Effects of Different Mixtures of Biodiesel, Bioethanol, and Diesel on Tractor Engine Vibrations Using RSM and ANFIS

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Abstract

The vibrations generated by the use of different fuel mixtures in tractor engines can lead to accelerated wear of engine components, significant increases in maintenance costs, and reduced comfort and safety for operators. Nowadays, renewable fuels, namely biodiesel and bioethanol, have been of great interest to many researchers. In the present study, vibrations of the engine of MF285 tractor were measured in three directions, at speeds of 1000, 1600, and 2000 rpm for ten different fuel levels obtained from different compositions of biodiesel, bioethanol, and diesel fuels. To analyze the effects of the concerned parameters on engine vibrations, the response surface methodology (RSM) and artificial neural network fuzzy inference system (ANFIS) were applied. The obtained results demonstrated that increasing the engine speeds was in direct proportion to the vibrations increase. Furthermore, pure diesel fuel accounted for the major portion of vibrations, and $B_5E_4D_{91}$ had the highest vibrations among the fuel compositions. Moreover, vibrations were meaningfully reduced with the increase of biodiesel in fuel compositions. The optimization analysis revealed that the most effective fuels, exhibiting the lowest vibration levels, were identified as $B_{25}E_6D_{69}$ through RSM and $B_{25}E_4D_{71}$ via ANFIS.

Keywords: Bioethanol, Biofuel, Diesel, Vibration meter

Introduction

Due to the environmental pollution caused by combustion of fossil fuels and since they are nonrenewable, nowadays clean fuels such as biodiesel are of paramount importance. Biofuels with organic sources are assumed as one of the primary sources of renewable fuels or alternatives to fossil fuels. Combustion of plant-based fuels can be considered as an indirect application of solar energy. Biofuels mainly emit less pollution than fossil fuels and can be easily produced from the remains of plant materials. Engines are employed as power sources in industry and agriculture where many engineers are intended to investigate them and reduce their vibration problems. Vibrations are examined from different standpoints in engineering sciences. Tractors, as the most important sources of mechanical power on farms, have posed numerous problems associated with occupational health and safety of users. Engine vibration affects vehicle vibration, and is important for fault detection of engine and also driving comfort. Engine parts are damaged by vibration amplitude, and noise has negative effects on engine life (Saridemir & Polat, 2023). Vibration is caused by the combustion process caused by the explosive reaction of the air-fuel mixture under high pressure and temperature inside the combustion chamber. The type of used fuel affects it (Lima Júnior, Magalhaes, Ferreira, & Pereira, 2020).

Two biofuels, including biodiesel and bioethanol, can be used in diesel engines in pure or mixed forms since their features are identical to petrol and diesel (Ferella, Mazziotti Di Celso, De Michelis, Stanisci, & Vegliò, 2010). These biofuels require a vibration analysis before changing the engine fuel, which is the focus of this research. A wide range of studies have been performed to investigate the origins of engine vibrations and methods to reduce them (Taghizadeh-Alisaraei *et al.*, 2016). However, there are still many areas of study, including the effects of fuel types on vibrations, which have remained uninvestigated. The vibrations and strokes generated by using a particular fuel type in diesel engines can lead to significant wear and tear on engine components, skyrocketing maintenance costs, increased fuel consumption, and heightened discomfort and safety concerns for users (Salokhe, Majumder, & Islam, 1995). Compared to spark engines, more noise and vibrations are produced by diesel engines, especially in large engines with high ignition pressures and high compression ratios, having adverse effects on the users' ears and bodies (Selim, 2001). Researchers showed that acceleration could be boosted by increasing the speed of engines for all mixtures of diesel and bioethanol fuels (Taghizadeh-Alisaraei & Rezaei-Asl, 2016). Other studies have also been performed on using biodiesel fuels bearing various fruitful results. Rahimi, Ghobadian, Yusaf, Najafi, and Khatamifar (2009) used a mixture of diesel and biodiesel fuel from sunflower oil and ethanol extracted from potato waste. The results demonstrated that the maximum power and torque of engines were slightly reduced using this fuel composition, while the average specific fuel consumption increased (Rahimi, Ghobadian, Yusaf, Najafi, & Khatamifar, 2009). Rice bran oil was used to produce biodiesel, which, when mixed with diesel and ethanol, was utilized as a fuel for diesel engines. The results showed that the highest thermal efficiency was obtained for 15% ethanol in the biodiesel and bioethanol blended diesel fuel (Subbaiah *et al.*, 2010). Using a mix of ethanol and diesel can enhance the thermal efficiency of engines and reduce the particulates and NOx pollution (Hansen, Zhang, & Lyne, 2005). The results of relevant studies show that the vibration acceleration depends on the coordinate directions, engine speed, and fuel type. That is to say, the most severe vibrations occur in vertical directions, and vibrations are intensified by increasing the speed due to the increased number of courses and strokes per unit of time. Furthermore, they are reduced using pure biodiesel compared with pure diesel (Patel *et al.*, 2016). Reducing the engine speed lessens both the tensional vibration of the crankshaft and the vibration acceleration (Patel *et al.*, 2016).

Erdiwansyah *et al.* (2022) used different fuel blended with methanol and gasoline (between 5% and 10%) and three speeds of motor (1000, 1200, and 1400 rpm) on a four-cylinder gasoline engine. The findings indicate that fuel blends of methanol and gasoline exhibit the highest vibration levels at engine speeds between 1200 and 1400 rpm, compared to those observed at 1000 to 1200 rpm (Erdiwansyah *et al.*, 2022). Cahyono and colleagues investigated the characteristics of biodiesel fuel blends infused with citronella oil, subsequently testing them on a single-cylinder diesel engine. The results showed that the inclusion of citronella oil in the blends led to a reduction in motor vibration when compared to B30 fuel (Cahyono, Semin, & Putri, 2024). Velmurugan and colleagues reduced the vibration of a four-stroke diesel engine by using a new fuel blend with the addition of biodiesel, palm oil, and nano particles such as titanium oxide (Velmurugan, Aathif Akmal, Paramasivam, & Thanikaikarasan, 2020). Chaitidis and colleagues measured the vibration of diesel motor in different engine rpm (850, 1150, and 2000) and variety of biodiesel blends (B20, B40, B60, and B80). The results indicated that increasing the proportion of biodiesel in fuel blends resulted in greater vibration and noise in the diesel motor (Chaitidis, Marhavilas, & Kanakaris, 2022). Susilo, Listiyono, and Khambali (2022) investigated the effect of a diesel-essential oil mixture on a diesel engine, related to engine performance, noise, and vibration. The experiments were performed on a 402 CC Dongfeng diesel engine. The results show that the B10 mixture has the lowest vibration at 1300 rpm (975.7 Hz) and the highest at 1900 rpm (989.8 Hz) (Susilo, Listiyono, & Khambali, 2022). Lima Júnior *et al.* (2020) analyzed vibrations of engines with two different fuels, Brazilian commercial diesel (B8) and Biodiesel (B100). They also analyzed the fuel consumption, level of particulate matter emissions, and engine temperature. The results showed that B8 diesel fuel had higher energy content than B100 biodiesel fuel across all three analyzed speeds. Total vibration of B8 diesel was 4.5% to 21% higher than B100 biodiesel, according to the speed range (Lima Júnior *et al.*, 2020). In a research, the impacts of blends of biodiesel from waste cooking oil and various metal-oxide based nanoparticles (D100, B10, B10TiO_2, B10$Al2O_3$, and B10SiO_2) on the vibration, noise characteristics, emission, combustion, and performance of a single-cylinder diesel engine were investigated (Ağbulut, Karagöz, Sarıdemir, & Öztürk, 2020). Their results showed that the highest vibration and noise data were seen in B10. The addition of nanoparticles into B10 slightly reduced these measurements (Ağbulut *et al.*, 2020).

The acceleration of the front part of the tractor engine is significantly boosted through increasing the speed of the engine from 1000 to 2200 rpm in three vertical, horizontal, and lateral directions. Increasing the engine speed from 1400 to 2200 rpm yields an increase in the vibration acceleration of tractor engines due to the larger number of combustion courses and piston strokes per unit of time (Heidary, Hassan-Beygi, Ghobadian, & Alisaraei, 2013). Investigation of noise and vibrations caused by the combustion process in internal-combustion engines has always been of interest to researchers. Vibrations have direct destructive effects on engine components and users. Compared to petrol engines, more noise and vibrations are produced by diesel engines, producing adverse effects on engines and users (Guzzomi, Hesterman, & Stone, 2007; Keskin, 2010). The effects of a mixture of petrol and ethanol were investigated on the vibrations of cylinder blocks and noise of spark-ignition engines. The results showed that increasing ethanol in the mixture led to more engine vibrations and noise, especially between 1500 and 2500 rpm (Keskin, 2010). The vibrations of a mixture of biodiesel and diesel fuels in Perkins six-cylinder compression-ignition engines were studied before and after repairing the engines. The results indicated that the fuel mixture had significant impacts on the degree of vibrations such that 20% and 40% biodiesel mixtures offered the lowest vibrations. However, 15% and 30% biodiesel mixtures had the most severe vibrations. In addition, the results showed that the vibrations dropped dramatically after repairs (Taghizadeh-Alisaraei, Ghobadian, Tavakoli-Hashjin, & Mohtasebi, 2012). In another study, the results demonstrated that the mean of vibration acceleration increased in all gears and positions by increasing the rotational speed of the engine. The vibration acceleration varied along the coordinate directions. In general, the vibration acceleration was highest in the vertical direction, followed by the lateral direction, and lowest in the longitudinal direction (Mirnezami, Hassan-Beygi, Banakar, & Ghobadian, 2017). Engine speed is the most crucial factor affecting engine power. Furthermore, the quantity of biodiesel fuel and engine speed are the most important indices of the amount of specific fuel consumption (SFC) (Buragohain & Mahanta, 2008; Mirnezami *et al.*, 2017; Xu, Yin, Liu, & Jia, 2017).

The internal combustion engine is an important source of noise and vibration in a tractor. Given that various researches have been conducted on engine vibrations, the majority of tests on engines have been performed using fossil fuels. However, no comprehensive research has been performed on the utilization of different combinations of biodiesel, bioethanol, and diesel fuels, and their effects on the vibrations (acceleration) of engines. Hence, in the present study, the vibrations of the engine of a MF285 tractor were measured in three directions at speeds of 1000, 1600, and 2000 rpm for ten different fuel levels obtained from different compositions of biodiesel, bioethanol, and diesel fuels. The volumetric percentages of biodiesel used in fuel combinations are 5, 10, and 15, and 2, 4, and 6 for bioethanol. To analyze the effects of the concerned parameters on engine vibrations, the response surface methodology (RSM) and artificial neural network fuzzy inference system (ANFIS) are applied. After optimization, the best fuel is obtained in terms of having the least vibration of the engine by the RSM and ANFIS. Meanwhile, all the predicted results are validated against the experimental data.

Materials and Methods

In the present study, a rapeseed-based biodiesel fuel was produced in a biodiesel production workshop using hydrodynamic cavitation reactors. Fig. 1 shows the process of producing biodiesel and its components.

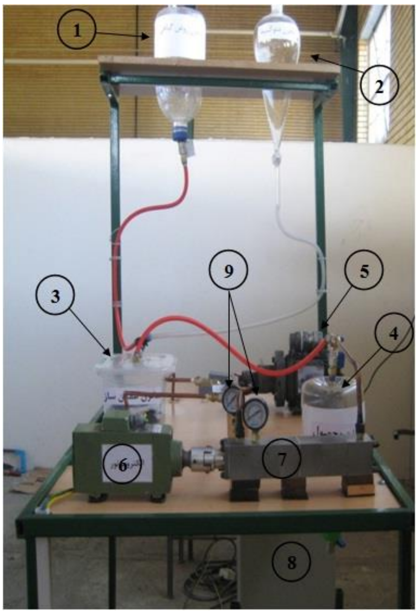

Fig. 1. Biodiesel production system by hydrodynamic cavitations reactor
(1- Oil tank, 2- Metoxed tank, 3- Homogenization tank, 4- Product tank, 5- Positive displacement pump, 6- Electro motor, 7- Hydrodinamic cavitations reactor, 8- Inverter, and 9- Pressure gauge)

To produce biodiesel, rapeseed liquid oil, 99% pure methanol alcohol with a molar ratio of 6:1, and sodium hydroxide catalyst equal to one weight percent of oil were used. The conditions of biodiesel production included maintaining a temperature of 50 °C, a five-minute reaction time, a mixing intensity of 8000 rpm, and a pump flow rate of 0.83 L min^{-1}. Following various stages of purification, including separating glycerin, methanol and water washing, 98% of the produced biodiesel was methyl ester. Then, 10 different fuel mixtures were prepared from biodiesel (Bi), bioethanol (Ej), and diesel (Dk). These compounds are as follows: $B_5E_2D_{93}$, $B_5E_4D_{91}$, $B_5E_6D_{89}$, $B_{15}E_2D_{83}$, $B_{15}E_4D_{81}$, $B_{15}E_6D_{79}$, $B_{25}E_2D_{73}$, $B_{25}E_4D_{71}$, $B_{25}E_6D_{69}$, $B_0E_0D_{100}$, where the subscripts represent the volumetric percentage in the fuel mixture. To conduct the experiment, a single-differential MF 285 tractor, manufactured by the Iranian Tractor manufacturing Company, was used. To collect the signals of engine vibrations, a VM120 vibration meter, made by Monitran Co., was employed. Three engine speeds of 1000, 1600, and 2000 rpm were considered as well as three directions x, y, and z. The experiments were carried out on dirt roads in constant and controlled manners, and the tractor was serviced prior to the experiments. The experiments on fuel mixtures were conducted in the stationary mode for all fuel mixtures in the non-load state. Moreover, the experiment equipment was installed on the right side of the engine in the driver’s line of sight, with no apparatus connected to the tractor. Vibrations were measured in three engine speeds, three repetitions, and three directions. A total of 270 experiments were conducted with respect to the 10 fuel levels. To test the given fuels, the pipes of the fueling circuit were cut off from the input and output of the secondary fuel filter. By creating a sub-circuit, the concerned fuels that were stored in a reservoir on the right side of the hood of the tractor entered the rotary injection pumps (like a watermill). Fueling was slow or disrupted because the primary pump (triangular pump) was disconnected from the fuel transfer to the injection pump, necessitating deaeration. To resolve this problem, the fuel reservoir was to be located at a higher point than the location of the injection pump in order for the fuel to be directed into the fueling circuit by the gravitational force. Therefore, benefiting from this information, the fueling operation was precisely conducted without any air in the course of the fueling circuit. A fuel return pipe was mounted on the top of the auxiliary fuel tank to transfer the rejected fuel into the reservoir. To commence the next experiment, the tractor was given sufficient time to consume its previous fuel in order to avoid fuel blending. After collection and storage of data related to the vibration acceleration of the MF 285 tractor engine, it was necessary to analyze them at different levels using RSM and ANFIS.

Modeling through RSM

RSM is a collection of mathematical and statistical modeling methods used for multiple regression analysis and applied to examine the relationship between one or more measured parameters. In this study, a three-dimensional hysterical data design was used for evaluation. To investigate the effects of the concerned parameters on engine vibrations in RSM, the three parameters including percentage of biodiesel variations, percentage of bioethanol variations, and engine speed in rpm were assumed as inputs where the mean of engine vibration in m s^{-2} was assumed as the output. Encoded and real levels of independent variables are presented in Table 1. The experiment design was arranged with three factors and three levels, including 21 factor points to adjust a second-order response surface. In order to validate the model, 9 input vectors from the test data were added to the model, and the output parameter was compared with the RSM predictions. Design-Expert software version 7.0.0 has been used to analyze and model the experimental data as well as designing respective diagrams.

Modeling through ANFIS

This system, an optimum combination of fuzzy logic and artificial neural network (Buragohain & Mahanta, 2008; Metin Ertunc & Hosoz, 2008), is invaluable for solving nonlinear problems in agricultural engineering applications (Arkhipov, Krueger, & Kurtener, 2008; Buragohain & Mahanta, 2008; Cheng, Cheng, & Lee, 2002). Furthermore, it is capable of establishing and inferring the linguistic concepts of nonlinear relationships between inputs and outputs (Naderloo *et al.*, 2012). Data analysis was performed using ANFIS to meet two objectives. The first objective was to simulate the effects of the changes of various parameters on engine vibrations, and the second one was to present a predictive model.

Five important and effective factors were optimized in the ANFIS model: 1) type of input fuzzy sets (input membership functions include trimf, trapmf, gbellmf, gaussmf, gauss2mf, pimf, dsigmf, or psigmf), 2) number of input fuzzy sets (number of membership functions ranges between 2 and 6), 3) type of output fuzzy sets(output membership functions include linear or constant), 4) type of optimization (two optimization methods include backpropagation or hybrid), and 5) number of epochs (3 to 100). Thirty percent of the data (9 data sets) were used as the test set, and the remaining 70% (21 data sets) were assumed as the training set. The ANFIS models were developed using MATLAB R2013b with ANFIS Toolbox. Ultimately, the best obtained ANFIS model had three inputs (biodiesel, bioethanol, and engine speed) and one output (mean of engine vibrations). There were three Gaussian input fuzzy sets and a linear output fuzzy set. Additionally, a hybrid optimization method was applied with 30 epochs. In the end, the actual results were compared with the predicted results by the ANFIS model.

Results and Discussion

All measured data and the mean of engine vibrations are shown in Table 1.

Table 1- The design of the experiment and the measured data

Run	Label in RSM						Average vibration (m s^{-2})
	A		B		C		
	Biodiesel (%)	Code in RSM	Bioethanol (%)	Code in RSM	Engine speed (rpm)	Code in RSM	
1	5	-1	2	-1	1000	-1	2.31
2	5	-1	2	-1	1600	0.2	3.54
3	5	-1	2	-1	2000	1	4.91
4	5	-1	4	0	1000	-1	3.10
5	5	-1	4	0	1600	0.2	3.89
6	5	-1	4	0	2000	1	5.48
7	5	-1	6	1	1000	-1	2.05
8	5	-1	6	1	1600	0.2	3.13
9	5	-1	6	1	2000	1	5.05
10	15	0	2	-1	1000	-1	2.14
11	15	0	2	-1	1600	0.2	3.07
12	15	0	2	-1	2000	1	4.78
13	15	0	4	0	1000	-1	1.91
14	15	0	4	0	1600	0.2	3.27
15	15	0	4	0	2000	1	4.66
16	15	0	6	1	1000	-1	2.03
17	15	0	6	1	1600	0.2	3.17
18	15	0	6	1	2000	1	4.48
19	25	1	2	-1	1000	-1	2.09
20	25	1	2	-1	1600	0.2	3.15
21	25	1	2	-1	2000	1	3.88
22	25	1	4	0	1000	-1	1.71
23	25	1	4	0	1600	0.2	2.78
24	25	1	4	0	2000	1	4.68
25	25	1	6	1	1000	-1	1.97
26	25	1	6	1	1600	0.2	3.08
27	25	1	6	1	2000	1	4.49
28	0	-1.5	0	-2	1000	-1	2.65
29	0	-1.5	0	-2	1600	0.2	4.23
30	0	-1.5	0	-2	2000	1	4.25

The bar graph for the analysis of the measured data is shown in Figure 2. In this graph, the mean of engine vibrations is shown for different fuel mixtures over the intended periods.

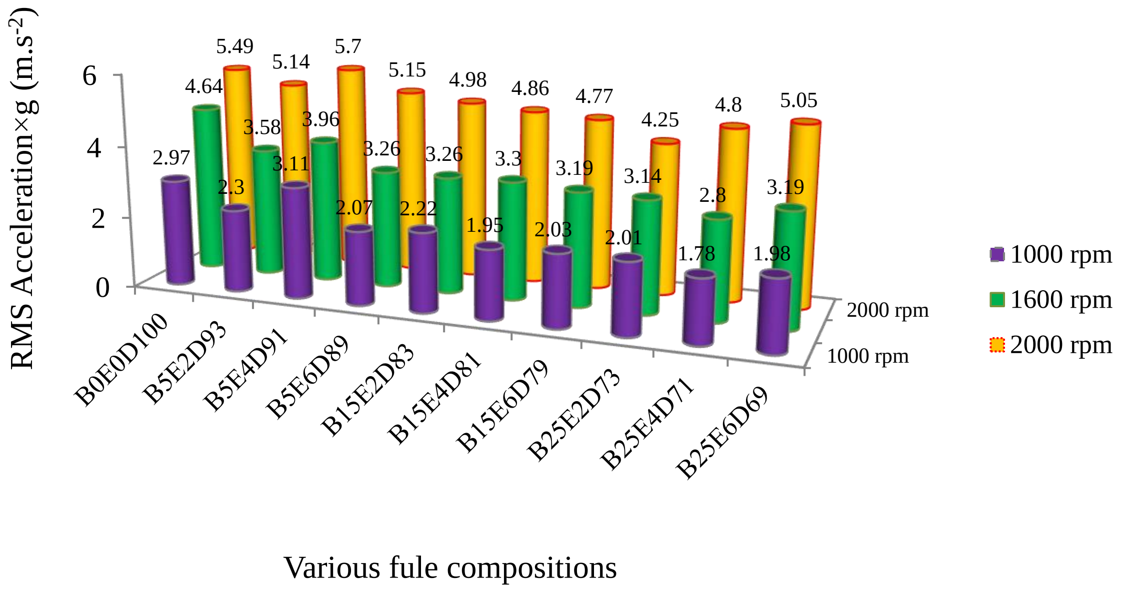

Fig. 2. Total vibration values (vibration outcome) for various fuels under different period

As outlined in the graph, increasing the engine speed leads to a rise in the vibrations of the body of the engine due to a larger number of combustion courses and piston strokes per unit of time (Ghaderi, Naderloo, Javadikia, Mostafaei, & Rabbani, 2019; Javadikia, Naderloo, Safrangian, Mostafaei, & Mohtasebi, 2016; Safrangian, Naderloo, Javadikia, Mostafaei, & Mohtasebi, 2017). This result was in good agreement with the results of previous studies (Heidary *et al.*, 2013; Patel *et al.*, 2016; Salokhe *et al.*, 1995; Taghizadeh-Alisaraei *et al.*, 2012, 2016). Furthermore, Fig. 2 also indicates that pure diesel fuel had the most vibrations among all of the concerned fuels, and $B_5E_4D_{91}$ fuel had also the highest extent of vibrations among the fuel mixtures.

Taghi zadeh-ali saraei *et al.* (2012) investigated nine different fuel combinations at seven engine speeds and showed that the lowest vibration was for B40 and B20, and the highest vibration was associated with B15, B30, and B50 fuels (Taghizadeh-Alisaraei *et al.*, 2012). On the contrary, Heidary *et al.* in 2013 obtained the opposite results, so that B100 and B5 fuels had the least vibrations, and B10 fuel produced the highest extent of vibration (Heidary *et al.*, 2013). The results obtained from the present study are closer to the results obtained by Heidary *et al.* In another study, the use of mustard oil biodiesel fuel reduced the vibration of the engine due to the enhanced oxygen quality (Tüccar, 2021). In explaining the cause of the changes in engine vibration in the combination of different fuels, it can be said that since the cetane number of ethanol is lower than biodiesel and diesel and the cetane number of biodiesel is slightly higher than diesel, the cetane number of the fuel is affected by different fuel combinations. This indicates that a higher cetane number of the fuel correlates with a shorter ignition delay and leads to reduced cylinder pressure at the piston peak, which in turn increases engine vibration and knocking (Ağbulut *et al.*, 2020; Anand, Sharma, & Mehta, 2011; Debnath, Sahoo, & Saha, 2013; Emiroğlu & Şen, 2018; Radhakrishnan, Munuswamy, Devarajan, & Mahalingam, 2019).

The analytical results of RSM are shown in Table 2.

Table 2- Results of the analysis through RSM

Source	Sum of squares	df	Mean square	Value	Prob > F
Model	33.41834621	9	3.713149579	35.43764	< 0.0001
A-Biodiesel	1.830436943	1	1.830436943	17.46937	0.0005
B-Bioethanol	0.02233838	1	0.02233838	0.213194	0.6493
C-Engine speed	30.0939629	1	30.0939629	287.2115	< 0.0001
AB	0.105229453	1	0.105229453	1.004291	0.3282
AC	0.002668351	1	0.002668351	0.025466	0.8748
BC	0.281520349	1	0.281520349	2.68678	0.1168
A^2	0.117845216	1	0.117845216	1.124694	0.3015
B^2	0.446491739	1	0.446491739	4.261238	0.0522
C^2	0.795042817	1	0.795042817	7.587748	0.0122
Residual	2.095596278	20	0.104779814		

The coefficient of determination (R^2) in RSM was determined to be 0.9410. The real values of the mean of engine vibrations are illustrated in Fig. 3 versus the predicted values by RSM. The large and small graphs show the model's performance on the entire data set and the test set, respectively, comparing actual outcomes to predictions. Table 3 shows the performance of the best model in ANFIS. As specified in the table, although the correlation coefficient of the model for the test set is a little lower than that of the training set, the performance of the model is appropriate and acceptable compared to the entire data.

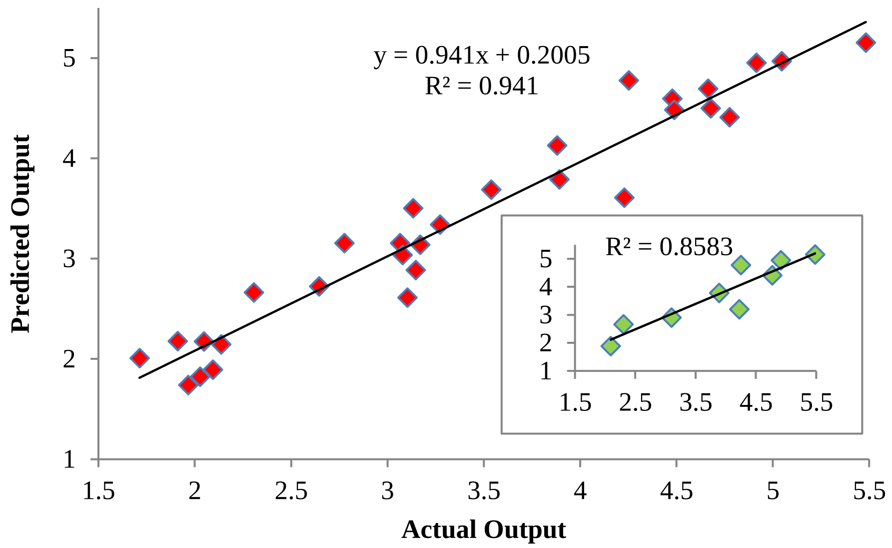

Fig. 3. Actual values and predicted values of mean vibration developed by RSM model; the smaller graph is for the test dataset

Table 3- Results of the best obtained ANFIS model

	Mean absolute error	Mean squared error	P-value	Correlation coefficient
Results for test data	0.338051	0.189907	0.000768	0.906
Results for total data	0.142017	0.077838	3.26×10^{-18}	0.967
Results for training data	0.001847	7.46×10^{-4}	4.77×10^{-44}	0.999

Fig. 4 demonstrates the real and predicted values of the mean of engine vibrations using the ANFIS model. Similarly, the large and small graphs are related to the entire data and test set, respectively, i.e., the performance of the model compared to the predicted status.

In general, the model derived from ANFIS is an appropriate model capable of investigating the effects of the input parameters on the vibrations of the engine. In addition, regarding the good performance of the model in the test, it can predict engine vibrations for various inputs that have not been tested already. The values of R^2 for the test set in RSM and ANFIS models were obtained as 0.86 and 0.82, respectively. A comparative analysis of the performance between RSM and ANFIS was conducted by plotting the residual graph, or model error, for both models, as illustrated in Fig. 5.

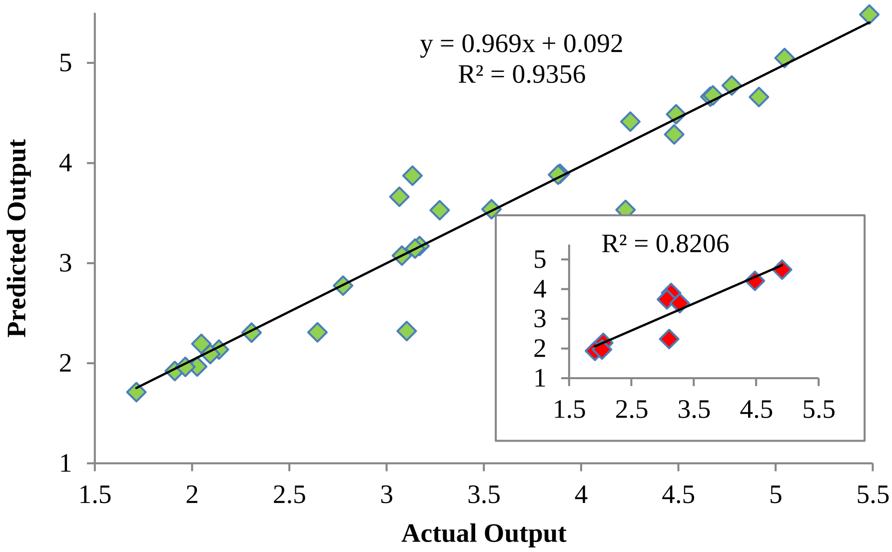

Fig. 4. Actual values and predicted values of mean vibration developed by ANFIS model; the smaller graph is for the test dataset

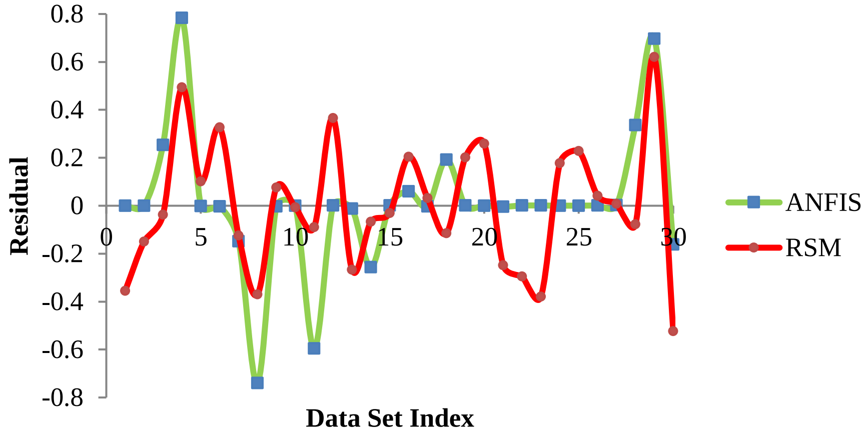

Fig. 5. The residuals graphs of ANFIS and RSM models

As shown in Figure 5, the error range of the ANFIS model was larger. However, the RSM model exhibited greater fluctuations in its error range, while the ANFIS model demonstrated impressively low errors in samples 19-27. Nevertheless, the performance of both models was acceptable and similar in many ways.

The disturbance graph of three input parameters compared to the mean of engine vibrations is shown for both models in Fig. 6. The figure depicts the interactions between the input parameters and the entire engine vibrations. The intersection of these graphs was their central point, indicating the mean variation range for each of the input parameters. Also, it showed interactions of the parameters as well as their effects on the mean of total vibrations, i.e., vertical axis. Also, the interactions between the input parameters can be studied, too.

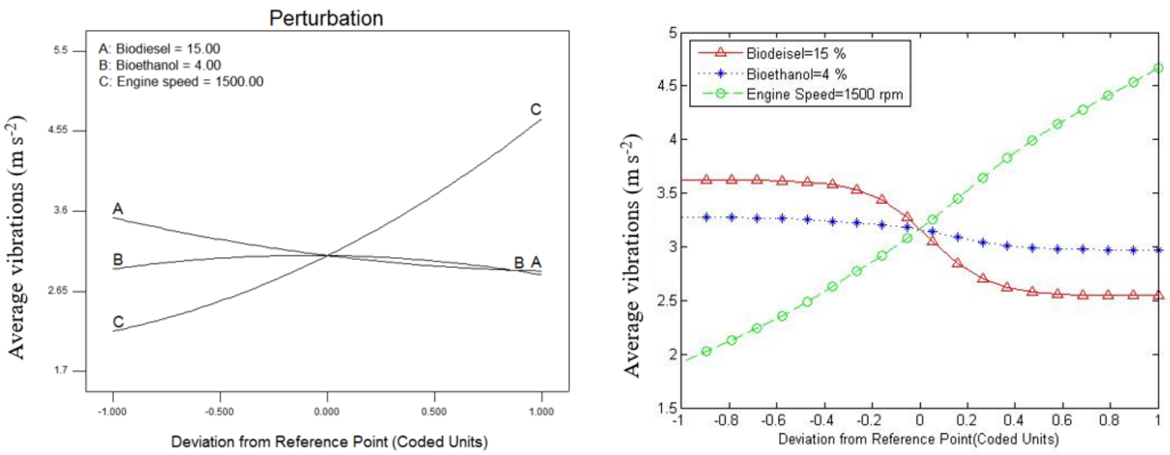

Fig. 6. The disturbance graph of the effects of the input parameters on the mean of engine vibrations

According to Fig. 6, increasing the engine speed yielded an increase in the mean of engine vibrations in both models, which was in good agreement with the results of previous studies. In both models, with the increase of biodiesel concentration, the mean of engine vibrations was reduced, which was in good agreement with the results of other studies (Patel *et al.*, 2016; Taghizadeh-Alisaraei *et al.*, 2012; Zöldy, 2011). In the RSM model, as bioethanol concentration increased from two to four percent, the mean of engine vibrations slightly increased. Moreover, as bioethanol concentration increased from four to six percent, the mean of engine vibrations was slightly reduced. These results are slightly inconsistent with the results of a study indicating that increasing the percentage of ethanol led to a permanent increase in vibrations of the engine. This might be attributed to the use of industrial ethanol instead of bioethanol or the ethanol blended with gasoline used in diesel engines. However, in the present study, a mixture of bioethanol, diesel, and biodiesel was used in a diesel engine (Keskin, 2010). It is worth noting that the slopes of the graphs of engine speeds in both models were much steeper than the slopes of those of both biodiesel and bioethanol graphs. In other words, the increase in vibrations due to a rise in the engine speed was higher than that by reducing the biodiesel and bioethanol concentrations. The effects of various parameters on the mean of engine vibrations are shown in the three-dimensional colored graphs in Figs. 7 to 9.

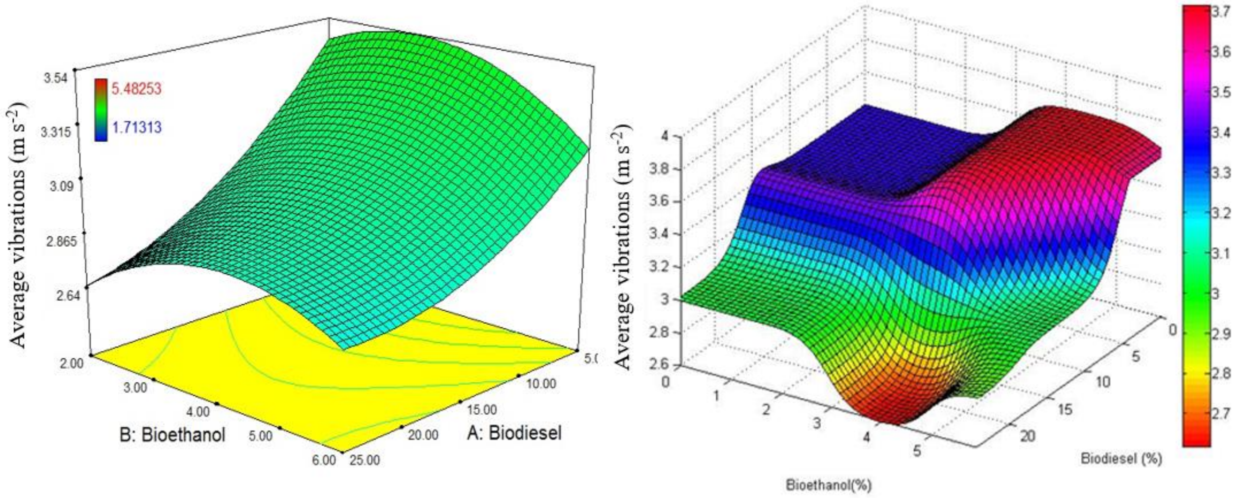

Fig. 7. Three-dimensional graph of biodiesel and bioethanol changes on average vibrations of the engine in ANFIS (right) and RSM (left) models

Fig. 7 shows that as bioethanol and biodiesel concentrations increased, the mean of engine vibrations was reduced. The highest vibrations occurred for the concentrations of bioethanol and biodiesel in the mixture of 4% and 25%, respectively. The critical point of vibration occurred once the fuel was composed of five percent biodiesel and four percent bioethanol ($B_5E_4D_{91}$), with the largest mean of engine vibrations of all fuel mixtures.

As seen in Fig. 7, increasing biodiesel concentration, the mean of engine vibrations was significantly reduced in both models. However, it is not possible to have the same interpretation on bioethanol since the mean of engine vibrations gradually increased and then decreased by increasing bioethanol concentration in RSM model. In ANFIS model, increasing bioethanol concentration percentage from zero to two, two to four, and four to six, the mean of engine vibrations almost remained constant, dropped, and increased, respectively.

The obtained results from the study conducted by Taghizadeh-Alisaraei and Rezaei-Asl (2016) showed that the addition of bioethanol to diesel fuel with 6% concentration, as compared with pure diesel fuel, increased the torque and engine power by an average of 8.3%. In comparison with pure diesel, applying this fuel mix increased the acceleration of the engine block by 4.79%, while an increase in bioethanol initially reduced the vibration. It seems that with an increase in bioethanol concentration in diesel fuel by more than 8%, the combustion delay will increase and the engine will operate irregularly. In other words, the pressure changes inside the cylinder and strokes occur. By increasing the concentration of bioethanol in pure diesel fuel, the vibration of the engine increases, which is in good agreement with the obtained results (Taghizadeh-Alisaraei & Rezaei-Asl, 2016).

As illustrated in Fig. 8, decreasing engine speed along with increasing biodiesel concentration, the mean of engine vibrations was reduced in both ANFIS and RSM models. The steep slope of engine speed-mean of engine vibrations diagram compared to the gentle slope of biodiesel-mean of engine vibrations diagram indicated that reducing the engine speed has more dominant effects on reducing vibrations. In 2017, Çelebi *et al.* showed that the vibration of the engine block increased by increasing engine speed, which corresponds to the result obtained (Çelebi *et al.*, 2017).

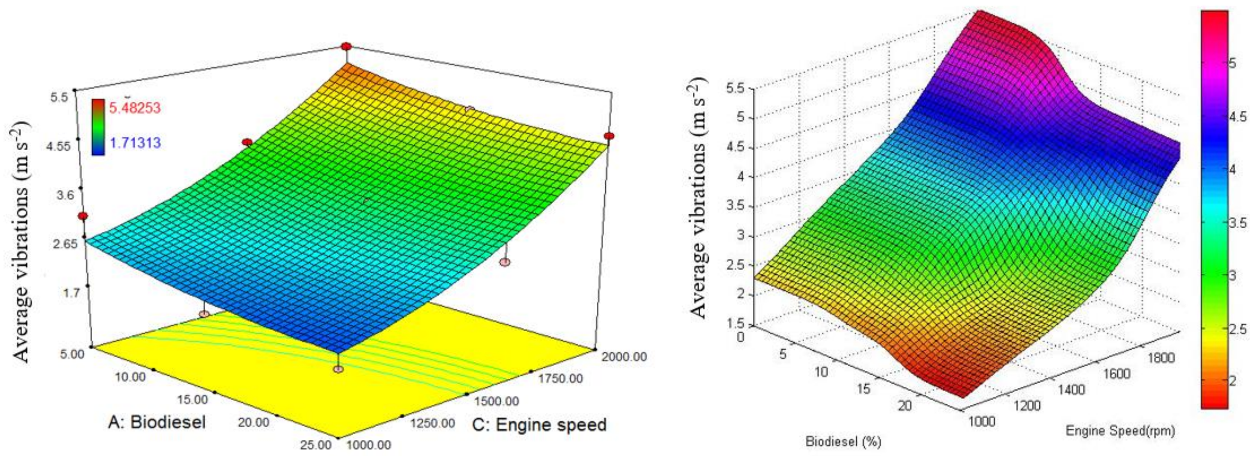

Fig. 8. Three-dimensional graph of biodiesel and engine speed changes on average vibrations of the engine in ANFIS (right) and RSM (left) models

As it can be observed in Fig. 9, in both models, the mean of engine vibrations increased with the rise of engine speed and fall of bioethanol. The lowest vibrations occurred for the concentration of bioethanol and engine speed of 4% and 1200 rpm, respectively. In 2016, Syed et al. investigated the effect of ethanol fuel mixes (E2, E5, E10, E15, and E20) on the vibrations of the engine block at the speeds of 1200, 1600, 2000, and 2400 rpm. They concluded that the lowest vibration of the engine block was for the E10 fuel mixture, while the highest vibration was for the E20 fuel mixture, which is in great agreement with the results of the present study (Javed, Murthy, Baig, & Rao, 2016).

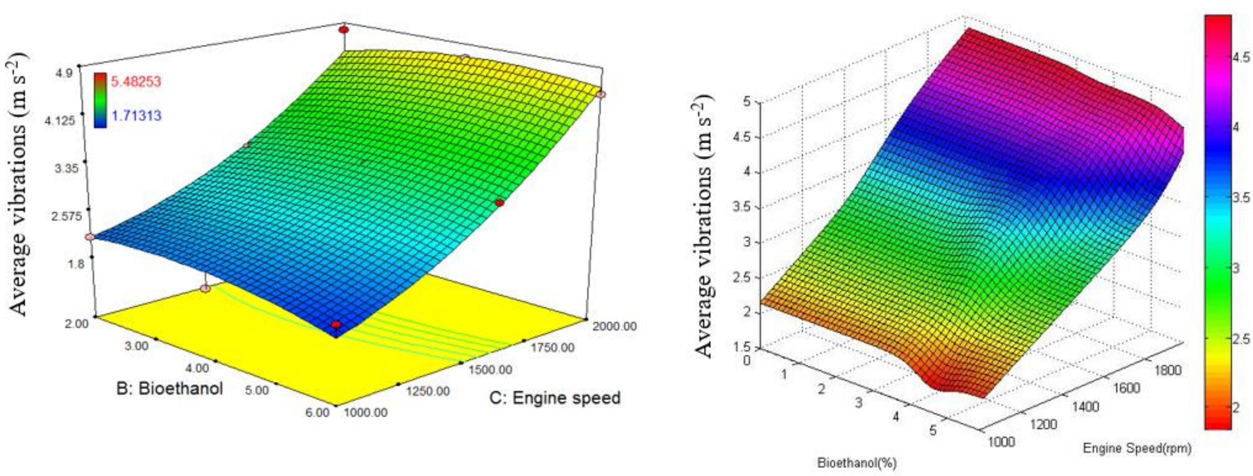

Fig. 9. Three-dimensional graphs of bioethanol and engine speed changes on average vibrations of the engine in ANFIS (right) and RSM (left) models

Results of RSM Optimization

In RSM optimization, to identify the best fuel combination with the lowest engine vibrations, the conditions represented in Fig. 10 were applied. In other words, the optimization was aimed to find an appropriate fuel combination with the lowest engine vibrations. In RSM, $B_{25}E_6D_{69}$ was selected as the appropriate fuel mixture. Regarding the maximum amount of biodiesel in the mixture, it could be inferred that the replacement of diesel fuel with biodiesel by 25% not only is possible but also can result in lower vibration effects.

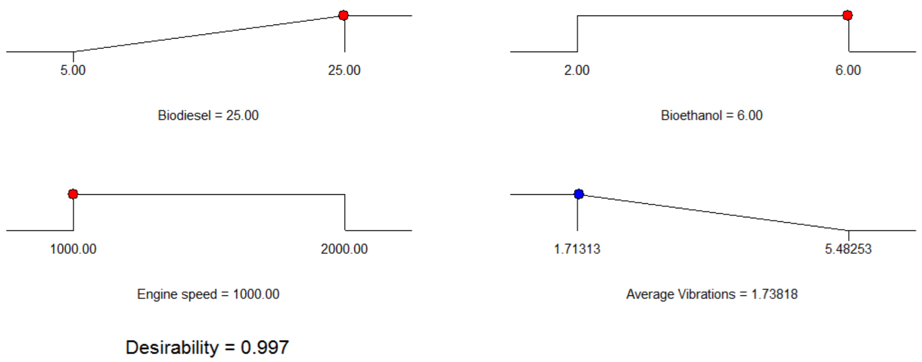

Fig. 10. The optimization conditions towards identifying the best mixture with the lowest engine vibrations

Conclusion

Regarding the limited sources of diesel fuel and substitution of organic oils or waste, the present study aimed to investigate the engine vibrations of MF285 tractor caused by replacing a part of diesel fuel with biodiesel produced from rapeseed oil and bioethanol. The effects of ten fuel mixtures, made from different combinations of diesel, biodiesel, and bioethanol fuels with different volumetric percentages over different periods, on the tractor engine vibrations were analyzed through ANFIS and RSM models. The obtained results revealed that as the engine speed increased, the vibrations dramatically increased. Furthermore, increasing the bioethanol concentration, the vibrations were diminished. However, by increasing bioethanol concentration, the vibrations increased to some extent and then dropped. To reach the lowest engine vibrations, the best fuels in RSM and ANFIS models were $B_{25}E_6D_{69}$ and $B_{25}E_4D_{71}$ fuels, respectively, in which the volumetric percentage of biodiesel was 25%.

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Authors Contribution

A. Safrangian: Data acquisition, Review and editing services

H. Javadikia: Supervision, Conceptualization, Methodology, Technical advice, Data acquisition, Data pre and post processing, Statistical analysis, Software services, Numerical/computer simulation, Validation, Visualization, Text mining, Review and editing services

L. Naderloo: Supervision, Conceptualization, Methodology, Technical advice, Data acquisition, Data pre and post processing, Statistical analysis, Software services, Numerical/computer simulation, Validation, Visualization, Text mining, Review and editing services

M. Mostafaei: Guidance on biodiesel production

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تأثیر ترکیب‌های مختلف بیودیزل، بیواتانول و گازوئیل بر ارتعاشات موتور تراکتور با استفاده از RSM و ANFIS

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چکیده

ارتعاشات ایجادشده در اثر استفاده از مخلوط‌های سوخت مختلف در موتور تراکتور می‌تواند منجر به سایش سریع قطعات موتور، افزایش قابل‌توجه هزینه‌های نگهداری و کاهش راحتی و ایمنی برای اپراتورها شود. امروزه سوخت‌های تجدیدپذیر، یعنی بیودیزل و بیواتانول، مورد توجه بسیاری از محققان قرار گرفته‌اند. در مطالعه حاضر، ارتعاشات موتور تراکتور MF285 در سه جهت، در دورهای ۱۰۰۰، ۱۶۰۰ و ۲۰۰۰ دور در دقیقه برای ده سطح سوخت مختلف حاصل از ترکیبات مختلف سوخت‌های بیودیزل، بیواتانول و دیزل اندازه‌گیری شد. برای تجزیه و تحلیل اثرات پارامترهای مربوطه بر ارتعاشات موتور، از روش سطح پاسخ (RSM) و سیستم استنتاج فازی شبکه عصبی مصنوعی (ANFIS) استفاده شد. نتایج به‌دست‌آمده نشان داد که افزایش دور موتور با افزایش ارتعاشات نسبت مستقیم دارد. علاوه بر این، سوخت دیزل خالص بخش عمده ارتعاشات را به خود اختصاص داده و B5E4D91 بیشترین ارتعاشات را در بین ترکیبات سوخت داشت. علاوه بر این، با افزایش بیودیزل در ترکیبات سوخت، ارتعاشات به‌طور معنی‌داری کاهش یافت. تحلیل بهینه‌سازی نشان داد که مؤثرترین سوخت‌ها، که کمترین سطح ارتعاش را نشان می‌دهند، از طریق RSM به نام B25E6D69 و از طریق ANFIS به نام B25E4D71 شناسایی شدند.

واژه‌های کلیدی: بیواتانول، سوخت زیستی، گازوئیل، لرزش‌سنج

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