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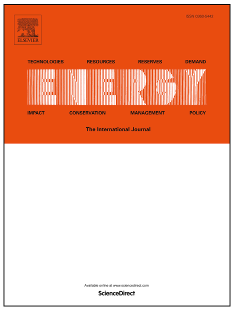

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Improving the gasoline properties by blending butanol-Al_2O_3 to optimize the engine performance and reduce air pollution

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Abstract

In this study, butanol, as an oxygenate additive and alumina as a nano metal particle, was mixed with pure gasoline. Different blends were tested, and operational tests were done on an engine with different engine speeds. Those additives were added to decrease air pollution due to the higher oxygen content of butanol, which can make combustion more complete, and nano metal

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additive, which has suitable potential to enhance engine performance, especially Brake Specific Fuel Consumption (BSFC). The results indicate that adding the additives mentioned above to the pure gasoline has led to an increase the engine performance. In this regard, the engine power has increased by 10% by adding alumina. Moreover, combining the base gasoline with additives enhances CO2 and reduces NOx and emissions of hydrocarbons. In this research, carbon monoxide was diminished by adding alcohol up to 50% in some conditions, and the emitted hydrocarbons through the atmosphere were declined by up to 20%. Moreover, optimization results showed that higher optimization is achieved when 5% of butanol and 1 g of alumina are used. Under these conditions, the results of CO, CO_2, NOx and HC emissions were 1.099, 4.699, 113.9 and 77.5 ppm, respectively.

Keywords: Additives, Nano-particles, Pollution, Gasoline, Butanol, Al_2O_3

1. Introduction

Preserving energy sources and stricter environmental rules on controlling the engine's output pollutants need cleaner ignition, complete combustion, and engine operation[1–4]. Within the last recent years, energy demand has been increased.[5] Although gasoline and diesel fuels are interesting ones due to their energy, they enhance the exhaust emissions that have restricted their application. Hence, researchers[5–8] tried to find some techniques to solve this problem. Petroleum-based fuels such as diesel and gasoline play a significant role in transportation, and finding a fuel with a better formulation is substantial, especially for environmental aspects[9–11]. In this case, researchers tried to eliminate those fuels' drawbacks in the last decades, notably air pollution. It was concluded that blending alcohol could eradicate this problem due to their oxygen content [12]. Dwivedi et al. [13]worked on a research study based on previous research and suggested that biodiesel is a good alternative for Diesel fuel due to its friendly environmental properties. Dwivedi and Sharma [14] showed that incomplete combustion is the main reason for air pollution that can be eliminated by improving biodiesel's cold flow property by blending biodiesel with diesel. They reported that a cold flow improver such as Olefin-ester copolymer and Octa-1 maleic anhydride copolymer could solve this problem.

Using additives for fuel is considered one of the most effective techniques for reducing fuel consumption[15–19]. Additives are classified according to their applications. For example, oxygenate additives such as ethanol, methanol, and butanol may reduce air pollution by completing combustion[20–22]. One of the most effective additives is a nanoparticle, which can be applied to achieve this aim, and it can contribute to disperse the additive into the fuel homogeneously. The most crucial concern with fossil fuels is dispersing environmental pollutant particles such as CO_2, CO, NO_x, and CH [23–28]. Within recent years, butanol has been identified as an alternative fuel for diesel fuels and gasoline. As the conversion of butanol into fuel is more toxic and costly, its production rate is less than methanol and ethanol[29–32]. Hussein et al. [33] combined four additives, including methanol, ethanol, tertiary butyl alcohol, and diizopropyl ether, in different volumes with gasoline. The results showed that speed, power, efficiency, and mass discharge of fuel had been increased by adding more additives to the compound. In reverse, the consumption of special fuel and the equivalence ratio is reduced. The mixture of the base gasoline with the additives tends to increase carbon dioxide, hydrocarbons, and carbon monoxide emissions.

Valiansari et al. [34] did the tests in two cases of complete partial loads. The full load test was done at different speeds, and the partial load was only done at the speeds of 2000 and 3000 rotation/min. In all of these tests, the ignition time was optimized. The results indicate that as ethanol is increased in the compound, respiratory efficiency, power, and engine velocity were enhanced. The consumption of special fuel is decreased at slow speeds, and it is increased at fast speeds.

On the other hand, ethanol in the compound has triggered a remarkable reduction in unburnt hydrocarbons. Carbon monoxide hydrocarbon has been somehow decreased, but the amount of nitrogen oxide shows a slight increase. Finkert et al. [2] blended ethanol with gasoline. The results demonstrated that as the percentage of ethanol is enhanced in the blend, the ignition parameters like the maximum pressure inside the cylinder, the maximum amounts of the first derivation and the second pressure, and the released heat rate are enhanced. The brake power and the output velocity in the high rotation of the engine were increased. The consumption of the particular fuel of engine brake is declined in ethanol-gasoline blends, whereas the brake thermal efficiency and the engine volume performance have been increased. E5, E10, E15 and E20 were practiced to reduce carbon monoxide pollutants compared to pure gasoline. Compared with pure gasoline, the amount of carbon dioxide was increased as much as 3.87, 6.06, 6.76, and 10.14%, respectively. Moreover, the unburnt hydrocarbon pollutant has been diminished up to 16.94%, while the nitrogen oxide pollutant amount is increased. Elfaskhani[35] studied the operation and pollutants from a spark-ignition engine with ethanol- methanol- gasoline fuel. The tests included the mixture with a low combination percentage of ethanol- methanol (3 to 10%) in benzene compared to the mix of ethanol-gasoline and methanol-gasoline and pure gasoline. The results demonstrated that when ethanol-methanol was used, the UHC and CO gases emission was remarkably reduced compared to pure gasoline. Li and co-worker[36] deliberated the influence of blending three additives (acetone, ethanol, and butanol) with gasoline. They concluded that ABE-gasoline blends with various ABE component ratios under stoichiometric conditions exhibited a reduction in the combustion phase, which also decreased HC emission by increasing acetone and decreasing butanol concentration.

On the other hand, this blend triggers the enhancement of NOx emission. They showed that CO was initially decreased and then increased. This might be influenced by two factors:1) increasing the oxygen content of the blended fuel compared to neat gasoline and 2) reducing combustion temperature. In other research work, Li and colleagues [37] studied the influence of ABE-Gasoline. They claimed that lower UHC and CO emissions of ABE-Gasoline might be for the sake of the effect of acetone. As the duration of higher combustion of the new blend is likely to promote oxidation, it reduces UHC and CO emissions. Tian et al. [38] mulled over the influence of the addition of n-butanol on gasoline. They reported that this additive could reduce CO and NOx emissions. They resulted in higher oxygen content and a large latent heat of vaporization of n-butanol. They also illustrated that when the n-Butanol is increased, the CO emissions are enhanced at low engine speeds. Since the fuel injected into the cylinder is improved at a low speed and the high latent heat of vaporization of n-Butanol decreases the cylinder's temperature, the mixed gas combustion is insufficient to trigger an enhancement in CO emissions. Chan et al. [39] investigated the influence of blending Di-Methyl Carbonate(DMC) with gasoline on air pollution and engine performance. The results indicated that the blended fuel showed 30% less unburnt hydrocarbon species and 60% less particulate matter (PM) emissions than pure gasoline.

On the other hand, there is no remarkable difference between the BTE of DMC-Gasoline and pure gasoline. D8 was significantly reduced. Hence, it is understood that DMC's fuel oxygen content and its advantageous chemical structure are mainly responsible for such reductions. They suggested that less PM emission by blended fuel was obtained due to a decrease in the number of particles to particle interactions (e.g., coagulation, aggregation, and agglomeration). Finally, it was directed into smaller agglomerates. Other important reasons for that reduction are the oxygen presence in DMC, lower C/H ratio, the absence of aromatic compounds, higher oxygen/carbon (O/C) ratio, and C-C bonds. Some other research about different gasoline's additives has been displayed in Table 1.

This research's main objective was to study the influences of different additives such as nanoparticles and alcohol on fuel combustion. Another aim of this study was to investigate the impact of nanoparticle type and their rate on improving engine performance and reducing exhaust emissions. The current research aims to modify gasoline to better fuel environmental specifications and combustion performance. The other purpose of this research is to achieve the most optimum conditions from engine performance and fuel properties and economic perspectives. This research study aims to use a nano additive, and an oxygenate additive simultaneously to improve engine performance and reduce hazardous air pollution, which is the main novelty of this study.

Table 1. Influence of blending different additives on Engine performance, Exhaust emission and fuel properties

2. Materials and Methods

In this research, butanol, which is four-carbon alcohol, has been used. Its chemical formula is

C_4H_9OH. Butanol is often used as a solvent in chemical synthesis or as fuel. Table 2 summarizes the specifications of the butanol used in this research.

Table 2. The Butanol specification

Al_2O_3 with a purity of 99.5% and a size of 20 nm have been used (Fig. 1.a). Some of its specifications have been featured out in Table 3.

Fig. 1. The (a) Al2O3 particles, (b) dynamometer and XU7/GVC3 gasoline engine and (c) Analyzer for gas exhaust detection

Table 3. The Al_2O_3 particles specification

It has been purchased from Mehregan shimi Company, which represents the U.S Nano in Iran. Dynamometer is an instrument that is used to test a device from the power, velocity, and energy consumption viewpoints in the industry. It also controls and tests the endurance of pieces that connect it to the crankshaft of the engine. Furthermore, the dynamometer exerts resistance and load to the engine at a different angular speed. The load can be used by other brakes such as electrical brake, water brake, or friction brake. In this system, the dynamometer is connected to the engine by coupling, and the engines rotate the dynamometer (Fig. 1.b). This rotation has been connected to a dynamometer. We have utilized a dynamometer chassis (130 kW) equipped with an output refrigerant tower in our tests. Initially, the device is turned on by a switch that is on the control monitor (Fig. 1.c). Lastly, we run its program in the computer connected to it and push the Ignite bottom. After that, we push the start. The most crucial point is that the lubrication temperature shouldn't exceed 95 °C.

2.1. Equipment and Experiment Design

The experiments have been done in a laboratory at a temperature of almost 25 °C. A certain percentage of each alcohol is added to the diesel fuel. Afterward, the second additive is added in the intended amounts. Firstly, pure gasoline experiments have been done at various engine speeds (1500, 2000, 2500, and 3000). As the second part of the experiment, the butanol was added to the gasoline to calculate the influence of the alcoholic additive on gasoline emissions and chemical-physical properties. Lastly, 1 g of alumina has been added to the blend, and the experiments have been done with these additives. The Gasoline engine properties and two leading equipment for measuring emissions are featured in Tables 4-6.

Table 4. properties of Gasoline engine used in the experiments

Table 5. Specification of AVL 465 analyzer

Table 6. Specification of MRU 1600-L analyzer

The results are modeled and optimized by Design-Expert software and contribute to doing the tests and the outcomes. Table 7 divulges experiment design and the actual results for each condition.

Table 7. The experiment design conditions and related results for emission and engine performance

DOE (Design of Experiments) means to design experiments, including purposeful changes in the input data or the specifications of a process to observe and examine the changes in the output data or the results. Indeed, the operations include machines, materials, methods, human, the environment, and related measurements. It finally leads to produce production or service. DOE is a scientific alternative that facilitates comprehending the process better and acquiring more knowledge (schematically), and understanding input-output. DOE is a reference for the specialists (managers, engineers, and scientists) who deal with the improvement, product development, and process. Most engineers are acquainted with handling experiments related to the operation of productions and processes. When engineers are dealt with determining the best method for the investigation, they first think of high costs and time consumption. If engineers apply and perceive the concept of DOE, they understand how to change uncompetitive products into products with high quality and bring them back to international competitions. The method and application of this software in the present research are the same as our previous research [16].

3. Results and Discussion

Based on the dynamometer gasoline tank's capacity, two lit of the fuel compound was prepared by specific ratios of gasoline, butanol, and the nano metals of aluminum oxide and injected into the tank. According to the methodology's explanations, the amount of CO_2, CO, $NO_{x,}$ and CH pollutants and engine power were measured in various rotations from low gas to high gas (full throttle). Table 7 displays the results of the experiment. The number of the above parameters will be elucidated in the following sections.

3.1. Pollutants

3.1.1. Carbon Monoxide (CO)

Holistically, the main factor of CO production is regarded as one of the most dangerous pollutants for humans. Fossil fuels are not ultimately ignited. It is expected that since gasoline fuel has less (or even any) oxygen in its structure, adding butanol to it can increase the amount of oxygen. Consequently, the CO production is increased. This enhancement was observed at the beginning of the experiments when the engine was cold. As the engine rotation, lubrication temperature and engine temperature are boosted, it is observed that the fuel reaction is done faster. As a result, it is done more complete, and the carbon oxides are changed into carbon dioxides.

The results indicate that when the engine is cold, a part of the energy produced by the fuel ignition heats the engine and burning is not entirely done. So, a great deal of CO_2 is produced. In another condition, the production amount of this pollutant is gradually decreased. Thus, it is implied that produced fuel is efficient. Moreover, it is recommended that spending some minutes on heating the car engine dramatically contributes to the environment (Fig. 2.a.). The software's model indicates that: where A is butanol percentage and B is engine speed.

$$CO = +1.83 + 0.11 * A + 1.18 * B + 5.625E\text{-}003 * B^{2} - 0.63 * B^{3} \tag{1}$$

Fig. 2. The results of (a) CO and (b) CO2 emissions in various conditions of engine speed and butanol percentages in blended fuels

The results obtained from the models related to this section indicate that adding some percentages of oxygen additive increases these pollutants. Besides, the enhancement in engine speed cause to improve the CO emission. This behavior is the same as what Yacovitch and his colleague observed before [47]. The Fig. 3.a is shown that the used model is highly validated, and the experimental and the results of this model are very close to each other.

Fig. 3. The results of predicted response versus the actual value of related experiments for (a) CO, (b) CO_2, (c) HC, (d) NOx emissions in various conditions of engine speed and butanol percentages in blended fuels

The results taken from the software contribute to confirm the used model. Furthermore, these results indicated that the applied model has high credibility of co-efficiency.

3.1.2. Carbon Dioxide (CO_2)

Generally, carbon dioxide cannot be directly considered a pollutant for humans, but it might have destructive long-term effects. It is the production of the ignition reaction. It is a type of pollutant naturally produced by gasoline, although CO_2 is produced faster for excessive oxygen in the fuel (by adding butanol). However, it makes no significant difference because this amount can be simply supplied through air if excessive oxygen is not available. As expected, the amount of producing CO_2 has been increased by accelerating the speed. This enhancement causes more CO_2 production when the amount of air is increased. This increment causes to increase the amount of oxygen more than required for the production of carbon dioxides. It is evident that this factor led to less HC. CO_2 production is one of the reasons for this reduction (Fig. 2.b.). Moreover, it is observed that the production rate of CO_2 pollutant is enhanced when it is accompanied with aluminum oxide. The main reason for this enhancement is that alumina provides oxygen for oxidation of CO, and this enhances the CO_2 emissions [48].

$$CO_2 = +5.81 - 0.11 * A + 2.39 * B - 0.11 * A * B - 0.094 * B^2 - 1.67 * B^3 \quad (2)$$

The results achieved from the related models in this section indicate that although accelerating the speed considerably affects the decrease or increase of this gas like carbon monoxide, adding more alcohol content causes enhancing (even negligible) this pollutant in this part.

Fig. 3.b illustrates that the applied model is highly validated. The experimental results and the

outcomes obtained from the model are remarkably close to each other. The p-value for the achieved model is less than 5% (less than 0.0001) for carbon dioxide. The results taken from the software contribute to confirm the used model. Furthermore, these results indicated that the model has high reliability of co-efficiency.

3.1.3. Hydrocarbons (HC)

The production of hydrocarbons is something inevitable in the fuel process. The fact is that when the boiling point of the fuel solution gets lower, the amount of this pollutant becomes less and the car efficiency gets more.

$$HC = +55.56 - 0.063 * A + 40.80 * B - 27.30 * A * B + 34.50 * A^2 + 30.94 * B^2 - 32.85 * A^2 * B + 32.06 * A * B^2 - 35.06 * B^3 \quad (3)$$

The outcomes show that as the pressure gets more on the accelerator pedal, the temperature goes up. Indeed, the production amount of this pollutant has been increased. One more time, better results have been achieved from the fuel containing aluminum oxide. The results taken from this section reveal that increasing the speed has a dual effect on this gas's emission (Fig. 4.a).

Fig. 4. The results of (a) HC and (b) NOx emissions in various conditions of engine speed and butanol percentages in blended fuels

Enhancing butanol content causes to increase in the oxygen content of the blended fuel. In fact, it leads to complete the combustion more[49]. In this case, HC is efficiently reduced. Initially, it decreases the emission of this gas. Furthermore, it increases this emission at high speeds. Increasing the percentage of engine load can increase this pollutant. Fig. 3.c illustrates that the model is highly validated. The experimental results and the outcomes obtained from the model are remarkably close to each other.

3.1.4. Nitrogen Oxides (NOx)

Oxygen and nitrogen react with each other at the temperature of 1400 °C. This reaction usually happens in the car's exhaust. Holistically, the temperature increase and the presence of oxygen help enhance this gas with butanol's contribution. Combustion chamber temperature has a direct influence on NOx emission [50,51].

$$NO_X = +235.88 - 33.38 * A + 135.94 * B - 22.63 * A^2 - 59.63 * B^2 + 26.77 * A^2 * B - 47.63 * B^3 \quad (7)$$

In this section, the related models' results indicate that although accelerating the speed considerably affects the decrease or increase of this gas, adding more percentages of alcohol increases (even much higher than previous sections) this pollutant in this part. The reason for this enhancement has been defined at the beginning of this section. The emission of nitrogen oxides increases in two ways: 1)adding alcohol to hydro-carbonic cracks like diesel and gasoline: 2) more heat is needed to run the engine when added alcohols. In fact, it provides the temperature conditions for the production of this gas. 2) Adding alcohol causes to increase the oxygen percentage in fuel (Fig. 4.b). Although oxygen contributes to complete the ignition and reduce the pollutants, its only drawback is increasing the oxygen needed to be combined with nitrogen (at the temperature mentioned above) so that this gas is produced. On the other hand, by blending nanoparticles with gasoline and butanol, alumina acts as a catalyst and provides oxygen for CO oxidation and absorbs it that causes NOx reduction. Consequently, NOx emissions are reduced by applying alumina in blended gasoline [48,52].

Fig. 3.d discloses that the model has high validity. Notably, the experimental results and the outcomes obtained from the model are remarkably close to each other. The results taken from the software contribute to confirm the applied model. Furthermore, these results indicated that the model has a high consistency of co-efficiency. The p-value for the obtained model is less than 5% (0.0003) for nitrogen oxides, which confirms it.

3.2. The Engine Performance Results

This part's results are divided into two sections that have been separately provided in the following paragraphs.

3.2.1. power

Engine power is counted as one of the critical and influential factors in choosing an additive. Adding oxygen additives can diminish the thermal efficiency of the engine. This section includes output energy, which is also known as the energy in use. The first table in this section presents the results related to the output energy. Additionally, the results taken from the Design Expert are as the following.

$$Power = +12.47 - 0.73 * A - 0.64 * B - 0.16 * A * B + 0.32 * A^2 + 0.80 * B^3 \quad (8)$$

The results obtained from the laboratory and the Design Expert indicate that speed acceleration brings about a remarkable increase in this factor, whereas enhancing the percentage of alcohol firstly makes a drastic reduction in this factor. Eventually, this factor reflects a decreasing trend at high percentages of the additive. It is noteworthy that the highest phase has nothing to do with using Nano- metal and oxygen additive. The influence of alumina on engine power has mentioned in Table 7. Blending alumina with gasoline and butanol cause to enhance the engine power. Due to the presence of the alumina, higher evaporation rates occur due to the micro-explosion of the primary droplet, causing higher engine power [53].

Considerably, the highest amount related to engine energy is when no additive is used. It is precisely the time in which the higher output energy is obtained at the speed of 3000, which is equal to 13.79 (Fig. 5 a). The results taken from the Design Expert contribute to confirm the used model. Furthermore, these results indicated that the used model has high co-efficiency reliability (based on p-value) (Fig. 5 b). The used model has a high validity co-efficiency. The p-value for the obtained model is less than 5% (less than 0.0005) for the brake power. Thus, it contributes to confirming it.

Fig. 5. The results of (a) Power in various conditions of engine speed and Al_2O_3 loading percentages in blended fuels, and (b) predicted response versus the actual value of related experiments

3.2.2. BSFC (Brake Specific Fuel Consumption)

The BSFC (Brake Specific Fuel Consumption) or fuel efficiency in the engine is a measurement for the amount of fuel in kilograms consumed by the engine in one hour for 1kW brake power production [54]. BSFC is affected by three factors: the amount of additive, the useful output power, and the engine rotation amount. Racopoulos and his research group in the other research [55–57] expounded the influence of combining normal butanol on the fuel efficiency and concluded that adding the alcohol mentioned above to diesel fuel tends to increase the amount of fuel efficiency in the engine. Additionally, this experiment showed that fuel engine efficiency is declined by enhancing the engine output power. Racopolus et al. dissected the effect of blending ethanol with diesel. Their experiments indicated that as the engine load amount is increased, the amount of fuel efficiency in the engine is enhanced.

Blamurgun and Nalini [58] worked on the increase of engine performance by using normal propanol and normal butanol. They observed that adding any one of these additives increases fuel efficiency. They also concluded that increasing the engine output power tends to reduce fuel efficiency. Furthermore, they reported that when the engine's output power reaches its half amount in all volume percentages of alcohol, the amount of fuel efficiency in pure diesel is more than different diesel-alcohol compounds. In their experiments, the effect of normal propanol enhances the engine's fuel performance more than normal butanol. If the fuel is directed to burn completely, the fuel efficiency can be boosted in the engine. This definition conveys that more oxygen alcohol with smaller branches can improve this specification much more. Therefore, methanol is more likely to enhance fuel efficiency. Hence, it can boost fuel efficiency in the engine in similar conditions. It is observed that the BSFC amount is increased by adding ethanol to diesel fuel. This increase is caused by adding ethanol to the compound.

As a consequence, the percentage of oxygen fuel goes up. This is considered the most critical factor for completing the ignition. As a result, it makes the fuel burn entirely. More clearly, fuel is going to burn completely. This is while adding nitro compounds, specifically nitromethane, increases this specification.

$$\text{Fuel con.} = +1.65 + 0.87 * A + 0.58 * B + 0.26 * A * B - 0.69 * A^2 - 0.42 * A^2 * B \quad (9)$$

The results are taken from the laboratory and software present that speed acceleration considerably enhances this factor. Initially, increasing the percentage of alcohol declines this factor drastically. Lastly, this factor resumes its increasing trend in the high percentages of additive. It is noteworthy that the highest phase is when nano metal has been used. It means that nano metals prevent heat waste and increase thermal power, and they sharply enhance the amount of the used efficiency. The highest amount was related to adding one gram of nano metal and 15% alcohol at the speed of 300, which is equal to 2.303. The results taken from the software contribute to confirm the model used in this study. Furthermore, these results indicated that the model has a high reliability of co-efficiency due to the p-value. The amount of the p-value for the achieved model is less than 5% for BDFC.

3.3. Results Related to Optimization

The minimum and maximum limits and boundaries for all responses have been summarized in Table 8 to optimize the objective parameters. Based on the modeling procedure in optimum conditions, the optimization results and the predicted responses are presented in Table 9.

Table 8. The upper and lower limits and weight for significant parameters and responses to find optimum conditions.

Table 9. The optimization results and the predicted responses based on the modeling procedure

The outcomes achieved from the optimization results are as the following according to the priorities mentioned above. Henceforth, 6 cases have been suggested, and the first one is the best suggestion of all. Due to the optimization results and the related optimum conditions, it could be found that the lower percentage of Al_2O_3 is appropriate for exhaust emission engine performance. Also, the engine from 1700 to 1800 rpm is the best condition to reduce air pollution and enhance engine performance. In this case, air pollution can be reduced more due to lower engine temperature in the lower engine load. The results display that a higher percentage of nanoparticles should be used at higher speeds. In the optimal condition, optimal responses (CO, CO_2, HC, NO_x emissions, power, and fuel consumption were 1.1, 4.7, 77.5, 113.8 ppm, 13.5 kW, and 0.17, respectively) were obtained employing butanol-gasoline fuel blended with 5wt. Percentage of Al_2O_3 in engine speed of 1700 rpm.

4. Conclusion

Modeling and optimizing the gasoline-butanol-Al_2O_3 combustion process are performed by statistical analysis. Al_2O_3 percentage and engine speed are the control factors in this study. Six cubic models for CO, CO_2, HC, NO_x emissions, and power and fuel consumption were developed.

Based on the results, conclusions of this research are summarized as below:

1. Our findings show that adding butanol oxygenate additive causes to diminish HC emissions, while it enhances the nitrogen compounds.
2. Blending alumina, like a nano metal additive, causes to improve the output power. On the other hand, increasing Al_2O_3 showed a negative effect on BSFC.
3. Improving the speed in all percentages of the combination tends to enhance the exhaust emissions except HC. On the other hand, the engine speed showed different behaviors in NOx, CO, and CO_2 emissions. Although the enhancement in this rate caused the enhancement of the mentioned emission at the lower speed, the enhancement of this rate reduced those emissions at a higher speed.

4. The optimization outcomes results revealed that it is better to use alumina nanometal to enhance energy and efficiency (which is more critical for us) due to each factor's importance. In this case, when 5wt % of butanol with 1 g of alumina (1700 rpm engine speed) parameters are applied, the highest engine performance with a possible minimum amount of CO, CO_2, HC, and NO_x emissions were obtained.

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Table 1. Influence of blending different additives on Engine performance, Exhaust emission and fuel properties

Research group/ reference number	**Additives**					**Desulfurization rate**	**Exhaust Emission**			
	Alcohol	**%Alcohol**	**Nano and Other additives**				**UHC**	**NOx**	**CO**	**CO_2**
Lim et al [40]	Ethanol	3	-			-	0.46	0.36	0.62	-
		6	-			-	0.41	0.4	0.55	-
		10	-			-	0.39	0.48	0.56	-
Iodice et al [41]	-	-	-			-	1.48	0.156	8.4	298
	Ethanol	20	-			-	1.02	0.123	6.8	283
		30	-			-	1.28	0.117	7	262
Kareddula et al [42]	Ethanol	5	15PPO5E			-	28.48%	-0.41%	-24.11%	-
	-	0	15 PPO			-	52.63%	-24.23%	-9.70%	-
Yilmaz et al [43]	Methanol	5	-			-	-12%	1449 ppm	-	-
		5	Hydrogen	6		-	-	-	-	-
		5	Hydrogen	15		-	-	-	-	12.06%
		15	-	-		-	-40%	-	-	-
		15	Hydrogen	6		-	-	-	-	-
		15	Hydrogen	15		-	-	2296 ppm	0.09%	-
Yuanxu Li et al [37]	butanol	30				-	5/46 g/kWh	12.26	25.28	-
	ethanol	30				-	4.87	13.14	28.96	
Manigandan et al [44]	-	-	EGR* + Hydrojen	0 % + 0%		-	184ppm	1250 ppm		-
	-	-	EGR + Hydrojen	20% + 0%		-		260 ppm	2.40%	-
	-	-	T-EGR20% +Hydrojen	20% + 0%	TiO_2 5%	-		-	1.03%	-
	-	-	EGR + Hydrojen	0% + 5%		-	126 ppm	-		-
	-	-	EGR + Hydrojen	20% + 5%		-	-	-	1.20%	-
	-	-	T-EGR20% +Hydrojen	20% + 5%	TiO_2 5%	-	-	-	-	-
Li et al [45]	-	-	-	-	TiO_2 5%	57.44%	-	-	-	-
	-	-	β-CD-TiO_2-Ag	5%	TiO_2 5%	100%	-	-	-	-
wang et al [46]	-	-	ZSM-5 + FCC gasoline			75%	-	-	-	-
	-	-	NiO/TiO_2-ZSM-5 + FCC gasoline			97%	-	-	-	-
	-	-	ZrO_2/NiO-TiO_2-ZSM-5 + FCC gasoline			99%	-	-	-	-

Table 2. The Butanol specification

Specifications	Values
Molar mass	74.122 g/mol
Density	0.8098 g/cm3 (20 C)
Melting point	-89.5 C ، 184 K ،-129 F
Boiling point	243 F, 390 K, 117.2 C
Solubility in water	7.7 g/100 mL (20 C)
Refractive index (nD)	1.399 (20 C)
Viscosity	3 cP (25 C)

Table 3. The Al_2O_3 particles specification

Specifications	Values
Density (g/cm3)	3.95-4.1
Melting point (˚C)	2072
Boiling point (˚C)	2977
Molecular weight (g/mole)	101.96
Type	Powder

Table 4. properties of Gasoline engine used in the experiments

Rated power (hp)/speed (rpm)	97/6000
Maximum torque (Nm)/speed (rpm)	148/3500
Cylinder number	4
Compression ratio	9.25:1
Engine volume	1761

Table 5. Specification of AVL 465 analyzer

	Measurement range	**Resolution**
Opacity	0~100 %	0.10%
Acceleration time	0~5 s	0.05 s
Speed	250~7200 1/min	1 1/min
Oil temperature	0~120 °C	1 °C
CO	0~10% Vol.	0.01 %Vol.
HC	0~20 000 ppm vol.	1 ppm Vol.
O2	0~25 % Vol.	0.01 %Vol.
Ignition angle TDC sensor	− 60~100 ° ca	0.1 ° ca
Strobe	0~60 ° ca	0.1 ° ca
Dwell angle	0~100 %	1%

Table 6. Specification of MRU 1600-L analyzer

	Measurement range	**Resolution**
O_2	0~25 % Vol.	0.01 %Vol.
CO	0~15 % Vol.	0.01 %Vol.
HC	0~20000 ppm	1 ppm.
NO	0~2000 ppm	1 ppm.
Excess Air	calculated according to Brett Schneider	
Temperature	− 40~ 650 °C	0.1 °C
Speed	400~10000 1/min	1 l/min

Table 7. The experiment design conditions and related results for emission and engine performance

Variable				Response									
				EMISSION (ppm)				**Engine Performance**			**Other**		
Run		**%Butanol**	**rpm**	*CO*	*CO2*	*HC*	*NO_X*	*Power (kW)*	*Tor.*	*Fuel con.*	*LAM*	*COC*	*O2*
1	Gasoline	0	1500	1.71	4.8	108	154	13.1	32	1.6678	2.17	3.94	12.2
2			2000	1.61	5.2	101	163	13.69	32	2.1436	2.1	3.55	11.9
3			2500	2.06	6.8	109	245	13.71	32	2.2252	1.62	3.49	9.3
4			3000	2.61	6.7	103	302	13.79	32	2.868	1.52	4.21	8.8
5	Gasoline + butanol	5	1500	0.88	5.1	88	123	12.58	32	0.091	2.38	2.21	12.5
6			2000	1.13	5.2	70	286	13.4	32	0.2341	2.25	2.68	12.1
7			2500	1.75	6.6	85	344	13.24	32	0.349	1.69	3.14	9.5
8			3000	1.84	6.7	88	369	13.85	32	0.4109	1.66	3.23	9.4
9	Gasoline + Butanol + Al2O3 (1 gr)	5	1500	1.12	5.1	93	60	13.05	32	0.0292	2.34	2.7	12.8
10			2000	1.33	5	77	186	13.79	32	0.06	2.26	3.15	12.4
11			2500	2.17	6.8	93	302	13.48	32	0.151	1.59	3.63	9.1
12			3000	2.25	6.6	95	306	13.73	32	0.483	1.6	3.81	9.2
13		10	1500	1.45	4.9	69	102	12.3	32	1.136	2.26	3.43	12.5
14			2000	1.37	5.1	62	163	12.79	32	1.4396	2.24	3.18	12.4
15			2500	2.2	6.5	76	276	12.12	32	1.6738	1.63	3.79	9.4
16			3000	2.29	6.5	84	270	12.66	32	2.337	1.62	3.91	9.4
17		15	1500	1.27	5	215	3	11.99	32	1.5439	2.32	3.04	13
18			2000	1.67	5.1	92	145	12.22	32	1.4986	2.11	3.7	12
19			2500	2.22	6.3	92	213	12.1	32	1.9789	1.69	3.91	10
20			3000	2.61	6.2	101	226	11.9	32	2.3022	1.6	4.44	9.4

Table 8. The upper and lower limits and weight for significant parameters and responses to find optimum conditions.

Constraints

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight		Importance	
Percentage of		**is in range**		5	15	1	1	3
Engine speed		**is in range**		1500	3000	1	1	3
CO	**minimize**		1.12	2.61	1	5	5	
CO2	**minimize**		4.9	6.8	1	2	2	
HC	**minimize**		62	215	1	4	3	
NOX	**minimize**		3	306	1	4	4	
Power	**maximize**		11.9	13.79	5	1	5	
Fuel con.	**minimize**		0.006	2.337	1	3	3	

Table 9. The optimization results and the predicted responses based on modeling procedure in optimum conditions

Number	Percentage of butanol	Engine speed	CO	CO2	HC	NOX	Power	Fuel con.	Desirability %
1	5	1699	1.099	4.699	77.5	113.9	13.55	0.1696	0.563
2	5	1674	1.095	4.705	78.3	108.1	13.52	0.1733	0.562
3	5	1640	1.096	4.727	79.6	100.5	13.47	0.1782	0.555
4	5	1778	1.130	4.730	76.2	132.6	13.62	0.1582	0.547
5	6.34	3000	2.301	6.598	89.7	291.3	13.45	0.7978	0.007
6	15	3000	2.496	6.208	98.6	235.3	12.05	2.2442	0.000

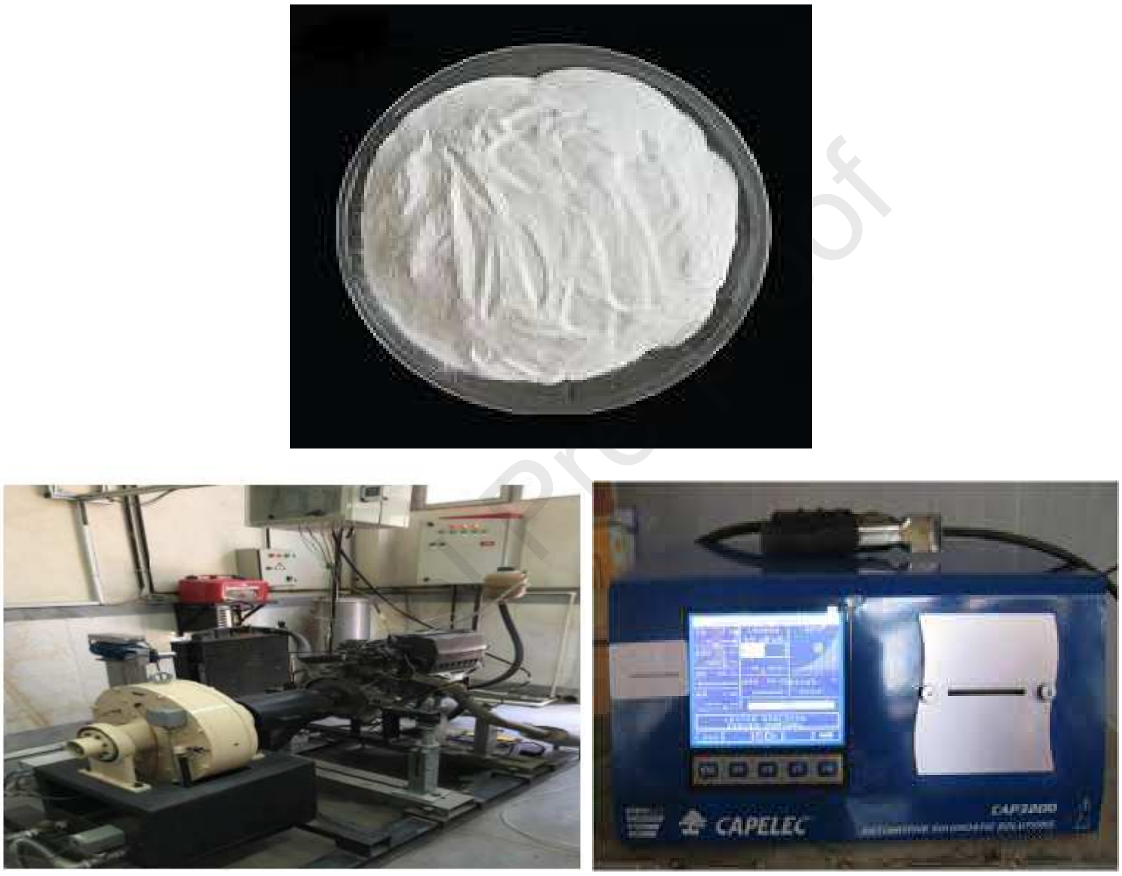
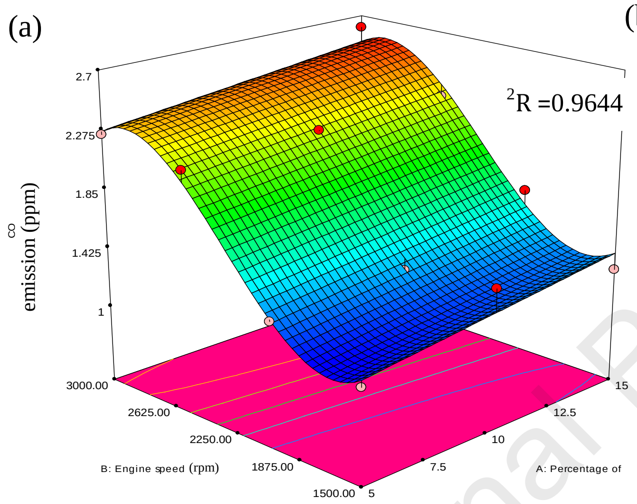


Fig. 1. The (a) Al2O3 particles, (b) dynamometer and XU7/GVC3 gasoline engine and (c) Analyzer for gas exhaust detection



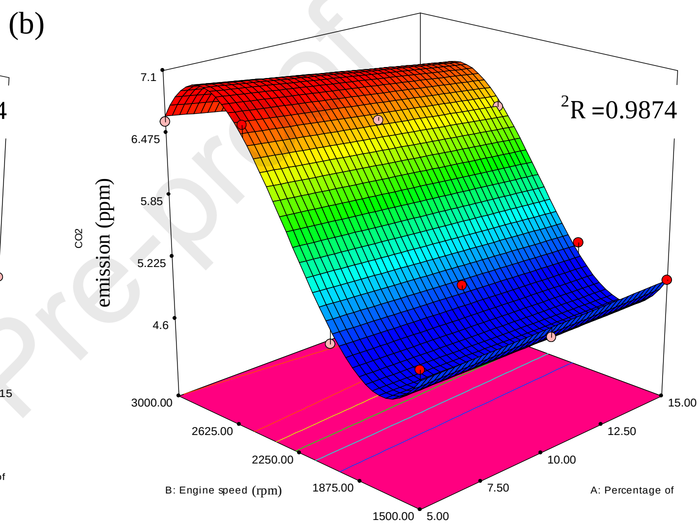


Fig. 2. The results of (a) CO and (b) CO2 emissions in various conditions of engine speed and butanol percentages in blended fuels

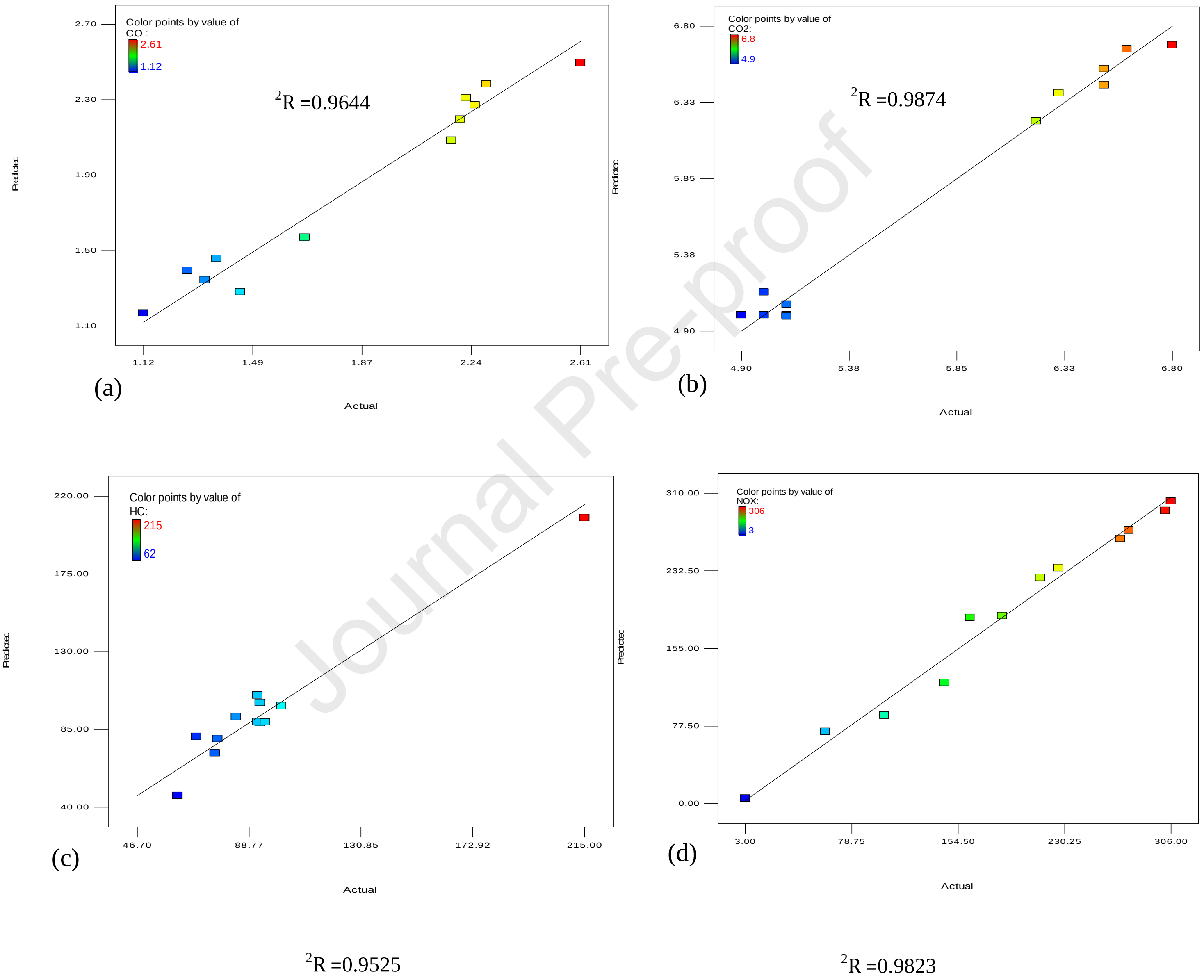


Fig. 3. The results of predicted response versus actual value of related experiments for (a) CO, (b) CO_2, (c) HC, (d) NOx emissions in various conditions of engine speed and butanol percentages in blended fuels

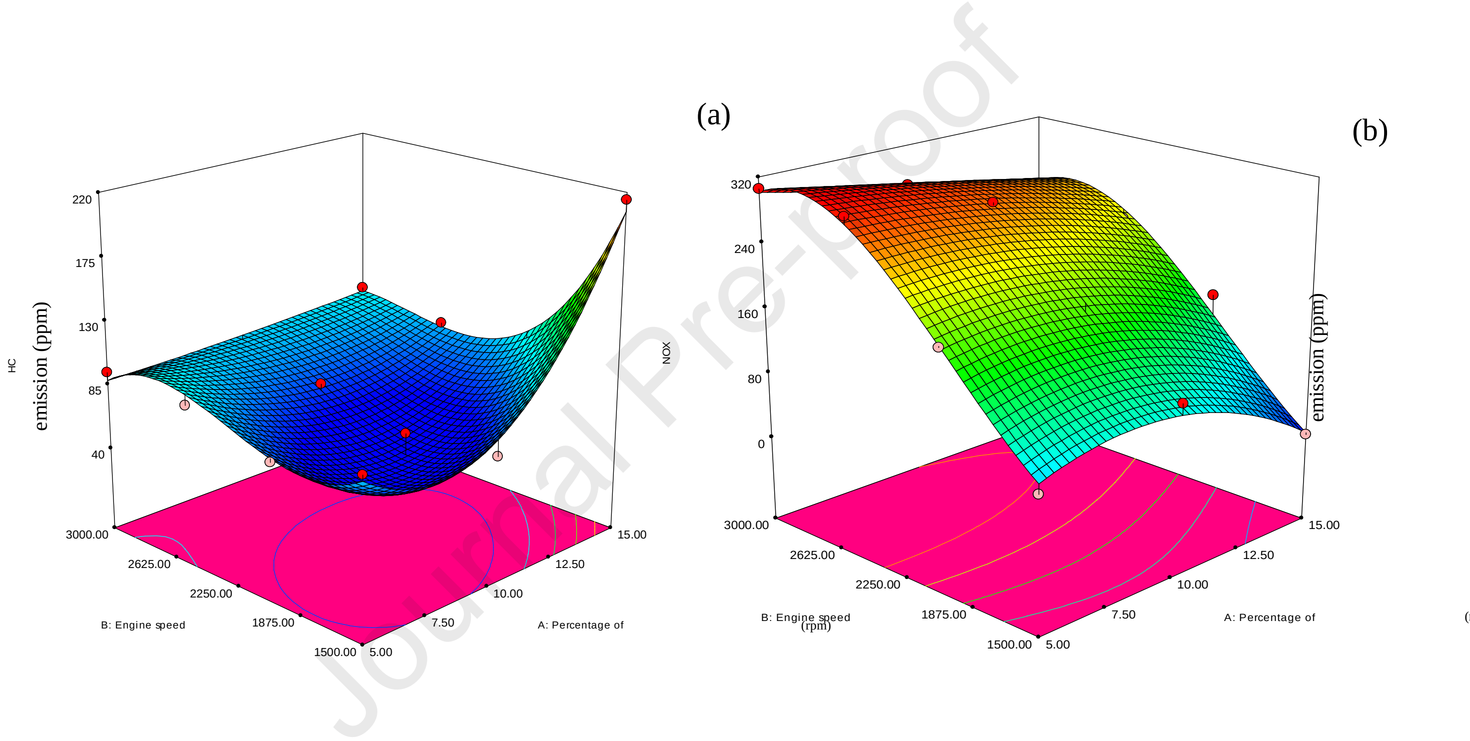
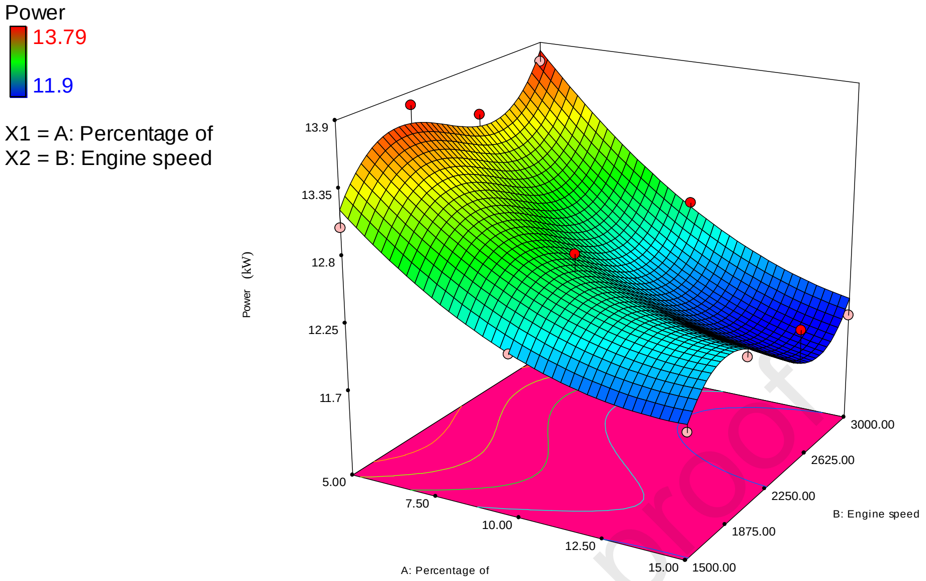


Fig. 4. The results of (a) HC and (b) NOx emissions in various conditions of engine speed and butanol percentages in blended fuels

(a)



(b)

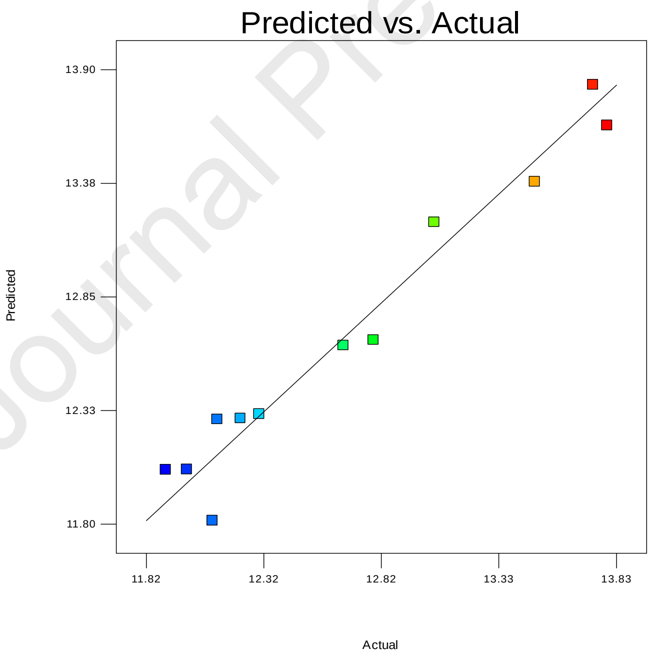


Fig. 5. The results of (a) Power in various conditions of engine speed and Al_2O_3 loading percentages in blended fuels, and (b) predicted response versus actual value of related experiments

- Synthesis of modified fuels from Butanol + Al_2O_3 Nano particles
- Modeling of the emissions, modified fuels properties and engine performance
- Verification and accuracy analysis are performed for models
- New blend formulations increase engine performance and reduce air pollutions
- Novel blended fuel enhances CO_2 and reduces NOx, hydrocarbons and CO

Declaration of interests

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

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: