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OPTIMIZATION OF PERFORMANCE AND EMISSION CHARACTERISTICS OF GASOLINE-ALCOHOL-BASED NANOFUELS USING TEACHING LEARNING-BASED OPTIMIZATION METHOD FOR SUSTAINABLE FUTURE

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A B S T R A C T

Zinc Oxide and Aluminum oxide nanoparticles (14 nm) were added to E20 (Ethanol 20% +80% Gasoline) and E20 based iso-stoichiometric ternary fuel blends of gasoline, ethanol, methanol (GEM) by means of ultrasonication technique at the concentrations of 5ppm and 10 ppm to formulate different nano fuel blends. All the test samples were tested on Spark-Ignition engine. Teaching-Learning based optimization technique (TLBO) is employed to optimize the results and identify the best performing blend. The parameters such as brake thermal efficiency (BTE), brake-specific fuel consumption (BSFC), carbondioxide (CO_2), carbonmonoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx) were optimized. The optimum results were obtained for nanoparticle concentration of 5ppm and engine speed of 2900 rpm for the ZnO fuel blends. The performance and the emission characteristics obtained at the optimum operating parameters were 36.5 % BTE, 0.22 kg/kWh of BSFC, 41ppm of HC, 788 ppm of NOx, 0.29% CO, 13.26% CO_2.

1. INTRODUCTION

Air pollution that poses a significant threat to the environment is mainly due to the combustion of fossil fuels in light duty vehicles, heavy duty vehicles, industries, and various other activities (uslu, 2020). Many urban areas of the world suffer from poor air quality due to high population density. The polluted air affects human health badly when inhaled as it consists of major toxic substances like carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx) and particulate matter. Besides affecting human health, they are also responsible for climate change, which is a serious concern for the global population (Bharath, 2021). To combat the climate change and reduce the harmful emissions from internal combustion engines, many government policies and agreements suggested adopting various technologies and strategies to produce more efficient engines with lower emissions. Among them the usage of biofuels in engines is proven to be safe as they can be produced from renewable energy sources like agricultural feedstocks (Elfasakhany, 2021). Biofuels like ethanol, methanol, propanol, butanol are some of the promising

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alcoholic fuels suitable for use in spark ignition engines as they have high octane rating. Alcohol fuels blended with fossil fuels in suggested proportions can be used in existing engines without any further modifications. Though the blended fuels have added advantages compared to gasoline, the presence of alcoholic content in fuels makes the engine parts more corrosive. In addition to that, their low energy content reduces the specific fuel consumption (BSFC) and makes it more expensive than fossil fuels (Patil & Desai, 2020; Elfasakhany, 2016).

The advent of nanotechnology had yielded fruitful results while overcoming these problems. Today, nanoadditives are recognized as one of the best fuel-based catalysts for improving fuel properties due to their higher surface area to volume ratio, faster vaporization, and shorter ignition delay properties (Prabu, 2019). Additives help in strengthening hydrocarbon bonds in fuel blends and thereby improvising their stability (Wijayanti et al., 2022). Abiyazani et al. (2022) formulated test fuels by mixing oxygenated additives like nanoparticles of Al_2O_3, MgO, and n-propanol to gasoline fuel and performed experimentation of four-cylinder SI engine at various operating conditions. The gasoline-proponal-nanoparticle blends improved engine performance and the fuel blends with Al_2O_3 showed better performance compared to manganese oxide. Gavhane et al. (2020) added Cu-coated ZnO nanoparticles to soybean diesel fuel (B25) and developed three nano-fuel blends by varying nanoparticle concentration. They confirmed that copper and zinc oxide nanoparticles in B25 soy fuel enhanced engine characteristics. Ağbulut et al. (2020) added TiO_2, SiO_2, and Al_2O_3 nanoparticles in fuel consisting of 10% of methyl ester cooking oil and 90% diesel, tested its performance on an internal combustion engine and found better engine performance. Additionally, the emissions of CO, NOx and HC have been considerably reduced due to the addition of metal oxide nanoparticles.

Amirabedi et al. (2019) added Mn_2O_3 nanoparticles to 90% of gasoline and 10% of ethanol blends at a concentration of 10 ppm and 20 ppm. It was found that the brake power was increased by 14.38% and 19.56% and the BSFC was reduced by 34.69% and 38.89% by adding 10 ppm,20 ppm to gasoline-ethanol fuel blends, respectively. The NOx concentration got reduced by 32.34% at 20 ppm of Mn_2O_3 along with other exhaust emissions. Valihesaria et al. (2019) added Fe_2O_3, TiO_2 nanoparticles in fuel blends of gasoline and methanol and studied the influence of nanomaterials on various engine parameters at different engine speeds. D-Optimal method of response surface methodology was used to optimize the results. The experimental tests revealed that there was an increase in the octane index by 10.9% for Fe_2O_3 blend and 9.9% for TiO_2 blends. Zamankhan et al. (2018) used CeO_2, MgO nanoparticles in gasoline and ethanol fuel blends and tested on four-cylinder SI engine for various engine operating parameters. The optimization results, mathematical models supported the experiment stating that there is an increase in performance of the SI engine as the nanofuels could generate greater power in the engine cylinder and lower the tailpipe emissions.

Established in the literature, it is encapsulated that specific fuel consumption, efficiency, emissions should be improved by means of optimizing the input parameters. Several conventional optimization methods have been employed by the researchers in engineering applications to optimize the input parameters and achieve the desired quality of the responses. But these methods could not handle complex problems effectively (Rao et al., 2017). Venkata Rao (2013) developed a novel optimization technique which is well-known as teaching learning-based optimization (TLBO). So far, this method has rarely been employed by the researchers in the automotive field for IC engine applications to optimize engine parameters. This paper is an attempt to apply the TLBO method to different nano fuel blends to find the best performing fuel basing on their outputs by optimizing the input parameters.

In this work, 20% of gasoline is replaced by alcohol fuels ethanol, methanol. The fuel blend E20 (80% gasoline + 20% ethanol) and its equivalent isostoimetric gem blends were prepared. In the next stage, fuel blends with ZnO nanoparticles and the fuel blends with Al_2O_3 nanoparticles were prepared. All the nanofuels blends thus formulated were tested on PFI-SI Engine and the fuels were optimized using TLBO technique. The TLBO technique optimizes the parameters with lesser computational work and higher consistency (Yadav, 2018). It distinguishes the poor and the best experiments, then an interaction is carried out between the poor and the best experiments to find the best solutions. Two input parameters (speed, nanoparticle concentration) and six outputs (BTE, BSFC, HC, CO, CO_2, and NOx emissions) are considered. The BTE of the fuel blend is intended to be maximized while minimizing the BSFC, HC, CO, CO_2, and NOx emissions. Experiments were conducted at different levels of speed and at different concentrations of ZnO, Al_2O_3 in different fuels and the experimental results were collected. The TLBO method optimizes input parameters to minimize HC, CO, NOx, SFC and maximize BTE with defined constraints (BTE>35% and BSFC < 0.22 kg/kw-hr).

2. MATERIALS AND METHODS

The experimental procedure includes the formulation of different fuel blends using gasoline, alcohols like ethanol and methanol in defined proportions as discussed in the next section. Preparation of nanofuels using nanoparticles and testing them on PFI-SI engine are also discussed in the following sections.

2.1 Nanoparticles

Nanoparticles can be used as potential fuel additives as they have a larger surface to volume ratio, exhibit unique catalytic properties. Among the different types of nanoadditives, metal oxide nanoparticles are used for this work. Metal Oxide nanoparticles could donate an oxygen atom and increase the fuel pool more oxygenated (Khan et al., 2019). This promotes complete combustion inside the engine cylinder and decreases the emissions. The ZnO and Al_2O_3 nanoparticles used in this study were commercially available. The nanoparticles were procured from Reinste Nano ventures limited and their specifications are presented in Table 1.

Table 1. Specifications of Nanoparticles.

	Alumina	**Zinc Oxide**
Composition	Al_2O_3	ZnO
Average particle size	40 nm	14 nm
Specific area	> 40m2/g	30±5 m2/g
Purity	> 99.9%	> 99%

2.2 Ternary Blends Formulation

Test samples were prepared using gasoline(G), ethanol(E) and methanol(M), nanoparticles of alumina and zinc oxide. The fuel mixture with 20% by volume of ethanol and 80% by volume of gasoline is mixed to form a binary fuel blend E20 and its equivalent isostoichiometric blends were prepared by introducing another alcohol called methanol i.e., the gasoline that is replaced for a certain percentage of ethanol gives the total methanol content to be added. These ternary fuel blends have similar properties to the E20 binary blend but increase the renewable energy content in the fuel pool.

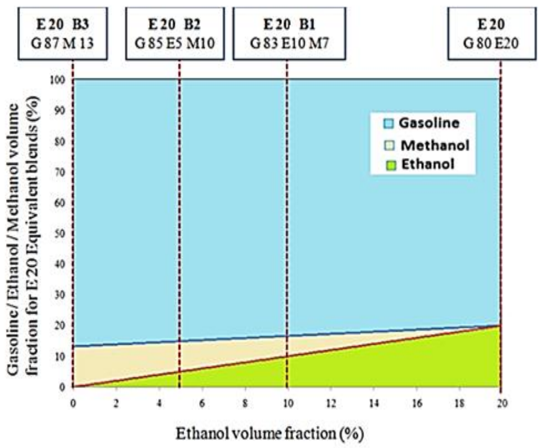


Figure 1. Formulation of E20 equivalent isostoichiometric GEM blend

The fuel blends were developed using the formulas given by Turner et al. in 2012. The fuel blends are presented in figure.1.A binary blend and a ternary blend were randomly selected to develop the nanofuels by adding nanoparticles of alumina and zinc oxide. The nanoparticles were added in two different concentrations based on the limit of their stability in the fuel. Zinc Oxide is stable up to 10 ppm and alumina is also taken up to 10 ppm. Thus, the concentrations considered in this study are 5 ppm and 10 ppm for ZnO, alumina. The nanoparticles were added to fuel mixture by using ultrasonic probe sonicator. Ultrasonic waves are sent into the fuel suspension to disperse nanoparticles into the fuel homogenously. The ultrasonication setup is shown in figure. 2. Different blends with different concentrations of nanoparticles and gasoline-alcohol percentages are presented in Table 2.

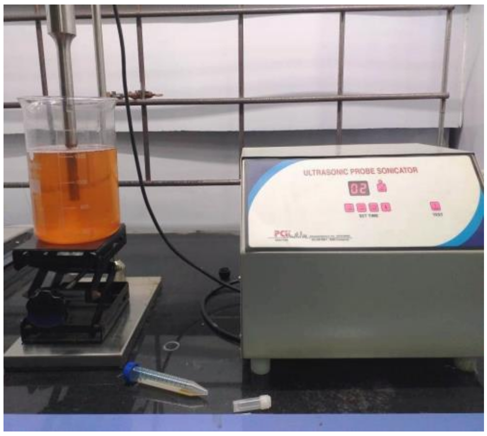


Figure 2. Ultrasonication setup

Table 2. Nano fuel blends considered for experimentation.

Blend No.	**Name of the blend**	**Nanoparticle Concentration in ppm**		**Gasoline-Alcohol percentages**		
		Al_2O_3	ZnO	G	E	M
1	E20Z5	0	5	80	20	0
2	E20Z10	0	10	80	20	0
3	E20B1Z5	0	5	83	10	7
4	E20B1Z10	0	10	83	10	7
5	E20A5	5	0	80	20	0
6	E20A10	10	0	80	20	0
7	E20B1A5	5	0	83	10	7
8	E20B1A10	10	0	83	10	7

2.3 Experimental Setup

Experiments were performed on a computerized single cylinder port fuel injection spark ignition engine. As shown in figure 3, the experimental setup consists of a Honda GX200 engine, and its specifications are presented in Table 3. The engine is coupled with an eddy current dynamometer. It has a stand-alone panel box that consists of a fuel tank, fuel measuring unit, electronic control unit, load indicator, temperature indicator and data acquisition system, as shown in Fig. 4.

Figure 3. Experimental setup

LabView-based engine performance software called IC engine soft was used for performance evaluation and to measure various performance parameters. The experiment was conducted at five different speeds to test its performance and emission characteristics at a constant speed of 5 kg. During the experimentation, the speed and load were adjusted using a knob and the readings were taken for each level.

All the necessary performance and combustion data were extracted using IC Engine software and emissions were collected form AVL exhaust gas analyser.

Table 3. Specifications of the engine.

Cylinders	1
Strokes	4
Rated Power	4.1 kW @3600 rpm
Cylinder Diameter	68mm
Stroke Length	54mm
Compression Ratio	8.5:1
Cooling system	Air Cooled

3. RESULTS AND DISCUSSION

3.1. Design of the Experiments

The nanofuels developed in Table 2 were optimized.
to find the best fuel based on their performance and the emission characteristics. In this work, five stages of speed, two levels of nanoparticle concentration, and eight fuel blends were taken, as shown in Table 4. A mixed level of design of experiments was followed in this study and planned the experimentation. All the performance and emission parameters are collected at each speed at constant load conditions for the fuel samples. The design of experiments, performance and emission characteristics are shown in Table 4.

Table 4. Design of experiments, performance, and emission characteristics

Exp. No.	Blend No.	Name of the fuel blend	Speed (rpm)	NPC (ppm)		BTE (%)	BSFC (Kg/kw-hr)	HC (ppm)	CO (%)	CO_2 (%)	NOx (ppm)
				A	B						
1	2	E20Z10	2900	10	0	35.25	0.22	39	1.09	14	753
2	2	E20Z10	3300	10	0	33.89	0.26	40	0.29	14.1	801
3	3	E20B1Z5	2500	5	0	34.2	0.23	54	0.31	12.3	593
4	3	E20B1Z5	2900	5	0	36.5	0.22	34	0.29	13.3	788
5	3	E20B1Z5	3300	5	0	33.4	0.23	20	0.24	14.4	871
6	4	E20B1Z10	2500	10	0	35.61	0.22	54	0.2	12.1	619
7	4	E20B1Z10	2900	10	0	37.12	0.21	39	0.19	14.2	711
8	4	E20B1Z10	3300	10	0	35.92	0.23	36	0.12	14.8	923
9	5	E20A5	2500	0	5	36.71	0.22	206	1.69	16.7	556
10	5	E20A5	2900	0	5	37.3	0.21	119	1.21	19.6	885
11	5	E20A5	3300	0	5	35.36	0.25	87	0.59	18	985
12	6	E20B1A10	2900	0	10	37.11	0.2	115	1.16	17.6	855
13	7	E20B1A10	2900	0	5	35.74	0.21	96	0.08	17	863
14	7	E20B1A10	2500	0	5	34.15	0.24	105	1.25	12.32	763
15	8	E20B1A10	2500	0	10	36.79	0.21	36	0.08	16.4	717
16	8	E20B1A10	2900	0	10	37.61	0.2	19	0.07	17	809

3.2. Optimization of fuel blends

In this phase, the inputs are optimized using teaching learning-based optimization (TLBO) method to get the required fuel blend. Performance of the engine is critical aspect apart from lower emissions; therefore, the efficiency should not drop and at the same time care must be taken to minimize fuel consumption also. The performance parameters BTE and BSFC were taken as constraints so that minimizing the emissions should not affect engine performance. Harmful emissions like HC, CO, and NOx emissions are aimed to be minimized while maximizing CO_2 emissions.

Objective functions for the responses BTE, BSFC, HC, CO, NOx, and CO_2 emissions are generated using data in Table 2 and Minitab 17 software as presented in equations (1) to (6) are as follows:

Minimize
$HC = 562.4 - 0.1510\ Speed - 6.63\ NPC$ (1)

Minimize
$CO = 10.21 - 0.003176\ Speed - 0.0377\ NPC$ (2)

Minimize
$NO_x = -214.1 + 0.3494\ Speed + 0.37\ NPC$ (3)

Maximize
$CO_2 = 4.68 + 0.003653\ Speed - 0.141\ NPC$ (4)

Constraints:

$BTE = 25.45 + 0.002912\ Speed + 0.099\ NPC \geq 32$ (5)

$BSFC = 0.3289 - 0.000029\ Speed - 0.00230\ NPC \leq 0.22$ (6)

Here NPC represents nanoparticle concentration of the either of the nanoparticles considered.

As the experimentation must be performed at defined speed ranges according to the specifications of the engine, the speed must not be below 1700 rpm and the maximum speed of the engine is 3300 rpm.

The nanoparticle concentration for the both the nanoparticles was taken as 5 ppm and 10 ppm. Therefore, the input parameter constraints are taken as follows:

1. $1700 \leq$ speed (rpm) ≤ 3300
2. $5 \leq$ NPC (ppm) ≤ 10

The TLBO technique comprises the teachers' phase and learners' phase. In the teachers' phase, experiments are treated as students and input parameters are treated as subjects. The Z_{BTE} and Z_{BSFC} are constraints for BTE and BSFC taken as 32% and 0.22kg/kw-hr respectively and the Z' is the overall constraint estimated using the equations (7) to (9).

$$Z_{BTE} = 32 - BTE \quad (7)$$

$$Z_{BSFC} = BSFC - 0.22 \quad (8)$$

$$Z' = \frac{Z_{BTE}}{(Z_{BTE})max} + \frac{Z_{BSFC}}{(Z_{BSFC})max} \quad (9)$$

From Table 5, (Z_{BTE}) max and (Z_{BSFC}) max are taken as 1.11 and 0.04 respectively in the estimation of overall constraint Z'. In the next step, difference_means is estimated to the inputs using equation (10) and new input parameters are generated by adding the difference_means to the inputs from Table 5. Random numbers for speed and nanoparticle concentration were taken as 0.5 and 0.7 respectively.

$$Difference\_means = x(y-\bar{y}) \quad (10)$$

where x, y, and $\bar{y}$ are the random number, input parameter and mean of input parameter.

Difference_means for Speed = 0.5x (2900- 2900) = 0

Difference_means for NPC = 0.7x(10–7.6) = 1.68

New Input parameters for experiment 1 are estimated as S= 2900 + 0=2900 rpm, NPC = 10 + 1.68 = 11.68 ppm. Similarly, new inputs for the other experiments are estimated and the corresponding BTE, BSFC, HC, CO, CO_2, and NOx are estimated using equations (1)-(6) and presented in Table 6. Again, ranks are assigned to the experiments. In the next stage, 16 best experiments were selected from Tables 5 and 6, as presented in Table 7 called combined phase in the teacher phase for the next stage of optimization.

In the next stage, best and poor experiments have been selected on random basis, and the interaction was carried out between them. A sample interaction was performed using equations (11) and (12) between 1 and 16 experiments as follows:

$$New\ speed = speed_1 + a_1\ (speed_1 - speed_{16}) \quad (11)$$

$$New\ concentration\ NPC = NPC_1 + a_2\ (NPC_1 - NPC_{16}) \quad (12)$$

The random numbers a_1 and a_2 are selected as 0.3 and 0.7 respectively. These random numbers are constant throughout the experiments. New input parameters and their corresponding responses BTE, BSFC, HC, CO, CO_2, NOx, are estimated using equations (1) to (6) as presented in Table 8. From Tables 7 and 8, fourteen first ranked experiments are considered as shown in Table 9 for the final stage of optimization of parameters**.**

The best solutions from Table 9 were selected using the crowding distance (CD) concept. The following procedure was used and the calculated crowding distance for 14 experiments:

1. The objective functions HC, CO, CO_2, and NOx were organized in ascending order and the CD for the lowest, highest values was assigned with infinity.
2. The CD for the remaining values was calculated using equation (13).

$$CD_i = \frac{O_{i+1} - O_{i-1}}{O_{max} - O_{min}} \quad (13)$$

where O_{i+1}, O_i, O_{i-1} are the values of the objective function. The CD for the HC, CO, CO_2 and NOx were estimated as given in Table 10 and the overall CDs were estimated by adding the CD of the four objective functions, as presented in Table 11. The Experiment 10 was selected as the best candidate solution using the central CD sorting concept. From Table 11, experiment 10 (2900 rpm ,5 ppm of nanoparticle concentration) was found to have optimum working conditions. This study recommends the E20B1Z5 fuel blend at 2900 rpm of engine speed to maximize the engine performance and minimize the emissions.

The engine performance characteristics such as BTE, BSFC and emission characteristics such as HC, CO, CO_2, NOx are analysed in this section. The interaction effect of the speed and concentration of the type of nanoparticles used for different types of fuel blends is discussed below.

3.2.1 Brake Thermal Efficiency

The GEM fuel blends with ZnO and Al_2O_3 additive showed a slight increase in brake power compared to pure gasoline. Nanoparticles added together with alcohols in gasoline offered a better fuel/air mixture that affected engine performance positively. As shown in figure 4(a), the BTE increased up to 2900 rpm speed and then decreased as the speed reaches 3300 rpm for ZnO-based nanofuels. Figure 4(b) shows the variation of BTE for Al_2O_3 at all the speed ranges, BTE increased from 5 ppm concentration to 10 ppm. Therefore, there is a significant effect of nanoparticle concentration in the fuel mixture. The power increased to maximum level when the engine speed increased and then the power drop started due to engine operating time (hours) and the friction losses. Similar types of engine performance results have also been found in previous studies also (Hussein et al., 2020; Awad et al., 2017).

Table 5. Initial population with input parameters and responses (Teacher phase)

Exp. No.	Blend No.	Name of the fuel blend	Speed	NPC	BTE	BSFC	HC	CO	CO_2	NOx	Z_{BSFC}	Z_{BTE}	Z'	Rank
1	2	E20Z10	2900	10	35.25	0.22	39	1.09	13.97	753	0	0	0	1
2	2	E20Z10	3300	10	33.89	0.26	40	0.29	14.12	801	0.04	1.11	1.694	6
3	3	E20B1Z5	2500	5	34.2	0.23	54	0.31	12.31	593	0.01	0.8	0.75	3
4	3	E20B1Z5	2900	5	36.5	0.22	34	0.29	13.26	788	0	0	0	1
5	3	E20B1Z5	3300	5	33.4	0.23	20	0.24	14.41	871	0.01	1.6	1.25	4
6	4	E20B1Z10	2500	10	35.61	0.22	54	0.2	12.14	619	0	0	0	1
7	4	E20B1Z10	2900	10	37.12	0.21	39	0.19	14.16	711	0	0	0	1
8	4	E20B1Z10	3300	10	35.92	0.23	36	0.12	14.79	923	0.01	0	0.25	2
9	5	E20A5	2500	5	36.71	0.22	206	1.69	16.65	556	0	0	0	1
10	5	E20A5	2900	5	37.3	0.21	119	1.21	19.56	885	0	0	0	1
11	5	E20A5	3300	5	35.36	0.25	87	0.59	18.01	985	0.03	0	0.75	3
12	6	E20A10	2900	10	37.11	0.2	115	1.16	17.55	855	0	0	0	1
13	7	E20B1A5	2900	5	35.74	0.21	96	0.08	16.96	863	0	0	0	1
14	7	E20B1A5	2500	5	34.15	0.24	105	1.25	12.32	763	0.02	0.85	1.03	5
15	8	E20B1A10	2500	10	36.79	0.21	36	0.08	16.39	717	0	0	0	1
16	8	E20B1A10	2900	10	37.61	0.2	19	0.07	17.03	809	0	0	0	1
			2900	7.67										

Table 6. New inputs and the responses (Teacher phase)

Exp. No.	Blend No.	Name of the fuel blend	Speed	NPC	BTE	BSFC	HC	CO	CO2	NOx	Z_{BSFC}	Z_{BTE}	Z'	Rank
1	2	E20Z10	2900	10	34.88	0.222	58.2	0.623	13.86	802.9	0.002	0.12	0.116	3
2	2	E20Z10	3300	10	36.05	0.21	2.2	0.65	15.32	942.6	0	0	0	1
3	3	E20B1Z5	2300	5	32.64	0.251	182	2.717	12.37	591.4	0.031	2.36	2.24	6
4	3	E20B1Z5	2900	5	34.39	0.233	91.35	0.811	14.56	801	0.013	0.61	0.713	4
5	3	E20B1Z5	3300	5	35.55	0.222	30.95	-0.46	16.02	940.8	0.002	0	0.043	2
6	4	E20B1Z10	2300	10	33.13	0.239	148.8	2.528	11.67	593.2	0.019	1.86	1.644	5
7	4	E20B1Z10	2900	10	34.88	0.222	58.2	0.623	13.86	802.9	0.002	0.12	0.117	3
8	4	E20B1Z10	3300	10	36.05	0.21	2.2	0.65	15.32	942.6	0	0	0	1
9	5	E20A10	2300	5	32.64	0.251	182	2.717	12.37	591.4	0.031	2.36	2.248	6
10	5	E20A10	2900	5	34.39	0.233	91.35	0.811	14.56	801	0.013	0.61	0.713	4
11	5	E20A10	3300	5	35.55	0.222	30.95	0.46	16.02	940.8	0.002	0	0.043	2
12	6	E20A20	2900	10	34.88	0.222	58.2	0.623	13.86	802.9	0.002	0.12	0.116	3
13	7	E20B1A10	2900	5	34.39	0.233	91.35	0.811	14.56	801	0.013	0.61	0.713	4
14	7	E20B1A10	2300	5	32.64	0.25	181.95	2.716	12.37	591.3	0.030	2.35	2.24	6
15	8	E20B1A20	2300	10	33.13	0.239	148.8	2.528	11.67	593.2	0.019	1.86	1.644	5
16	8	E20B1A20	2900	10	34.88	0.222	58.2	0.623	13.86	802.9	0.002	0.12	0.116	3

Table 7. Combined phase in teacher phase

Exp. No.	Blend No.	Name of the fuel blend	Speed	NPC	BTE	BSFC	HC	CO	CO2	NOx	Z_{BSFC}	Z_{BTE}	Z'	Rank
1	6	E20A10	2900	10	37.11	0.2	115	1.16	17.55	855	0	0	0	1
2	7	E20B1A5	2900	5	35.74	0.21	96	0.08	16.96	863	0	0	0	1
3	8	E20B1A10	2500	10	36.79	0.21	36	0.08	16.39	717	0	0	0	1
4	8	E20B1A10	2900	10	37.61	0.2	19	0.07	17.03	809	0	0	0	1
5	2	E20Z10	2900	10	35.25	0.22	39	1.09	13.97	753	0	0	0	1
6	3	E20B1Z5	2900	5	36.5	0.22	34	0.29	13.26	788	0	0	0	1
7	4	E20B1Z10	2500	10	35.61	0.22	54	0.2	12.14	619	0	0	0	1
8	4	E20B1Z10	2900	10	37.12	0.21	39	0.19	14.16	711	0	0	0	1
9	5	E20A5	2500	5	36.71	0.22	206	1.69	16.65	556	0	0	0	1
10	5	E20A5	2900	5	37.3	0.21	119	1.21	19.56	885	0	0	0	1
11	3	E20B1Z5	3300	5	35.55	0.222	30.95	0.46	16.03	940.8	0	0	0.04	2
12	5	E20A5	3300	5	35.55	0.222	30.95	0.46	16.03	940.8	0	0	0.04	2
13	2	E20Z10	2900	10	34.88	0.222	58.2	0.623	13.86	802.9	0	0.115	0.12	3
14	4	E20B1Z10	2900	10	34.88	0.222	58.2	0.623	13.86	802.9	0	0.115	0.12	3
15	6	E20A10	2900	10	34.88	0.222	58.2	0.623	13.86	802.9	0	0.115	0.12	3
16	8	E20B1A10	2900	10	34.88	0.222	58.2	0.623	13.86	802.9	0	0.115	0.12	3

Table 8. New working conditions after interaction

Name of the fuel blend	Speed	NPC	BTE	BSFC	HC	CO	CO2	NOx	Z_{BSFC}	Z_{BTE}	Z'	Rank	Int.
E20A10	2900	10	34.88	0.22	58.2	0.62	13.86	802.86	0.0018	0.115	0.11	2	1&16
E20B1A5	2900	5	34.38	0.23	91.35	0.81	14.56	801.01	0.0133	0.612	0.71	4	2&15
E20B1A10	2380	10	33.37	0.23	136.72	2.27	11.96	621.172	0.0168	1.629	1.44	6	3&14
E20B1A10	2900	10	34.88	0.22	58.2	0.62	13.86	802.86	0.0018	0.115	0.11	2	4&13
E20B1Z10	2780	10	34.53	0.22	76.32	1.003	13.42	760.9	0.0052	0.464	0.42	3	5&12
E20Z5	2780	5	34.04	0.23	109.47	1.192	14.13	759.08	0.0167	0.959	1.01	5	6&11
E20B1Z10	2380	10	33.37	0.23	136.72	2.27	11.96	621.17	0.0168	1.629	1.44	6	7&10
E20B1Z10	3020	10	35.23	0.21	40.08	0.24	14.3	844.78	0	0	0	1	8&9
E20A5	2380	5	32.87	0.24	169.87	2.46	12.66	619.32	0.0283	2.124	2.03	7	9&1
E20A5	2900	5	34.38	0.23	91.35	0.811	14.56	801.01	0.0133	0.610	0.71	4	10&2
E20Z5	3300	5	35.55	0.22	30.95	-0.45	16.02	940.77	0	0	0	1	11&3
E20A5	3320	5	35.61	0.22	27.93	0.52	16.1	947.75	0	0	0	1	12&4
E20B1Z10	2900	10	34.88	0.22	58.2	0.62	13.86	802.86	0.0018	0.115	0.11	2	13&5
E20B1Z10	2900	10	34.88	0.22	58.2	0.62	13.86	802.86	0.0018	0.115	0.11	2	14&6
E20A10	3020	10	35.23	0.21	40.08	0.24	14.3	844.788	0	0	0	1	15&7
E20B1A10	2900	10	34.88	0.22	58.2	0.62	13.86	802.86	0.0018	0.115	0.11	2	16&8

Table 9. Best experiments in the learner phase

Exp. No.	Blend No.	Name of the fuel blend	Speed	NPC	BTE	BSFC	HC	CO	CO2	NOx	Z_{BSFC}	Z_{BTE}	Z'	Rank
1	3	E20Z5	3340	5	36.25	0.215	5.3	1.222	16.91	1025	0	0	0	1
2	5	E20A10	3420	5	35.9	0.218	12.83	1.25	16.47	982.7	0	0	0	1
3	4	E20B1Z10	3020	10	35.23	0.218	40.08	0.241	14.3	844.8	0	0	0	1
4	6	E20A10	3020	10	35.23	0.218	40.08	0.241	14.3	844.8	0	0	0	1
5	6	E20A10	2900	10	37.11	0.2	115	1.16	17.55	855	0	0	0	1
6	7	E20B1A5	2900	5	35.74	0.21	96	0.08	16.96	863	0	0	0	1
7	8	E20B1A10	2500	10	36.79	0.21	36	0.08	16.39	717	0	0	0	1
8	8	E20B1A10	2900	10	37.61	0.2	19	0.07	17.03	809	0	0	0	1
9	2	E20B1Z10	2900	10	35.25	0.22	39	1.09	13.97	753	0	0	0	1
10	3	E20Z5	2900	5	36.5	0.22	34	0.29	13.26	788	0	0	0	1
11	4	E20B1Z10	2500	10	35.61	0.22	54	0.2	12.14	619	0	0	0	1
12	4	E20B1Z10	2900	10	37.12	0.21	39	0.19	14.16	711	0	0	0	1
13	5	E20A5	2500	5	36.71	0.22	206	1.69	16.65	556	0	0	0	1
14	5	E20A5	2900	5	37.3	0.21	119	1.21	19.56	885	0	0	0	1

Table 10. Crowding distances (CD)

Exp. No.	HC	HC_{CD}	CO	CO_{CD}	NOx	$NO_{x\,CD}$	CO_2	$CO_{2\,CD}$
1	5.3	∞	1.22154	0.040	1024.6	∞	16.906	0.0417
2	12.83	0.068	1.25	0.473	982.6	0.2979	16.468	0.0350
3	40.08	0.005	0.24148	0.041	844.7	0.0219	14.302	0.2813
4	40.08	0.0051	0.24148	0.049	844.7	0.0761	14.302	0.2466
5	115	0.114	1.16	0.121	855	0.1515	17.55	0.3409
6	96	0.303936	0.08	0.010	863	0.0640	16.96	0.0166
7	36	0.024913	0.08	0.111	717	0.0896	16.39	0.2919
8	19	0.105481	0.07	∞	809	0.1209	17.03	0.0795
9	39	0.014948	1.09	0.878	753	0.1515	13.97	0.1212
10	34	0.084704	0.29	0.857	788	0.1195	13.26	0.2466
11	54	0.278625	0.2	0.052	619	0.3307	12.14	∞
12	39	0.005381	0.19	0.121	711	0.2091	14.16	0.0447
13	206	∞	1.69	∞	556	∞	16.65	0.0590
14	119	0.453413	1.21	0.062	885	0.2552	19.56	∞

Table 11. Overall crowding distances

Expt. No	Blend	Name of the fuel blend	Speed	NPC	BTE	BSFC	HC	CO	CO2	NOx	O_{CD}
1	3	E20Z5	3340	5	36.253	0.215	5.3	1.222	16.91	1025	∞
2	5	E20A5	3420	5	35.904	0.218	12.83	1.25	16.47	982.7	0.874
3	4	E20B1Z10	3020	10	35.234	0.218	40.08	0.241	14.3	844.8	0.351
4	6	E20A10	3020	10	35.234	0.218	40.08	0.241	14.3	844.8	0.377
5	6	E20A10	2900	10	37.11	0.2	115	1.16	17.55	855	0.728
6	7	E20B1A5	2900	5	35.74	0.21	96	0.08	16.96	863	0.395
7	8	E20B1A10	2500	10	36.79	0.21	36	0.08	16.39	717	0.518
8	8	E20B1A10	2900	10	37.61	0.2	19	0.07	17.03	809	∞
9	2	E20B1Z10	2900	10	35.25	0.22	39	1.09	13.97	753	1.167
10	3	E20B1Z5	2900	5	36.5	0.22	34	0.29	13.26	788	1.308
11	4	E20B1Z10	2500	10	35.61	0.22	54	0.2	12.14	619	∞
12	4	E20B1Z10	2900	10	37.12	0.21	39	0.19	14.16	711	0.38
13	5	E20A5	2500	5	36.71	0.22	206	1.69	16.65	556	∞
14	5	E20A5	2900	5	37.3	0.21	119	1.21	19.56	885	∞

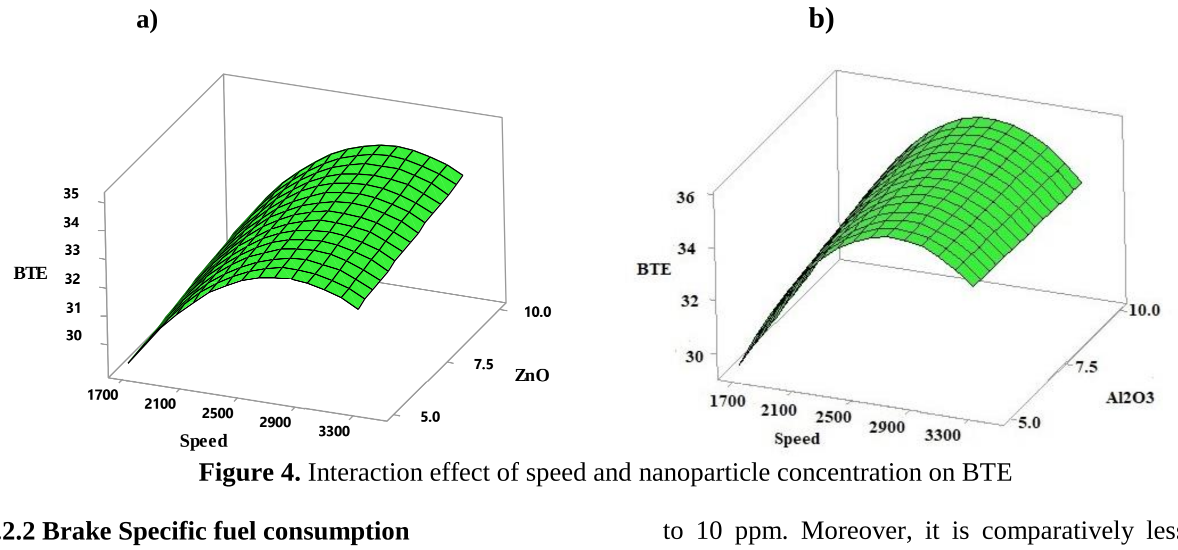


Figure 4. Interaction effect of speed and nanoparticle concentration on BTE

3.2.2 Brake Specific fuel consumption

Figures 5(a) and 5(b) show the interaction effect of speed with concentration of ZnO and Al_2O_3 nanoadditives, respectively, on BSFC. It is observed from both figures that BSFC decreased as the concentration of nanoparticle increased from 5 ppm to 10 ppm. Moreover, it is comparatively less for Al_2O_3 fuels. In both the cases, the BSFC decreased as the speed increased to 2900 rpm and then it starts increasing when the speed is further increased.

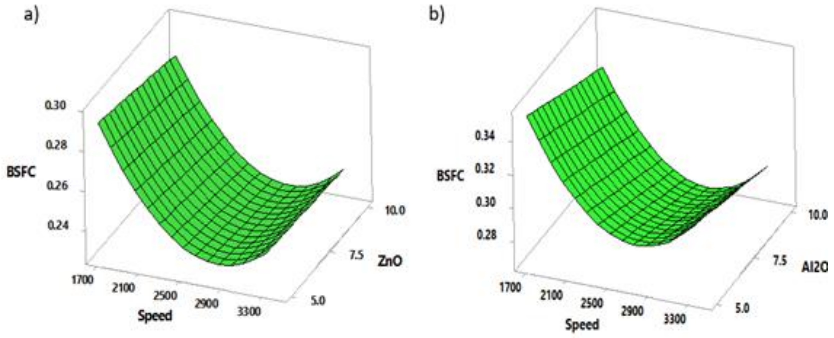


Figure 5. Interaction effect of speed and nanoparticle concentration on BSFC

The BSFC is found to be decreased slightly when the concentration of ZnO and Al_2O_3 nano additives increased. The addition of nanoparticles improves combustion due to the catalytic effect of metal oxide additives (Keskin et al., 2011), high oxygen content in alcohols lowers BSFC (Simsek et al., 2020a, b, c).

3.2.3 Hydrocarbon Emissions

Figure 6(a) and 6(b) shows interaction effect of speed with ZnO nano additives and Al_2O_3 nano additives respectively on the HC emissions. As the speed increases from 1700 rpm to 3300 rpm, HC emissions followed a decreasing trend i.e., with increase in speed and nanoparticle concentration. The HC emissions are found to be less in both the nanofuels . Presence of nanoparticles in the fuel blends decreased HC emissions by promoting complete combustion inside the cylinder (Celik et al., 2016). Similar kind of results were also found in previous studies (Rosdi et al., 2020; Hussein et al., 2020; Mourad & Mahmoud, 2019).

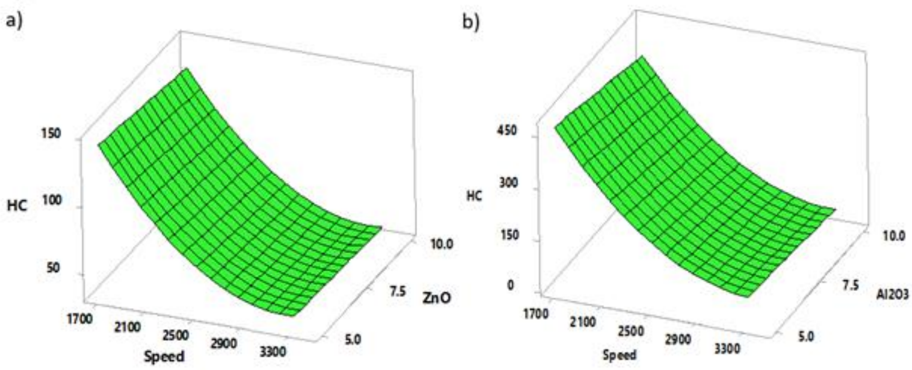


Figure 6. Interaction effect of speed and nanoparticles on HC emissions

3.2.4 Carbon monoxide

From the figures 7(a),7(b) it is evident that as speed increased from 1700 rpm to 3300 rpm, the CO emissions reduced. CO emissions also followed a declining trend as the ZnO concentration in fuel increased from 5ppm to 10ppm. But there was only a little change for Al_2O_3 fuels.

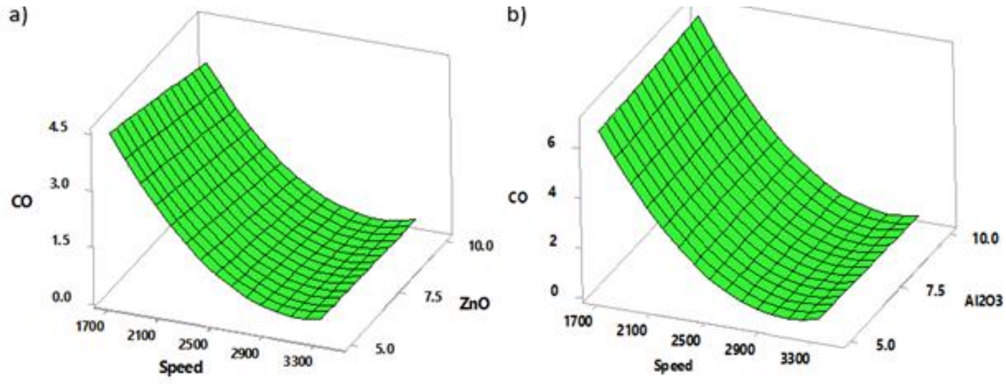


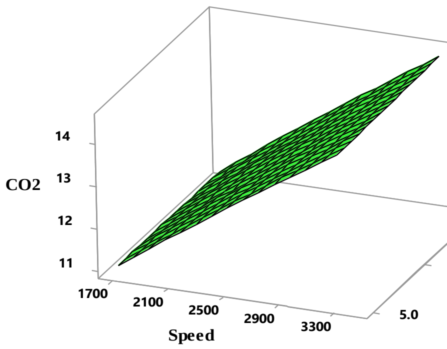
Figure 7. Interaction affects of speed and nanoparticle on CO emissions

However, addition of ZnO and Al_2O_3 nano particles showed a positive effect on CO emissions. Since the alcohol-based fuels have rich oxygen content, the combustion improved and the CO emissions reduced (Mourad & Mahmoud, 2019). Similar kind of results were also found by Hussein et al. (2020) and Simsek et al. (2020a).

3.2.5 Carbondioxode

From the figures 8(a),8(b) it is found that CO_2 increased with increase in speed and in concentration of nanoparticles. The addition of Al_2O_3 and ZnO nanoparticles in the fuel blends gave a positive effect in the reduction of CO_2 emissions compared to other gasoline-alcoholic blends.

a)



b)

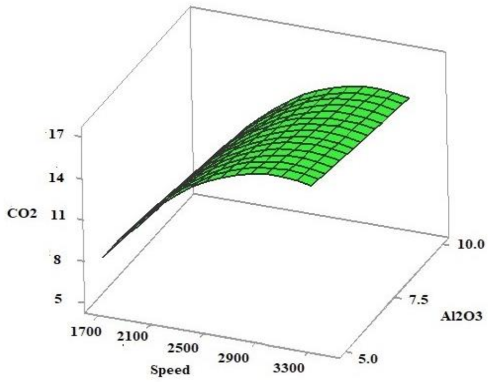


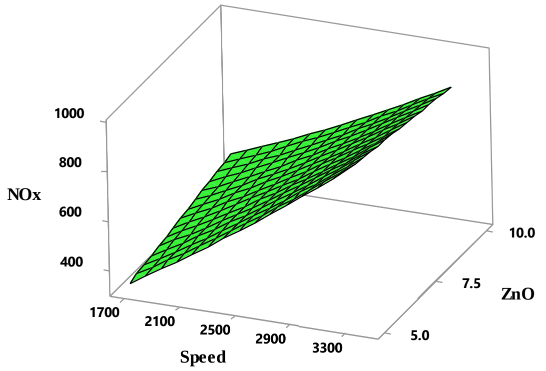
Figure 8. Interaction effects of speed and nanoparticles on CO_2 emissions

This is because of the lower ignition temperature when the metal oxide additives are used in fuels (Keskin et al. 2011). Oxygen atoms provided by nano oxides form more oxygen content in the fuel, subsequently it results in higher concentration of carbondioxode content. Similar results were found by Amirabedi et al. (2019) using MnO_3 nanoparticles**.**

3.2.6 Nitrogen dioxide

From the figures 9(a) and (b), it is noticed that as speed increases, the NOx value also increases due to increase in temperature but as the concentration of nanoadditives increases, the model differs. For ZnO, the NOx values decreased with concentration, whereas the trend was different for the Al_2O_3. The catalytic property of nanoparticles leads to higher temperatures at the end which ultimately results in the formation of more amount of NOx. Similar kind of results were also found by Simsek et al. (2019) and Rosdi et al. (2020).

a)



b)

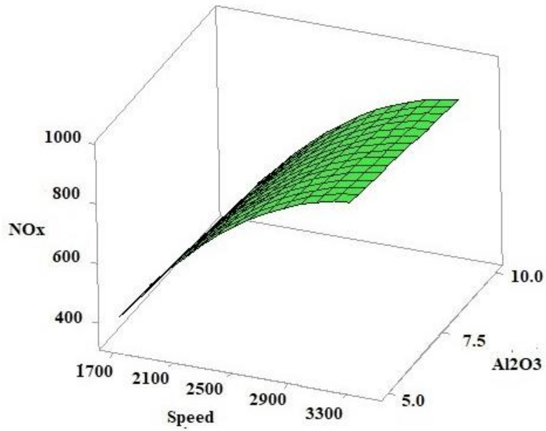


Figure 9. Interaction effects of speed and nanoparticles on NOx emissions

4. CONCLUSIONS

The main objective of this study is to investigate the influence of ZnO and Al_2O_3 nanoparticles added to gasoline, ethanol, and methanol blends with various fuel compositions ranging with maximum of 80% gasoline and 20% ethanol and 7% methanol on the performance and emissions parameters at various engine speeds. Teaching - learning - based optimization model is employed to determine the optimum nanoparticle concentration and engine speed. The following are the conclusions drawn from this study:

- Among the nanofuels samples considered , the fuel blends with ZnO nanoparticles performed best in view of maximum performance and minimum emission characteristics.

- The fuel blend E20B1Z5 gave 36.5% of BTE, 0.22 kg/kWh of BSFC, 41-ppm HC, 788-ppm NOx, 0.29% CO, 13.26% CO_2 at optimum operating parameters.
- It is found that the BTE increased as the engine speed increased to 2900 rpm and then the BTE dropped after the engine speed increased from 2900 rpm to 3300 rpm for both the ZnO, Al2O3 metal oxides mixed in the fuel at different concentrations.
- The CO_2 emissions also showed the same trend with respect to the speed, but it did not drop even the engine speed increased beyond the 2900 rpm.
- The BSFC and the emissions HC, CO and NOx reduced when the engine speed increased to 2900 rpm for both ZnO, Al_2O_3 metal oxides mixed in the fuel at different concentrations. After that there is no reduction when the engine speed increased from the 2900 rpm.

From above conclusions, summarized that the both the Zinc oxide and alumina nanoparticles are suitable for spark ignition engines, TLBO technique can be successfully used in modelling SI engine parameters.

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