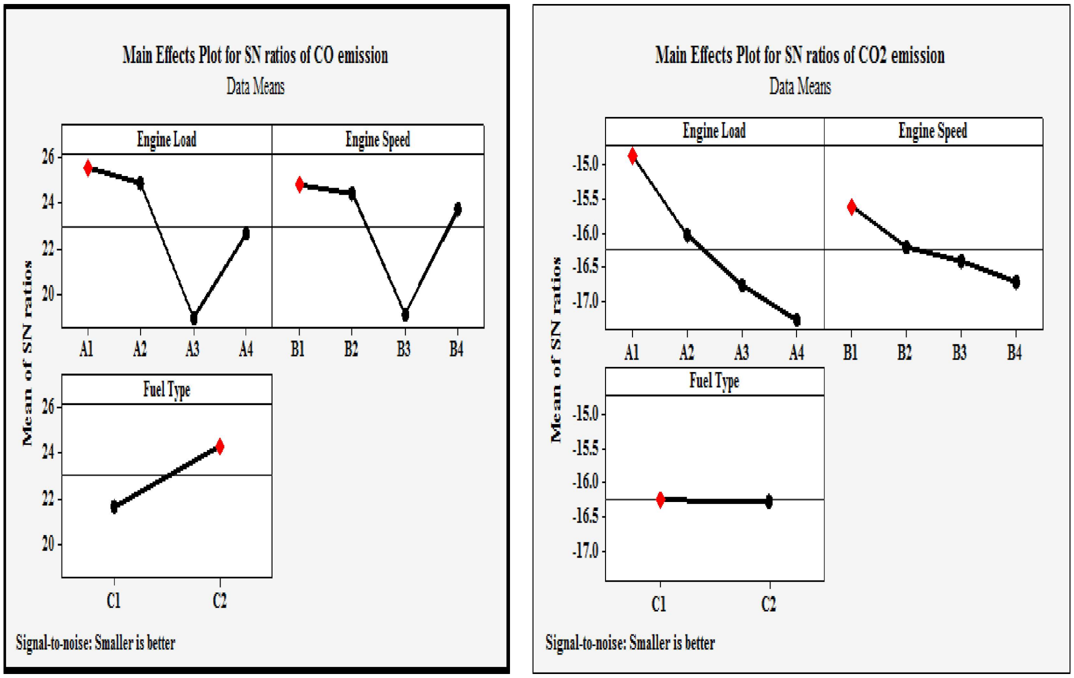

Figure 6.34 S/N ratio variation of CO emission and CO_2 emission versus engine load, speed & CNT nano additive incorporated biodiesel blended fuel

6.6.5 S/N Ratio Plot Analysis for NO and Smoke Emissions with CNT Nano Additive Incorporated Fuels

Fig.6.35 illustrates the S/N ratio curve of NO, and smoke emission response parameters of CNT nano additive incorporated OPB and SOB blended fuel, obtained from the Taguchi method. The S-N ratio calculation method of NO and smoke emission has been discussed in section 6.1.5. Using this S/N curve, the engine operating factors and their optimum level in engine NO and smoke emissions. The engine's lowest NO emissions have been obtained at 14 N-m engine torque, 1400 rpm speed with 5% water emulsified CNT incorporated OPB20 fuel. The optimum engine operating condition for NO emissions is A1-B1-C1. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 55.56%, and the engine speed and fuel type have a contributing factor of 33.33% and 11.11%, respectively, in engine NO emissions.

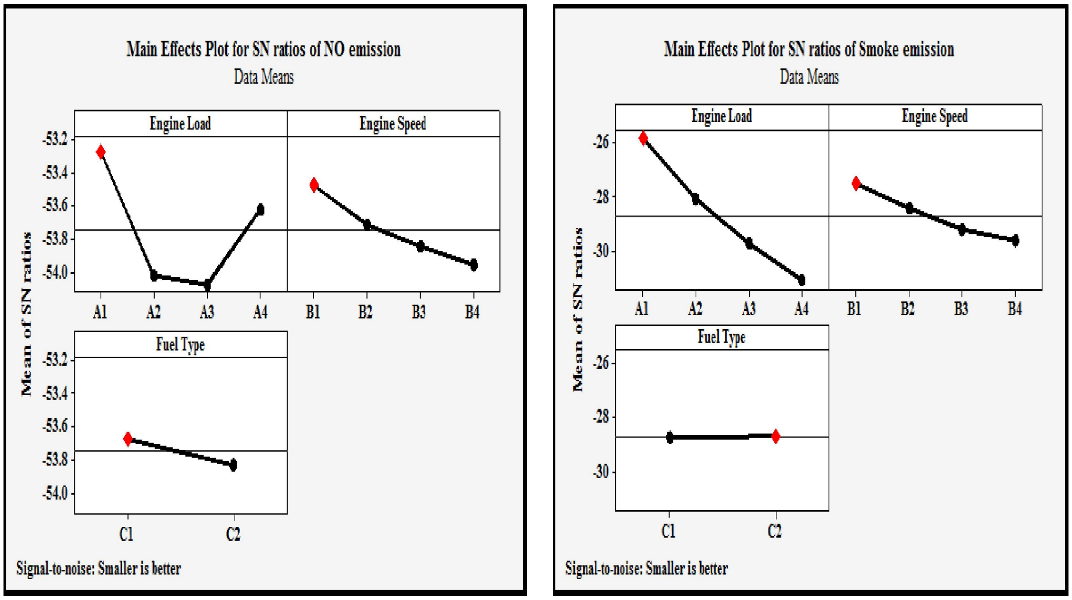

Figure 6.35 S/N ratio variation of NO emission and smoke emission versus engine load, speed & CNT nano additive incorporated biodiesel blended fuel

The engine's lowest smoke emissions have been obtained at 14 N-m engine torque, 1400 rpm speed condition with 5% water emulsified CNT incorporated SOB20 fuel. The optimum engine operating condition for smoke emissions is A1-B1-C2. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 70.84%, and the engine speed and fuel type have a contributing factor of 27.96% and 1.19%, respectively, in engine smoke emissions.

6.6.6 S/N Ratio Plot Analysis for Grey Relational Grade with CNT Nano Additive Incorporated Fuels

Fig.6.36 illustrates the S/N ratio curve of GRG of CNT nano additive incorporated OPB, and SOB blended fuel obtained from the Taguchi method. The S/N ratio of GRG has been calculated according to a higher is better-based equation using

Minitab16 software. The engine operating factors and their optimum level in engine performance and emission parameters have been obtained using this S/N curve. The engine optimum emissions and performances have been obtained at 14 N-m engine torque, and 1400 rpm speed with 5% water-emulsified CNT incorporated SOB20 fuel. The optimum engine operating condition in terms of optimum performance characteristics has been found A1-B1-C2. The ANOVA analysis of the S/N ratio concludes that engine torque is the most affecting factor, has a contributing factor of 54.48%, and engine speed and fuel type have a contributing factor of 35.24% and 10.27% in terms of engine response parameters.

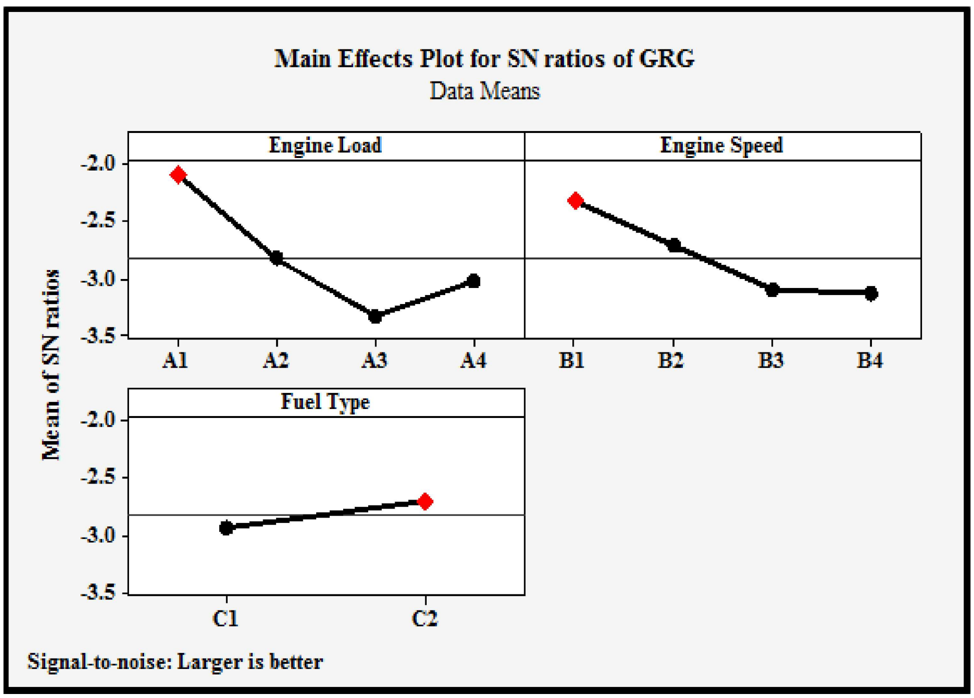

Figure 6.36 S/N ratio variation of GRG versus engine torque, speed & CNT nano additive incorporated biodiesel blended fuel

6.6.7 Confirmation Test CNT Nano Additive Incorporated Biodiesel Blended Fuel

A confirmation test was conducted with the optimum control parameters, and the predicted GRG (∈) was evaluated using the following equation.

$$\in = Xm + \sum_{i=1}^{q} (Xi - Xm)$$

Xm is the overall mean of GRG, *Xi* is GRG for the optimum level, and *q* is the number of control parameters. The predicted GRG at the optimum setting (A1 B1 C2) and experimental value of GRG are 0.8372 and 0.8333, respectively. The error between the predicted and observed value of GRG is found to be .0039 only.

6.7 Highlights

In this chapter, the experimentation is performed according to the L16 orthogonal array designed by Taguchi experimental design method. The S/N ratio analysis has been performed for engine performances and emission parameter responses with OPB blended fuels, SOB blended fuels, and water-emulsified fuels. The S/N ratio analysis also has been performed for engine performances and emission parameter responses with OPB blended nano fuel, SOB blended nano fuel, and CNT nano additive incorporated with 5% water emulsified OPB20 and SOB20 fuel. The Grey optimization technique was applied to find the overall optimal solution. The following observation is taken from the detailed analysis.

- The S/N curve analysis declared that 10kg engine loading and 2000 rpm engine speed were the optimum engine setting for the lowest engine BSFC and highest BTE and exergy efficiency.

- The S/N curve analysis declared that at 14 N-m engine torque and 1400 rpm engine speed was the optimum engine setting for the lowest CO, CO_2, HC, NO, and smoke

  emissions level.
- The S/N curve for OPB and SOB blended fuels declared that the NO, HC, and CO_2 emission was lowest with diesel fuels, and CO and smoke emissions were the lowest for OPB30 and SOB30 fuels.
- The S/N curve of water-emulsified fuel declared that the engine BTE and exergy efficiency were observed highest for WiDE5 fuel.
- The S/N curve of water-emulsified fuel declared that the engine NO and smoke emission were the lowest for WiDE15 fuel.
- The S/N curve of GRG of OPB blended fuel declared that at 14 N-m engine torque, 1400 rpm engine speed, and diesel fuel was the optimum engine setting for optimum engine performance and emission characteristics. The performance and emission parameters with OPB20 fuel were comparable with diesel fuel.
- The S/N curve of GRG of SOB blended fuel declared that 14 N-m engine torque, 1400 rpm engine speed, and diesel fuel were the optimum engine setting for optimum engine performance and emission characteristics. The performance and emission parameters with SOB20 fuel were comparable with diesel fuel.
- The S/N curve of GRG of OPB and SOB blended fuel declared that the performance and emission parameters with SOB20 fuel were found superior to SOB20 fuel.

- The S/N curve of GRG of water emulsified fuel declared that 14 N-m engine torque, 1800 rpm engine speed, and WiDE5 were the optimum engine setting for optimum engine performance and emission characteristics.
- The engine torque was observed most affecting input parameters with more than 50% contribution factor for each output response.
- The S/N curve analysis revealed that the 35 N-m engine torque, 2000 rpm engine speed, and CNT nano additive incorporated water emulsified biodiesel blended fuel was the optimum engine setting for the lowest engine BSFC and highest BTE and exergy efficiency.
- The S/N curve analysis revealed that the 14 N-m engine torque, 1400 rpm engine speed, and diesel fuel was optimum engine setting for the lowest engine EGT, NO, and CO_2 emission.
- The S/N curve analysis revealed that the 14 N-m engine torque, 1400 rpm engine speed, and CNT nano additive incorporated water emulsified biodiesel blended fuel was the optimum engine setting for the lowest engine EDR, CO, and smoke emissions.
- The S/N curve analysis of GRG revealed that the 14 N-m engine torque, 1400 rpm engine speed, and diesel fuel were optimum for overall performance and emission parameters. The result obtained with CNT nano additive incorporated water emulsified biodiesel blended fuel was comparable to diesel fuel.
- The S/N curve of CNT incorporated water emulsified OPB20 and SOB20 fuels revealed that 14 N-m engine torque, 1400 rpm engine speed, and CNT incorporated 5% water emulsified OPB20 fuel was the optimum engine setting for the lowest EGT, NO, and CO_2 emissions.

- The S/N curve of CNT incorporated water emulsified OPB20 and SOB20 fuel revealed that 35 N-m engine torque, 2000 rpm engine speed, and CNT incorporated 5% water emulsified SOB20 fuel was the optimum engine setting for the highest BTE, exergy efficiency, and lowest BSFC.
- The S/N curve of CNT incorporated water emulsified OPB20 and SOB20 fuel revealed that 14 N-m engine torque, 1400 rpm engine speed, and CNT incorporated 5% water emulsified SOB20 fuel was the optimum engine setting for lowest EDR, CO, HC, and smoke emissions.
- The S/N curve of GRG of CNT incorporated water emulsified OPB20 and SOB20 fuel revealed that 14 N-m engine torque, 1400 rpm engine speed, and CNT contained 5% water emulsified SOB20 fuel was optimum engine setting for overall optimum performance and emission parameters.
- The engine torque was observed most affecting input parameters with more than 45% contribution factor for each output response.

The detailed analysis found that the engine BTE, exergy efficiency, and sustainability index were enhanced with 5% water emulsified biodiesel blended fuel and further increased with the incorporation of nano additive. The effect of incorporation of CNT nano additive has been observed to be higher than Al_2O_3 nano additive. The overall engine performance and emission parameters were obtained with 14 N-m engine torque, 1400 rpm engine speed, and CNT incorporated 5% water emulsified SOB20 fuel engine operating condition.

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