Biodiesel production from tomato seed and its engine emission test and simulation using Artificial Neural Network

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ABSTRACT

In this study, tomato seed oil was used to produce Biodiesel fuel. To reduce the percentage of free fatty acids, the oil was reacted at a temperature of 40, 50, and 60°C with a mixture of sulphuric acid and the industrial methanol with different molar ratios of oil. The best conversion efficiency was achieved at 60°C and a molar ratio of 1:9. In the transesterification step, biodiesel was produced using a mixture of potassium hydroxide reactivity. Then, functional characteristics and pollutant gases of ordinary diesel fuel and mixtures of biodiesel at different speeds and loads were measured and compared. The tests were carried out in a 9-kV direct injection (DI) diesel engine. The results of analysis of variance by SPSS software showed that there was a significant difference in the level of R< 0.01 between the production of pollutants such as NOx, CO, HC, and other fume gases like CO_2 and O_2 at different speeds and loads. Duncan's multiple range test results also showed that the lowest emissions were generated from the B20 blend. An Artificial Neural Network (ANN) model which was used to predict the emission of the engine showed an excellent conformity with R-values of 0.99 for both the training and test data.

1. Introduction

The production of biofuels from renewable sources is not a choice but a necessity for today's human society (or civilization). The rising oil prices and the reduction of the existing reserves as well as the adverse effects caused by the increasing use of this type of energy has encouraged researchers to explore new sources of energy. On the other hand, the production of environmental pollutants such as unburned hydrocarbons, nitrogen compounds, carbon monoxides and carbon dioxide is one of the most undesirable isadvantages of fossil fuels. The best way forward is to produce clean and sustainable energy. The main difference between the biodiesel and the gas oil is its oxygen content. The amount of oxygen in the gas oil is zero, while biodiesel contains 10 to 12% by weight of oxygen, which reduces the energy density and reduces the release of the suspended particulates and results in biodiesel being considered a clean fuel. Biodiesel fuel has a larger density, viscosity, and ignition point than gasoline, but its thermal value is lower [1], [2].

It is produced as a result of the processing of tomatoes, which is about 3% by dry weight of the primary tomato. Approximately 50% of the tomato is the second most important vegetable crop in the world after potatoes, with an annual production of 100 million tons in 144 countries. Tomatoes are used to produce products such as puree, juice, tomato sauce, and tomato paste. The remaining residue and waste contain skin, seeds and other parts. It is not suitable for human consumption and is commonly used as animal feed [3]. Tomato seed is the major waste of the tomato paste industry and is considered to be about 71% -72% by weight of the total waste produced in this industry [4]. Also, poor quality tomatoes are separated as waste during the sorting process in the factory. In addition, pulp dry weight of the waste is tomato seed which contains an average of 29% protein and 22% fat [5]. Tomato waste may be consumed in animal nutrition or used in plant fertilisers [6]. Another study has indicated that seed contains about 24% oil [7]. In another study, tomato seed was found to contain 18-23% oil which can be used to make biodiesel [8], [9]. Despite the huge production of tomato waste and having about 24% oil in its seed, only a few studies have investigated the production of biodiesel from tomato seeds.

There has been a lot of research on the impact of using bio-diesel on reducing engine emissions. In a study, a 4-sycle diesel engine on diesel roads was tested using mixed doses of different biodiesel (10%, 30%, 50%) and pure biodiesel. It turned out that biodiesels are a natural-friendly alternative to conventional fuels. Research shows that CO emissions has dropped by 3 to 10 percent [10].

In a study on a six-cylinder Cummins ISBe6 diesel engine, direct spraying of five types of cotton seed, soybeans, rapeseed, dates and palm oil was used. The researchers found that the amount of fine particulate matter decreased. In fact, while the biodiesel waste oil had the highest reduction in the amount of fine solid, soybean biodiesel had the lowest reduction. Different biodiesels increased the amount of NOX on average by 23-10%. Biodiesel was the smallest cotton seed and biodiesel rape had the highest NOX. Also, all types of biodiesel have reduced the amount of CO and HC (Wu et al., 2009). Research has also shown that the use of biodiesel reduces the amount of unburnt hydrocarbons (UHC) carbon dioxide (CO_2), carbon monoxide (CO), sulfur oxides (SOX), and particulate matter released from the exhaust. In the meantime, there is only a small increase in nitrogen oxides (NOx) that can be reduced by adjusting the fuel injection timing [1], [12].

In 2017, Harish et al. [13] produced a biodiesel using tomato seed by transesterification method. They used a transesterification reaction of 75% NaOH at a temperature of 55 ° C. Next, they examined the amount of pollutants and the performance of a single cylinder engine at a constant speed of 1500 rpm and fuel mixture ratios of 0%, 5%, 10% and 15% at loads of 0%, 25%, 50% and 100% of the engine. This study was undertaken to produce biodiesel from tomato seed by considering the acidic number of the tomato seed oil. The acid number was reduced to less than 1% by the esterification method. In addition, the effect of the ratio of different methanol molecules on oil and different temperatures in both the esterification and transesterification stages was studied. The optimum state of production was obtained in three modes of reactor temperature and three different methanol molar ratios. Engine emission was investigated at three different speeds and different engine conditions at 0, 5, 10, 15, and 20% diesel and biodiesel mixture ratios. Finally, computer simulations were performed using ANN model.

2. Transesterification Process for Biodiesel production

The most commonly used method for biodiesel production is transesterification (esoteric exchange), in which a mixture of oil and alcohol, in the presence of a catalyst form of mono alcoholic fatty acid, converts to the biodiesel and glycerine. In this reversible process as shown in Figure1, methanol is most commonly used because of lower prices and better physical and chemical properties (shorter molecular chains and polarity) than other alcohols. Vegetable oils are better raw materials for biodiesel production than other oils and fats, because, in less time, the conversion efficiency of triglyceride to methyl ester is much higher than Basic reactants. Also, acids and enzymes can act as mediators in the reaction. But basic and acidic compounds are more applicable since they shorten the reaction time and cost less. Also, some studies have shown that the enzymes are sensitive to methanol, so the methanol concentration in the mixture should be lower [14].

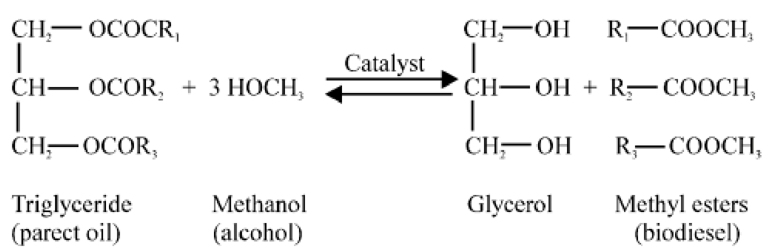


Figure1. Diagram of a chemical reaction of an overall transesterification of a vegetable oil [15].

To determine the type of reagent (e.g. acidic or basic) to be used in the reaction, the percentage of free fatty acid oil must be first determined. Research has shown that alkaline catalysts react with free fatty acids to produce water and soap. The produced soap disrupts biodiesel separation from glycerine and provides emulsion during leaching. Therefore, it is used in cases where the percentage of free fatty acid is less than 0.5% [16]. In the case of high free fatty acid, a two-stage esterification method should be used to produce biodiesel. Maghami et al. [17] found that oil with acidity less than 2 mg KOH/g is suitable for biodiesel production. Using the base catalyst for transesterification with waste oil with different amounts of acid, they showed that the oil with acidity less than 2 mg KOH/g affects the performance of the reaction. For acidity values less than 0.75 mg KOH/g oil, acidity has no significant effect on the reaction performance. They also found that by increasing the acidity from 1.0 to 3.5 KOH/mg, the oil yield decreased continuously, which is due to the formation of soap. This is caused by the reactions of KOH and free fatty acids. Maghami [18] reported that for acidity of over 3.5 mg KOH/g oil, no separation occurs in the reactor. They carried out the experiments with 1% KOH wt. as catalyst, MR, molar ratio of 1: 6 methanol and temperature of 55°C for 1 hour were performed. When the base oil acid is more than 1%, the use of two-step reactions (esterification/ transesterification) can be more practical. In this method, at the first stage of the process, using an acid and alcohol reactor, the free fatty acid oil is converted to the ester and its weight is reduced to less than 1%. The output products at this stage are triglyceride and ester. In the second step, given that the acidic index of the oil is reduced to less than 1 percent, it is possible to produce biodiesel by using a mixture of oils and alcohol in the presence of a catalyst. The output product at this stage is the fatty acid esters (biodiesel) and glycerine. Different studies have been done on the production of biodiesel from high acidity oils using the two-stage esterification. Bavafa et al. [19] produced biodiesel in a two-step esterification method using poultry fat oil containing free 35.88% fatty acid. In the first step, the oil was reacted for 2 hours with a mixture of 2% w/w of ferric sulphate and industrial methanol with a molar ratio of 1: 9 to oil at 60°C. Then, in the second step, from the mixture of ester and triglyceride, with methanol, in the presence of a potassium hydroxide reagent, biodiesel was produced. Maghami et al. [18] produced biodiesel from fish oil wastes. In the first step, they reduced the oil acidity by sterilisation. Next, the oil was reacted with sulphuric acid 1% by weight of oil, and industrial methanol with a molar ratio of 1: 9, 1: 6, 1: 3 to oil, at 40, 50, 60 ° C, for one hour. They concluded that the best efficiency of 87% of ester production was obtained at 60°C and a 1: 9 molar ratios. Then, in the second step, from the mixture of ester and triglyceride with methanol, biodiesel was produced in the presence of potassium hydroxide.

3. Materials and methods

3.1. Materials

About 15 litres of oil was extracted from around 50 to 60 Kg of the fresh tomato seed by Seed Oil Company. H_2SO_4 with 98% purity, methanol with 98% purity and KOH with 86% purity were also purchased from the chemical store of Tarbiat Modares University, Tehran, Iran.

Each vegetable oil is a mixture of fatty acids that affects its molecular weight. Similarly, it is necessary to know the composition of these fatty acids to calculate the methanol molar ratio for storing. Fatty acid compounds are reported in Table1 using the method reported in [20]. The molecular weight of oil (MW Oil) was calculated using methyl ethyl fatty acid (FAME) compounds by using equation (1) (Giuffrè, 2017):

$$MW\ Oil = \frac{\sum_{i=1}^{n} xi\, MWxi}{100} \quad (1)$$

Where x_i is the mass fraction (in %) of the individual FAME and MWx_i is the molecular weight of the individual FAME.

Table1. Acid composition and molar mass weight of the tomato seed oil used in the transesterification [20].

Fatty acid	%	Mass weight (G mol^{-1})	Mass Fraction(G mol^{-1}
C14:0	.11	228.37	0.30
C16:0	14.66	256.42	35.47
C16:1	.20	254.40	1.08
C17:0	.07	270.45	0.25
C17:1	0.00	268.43	0.97
C18:0	4.82	284.47	12.94
C18:1	20.44	282.46	54.89
C18:2	57.42	280.44	163.96
C18:3	1.88	278.42	6.24
C20:0	0.34	312.53	1.15
C20:1	0.06	311.51	0.31
Total molar mass weight			277.56

3.2. Experimental Set-up and Procedures

To produce biodiesel, a double-glazed glass reactor with 8 litres capacity was used at Tarbiat Modares University New Research centre, Renewable Energy Laboratory, and Biodiesel Division. Glass reservoirs were used to prevent corrosion due to the use of high temperature chemicals to produce and purify biodiesel (see Figure 2a-d).

(a) (b) (c) (d)

Figure 2. Glass Reactor: (a) Transesterification step (b) Separation of 2 phases (c) leaching step (d) Separating water from biodiesel

In order to accelerate the reaction speed, its temperature was increased to near the methanol boiling point [21]. For this purpose, a circulator connected to the temperature setting device circulated the water at a suitable temperature between the two glass walls. Adding a mixture of alcohol and reactant to oil caused the mixture to become non-homogeneous, and the desired reaction was performed only at the contact level of the two phases. Therefore, an electric mixer was used to mix the materials during the reaction. In addition to making the mixture homogeneous, mixing the materials also helped the heat transfer [22] (see Figure 2a).

3.2.1 Transesterification Step

The water and Free Fatty Acid (FFA) contents are critical factors for the transesterification reaction. Base-catalysed transesterification reaction requires water free and low acid value (< 1) raw materials [23], [17]. These kinds of oil can be esterified by acid catalyst, but this is not economical because of the high reaction time and more methanol to oil molar ratios [24]. The literature shows that, to reach the ester content of 92 wt. % from lard wastes, it is necessary to use an acid catalyst of 5 wt. % and the reaction time will be about 3 hours [17]. For animal waste fat, 9 wt. % of acid catalyst and 48 h of reaction time has been reported to reach 90% methyl ester [25]. In fact, the transesterification reaction requires 1% of the weight of the oil to the KOH. The presence of water and free fatty acids in methanol or oil causes excessive consumption of KOH and its efficiency decrease. This phenomenon causes the reaction speed to slow down and not complete it at the expected time [18]. Even if the water in the oil and methanol is generally eliminated, the amount of free fatty acids should be calculated to determine the required KOH. The amount obtained for KOH was 1% by weight of added oil. For titration of waste oil, a pH meter was used. The applied method was as follows: Initially, 1 cc of tomato seed oil was dissolved in 10 cc of propanol alcohol and 1 g of KOH was added to the mixture by an automatic burette and the pH was read after mixing. When the pH reached a neutral level, (i.e., pH = 7), the amount of solution added by the burette was measured. The resulting volume specifies the required KOH value [26]. In this study, a Basic 20 pH-meter (Crison Instruments, Spain) was used to measure the pH of the solution. With three replications, the mean potassium used in the solution was calculated and the acidic number and oil acidity were calculated [27]. The acidity of the oil was determined as 18%, and since acidic number was higher than 5%, the stage of esterification should be carried out in two steps.

3.2.2 Esterification step

Based on the results of the titration test, the amount of free fatty acid was 18%. First, in this step, the free fatty acids in the oil reacted with methanol in the presence of sulphuric acid. Then, it was converted to methyl ester. The oil reacted with a mixture of sulphuric acid 1% wt. of oil and industrial methanol with different molar ratios of 1:3, 1:6 and 1:9 to oil at 40, 50 and 60°C for 1 hour. After the completion of the reaction, it was allowed for 72 hours to separate the main product (methyl ester and triglyceride) from the sub-products (water, sulphuric acid, and alcohol) as shown in Figure 3a [19]. After separating the main reaction products, a sample of the main ingredients was prepared and the percentage of free fatty acids was determined by titration. The results as shown in Figure 4 indicate that the highest acidic number reduction which was found about 95.7% was 0.77 KOH / g at 60°C and in a 1:9 molar ratios which was suitable for the Esterification reactions (Figure 3).

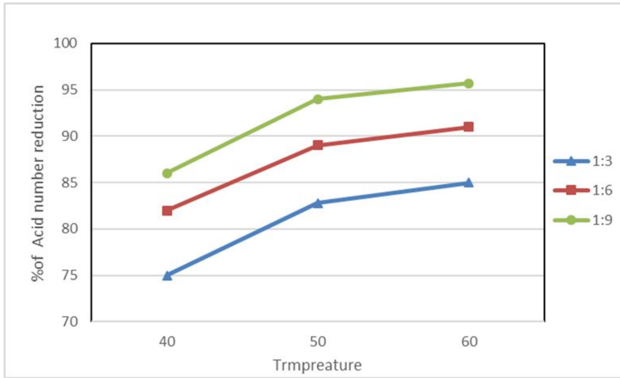


Figure 3. %Acidic number reduction based on temperature

3.2.3 Dissolving the KOH in alcohol

Given that KOH is solid, it must be soluble before entering the reaction. To do this, potassium hydroxide tablets are dissolved in methanol. With pure Methanol, the transesterification reaction will not be complete and the production efficiency will be less [26]. Dissolving KOH in alcohol is an exothermic reaction which causes severe alcohol evaporation. Therefore, the KOH dissolution ventilation system should be used in alcohol. For dissolution efficiency, a magnetic stirrer was used to prevent the high evaporation of methanol. In this study, a magnetic stirrer (MR3001, Heidolph Germany) was used to dissolve potassium hydroxide in methanol (see Figure 4). The amount of KOH used according to the acidic number of the oil is indicated by equation (2) below:

$$\left(\%FFA\frac{0.197}{\text{Purity of KOH}}+1\%\right)\times \text{ Oilwt} \quad (2)$$

The most appropriate amount for a transesterification reaction is a molar ratio of 1:6, which is 6 mole methanol per mole of oil [18].

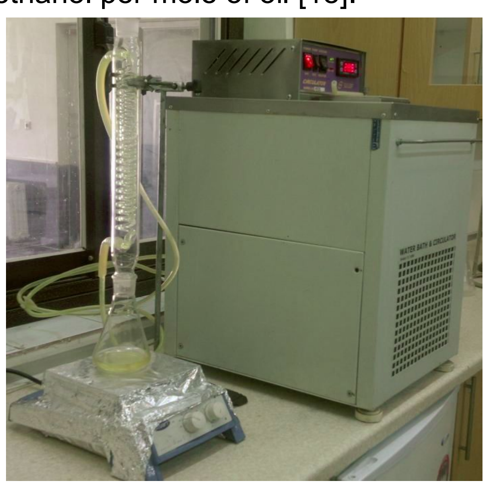


Figure 4. Circulator

After determining the amount of methanol and potassium hydroxide, the KOH, 1% by weight, was first dissolved in a methanol with a magnetic stirrer in methanol with a molar ratio of 1:6 molar. The oil was then prepared for the reaction and reacted to the optimum temperature. Then, the alcohol and the catalysts which had been mixed together were slowly added to the oil to form no soap. In the next step, the transesterification reaction was carried out at a temperature of 55°C at a rate of 24 rpm by the stirrer. In order to carry out the reaction of a sterile exchange, an 8-liter reactor containing a condenser, a thermal jacket and a water inlet was used. The temperature inside the reactor was controlled during the reaction. Balat and Balat [28] stated that some key variables such as reaction time, molecular ratio of alcohol to oil, temperature and pressure of reaction, catalyst, water content and free fatty acid amounts in fats and oils are effective in the transesterification. The authors mentioned that the global accepted alcohol ratio was about 6:1 molar glyceride at 1.30 in time. In another study by Maghami et al. [18], it was found that 87% of methyl ester and 79.86% of the yield can be achieved under optimum conditions of temperature of 55°C, catalyst loading of 1% by weight and a molar ratio of 6:1 for methanol. In this test, the molar ratio of oil: methanol (6:1) was considered constant and the catalyst content was considered slightly more than 1% according to formula 2 [17]. The temperature was also considered to be 55°C. The reaction time was also considered 1.30 minutes. The main reaction product was biodiesel (light yellow) which was separated from glycerine (dark colour) using the end of the reactor valve (Figure 2b). The time required for the complete separation of the 2 phases was 96 hours.

3.2.4 Biodiesel purification step

During the transesterification reaction, impurities such as residual alcohol, catalysts, free glycerol, water, metals, soap, as well as undesirable glycerides such as mono, di, and triglycerides and free acetic acids are produced in the final product of this reaction. The presence of these impurities in the biodiesel fuel will have an adverse effect on the diesel engine. The biodiesel processing and the purification stage are essential for the production of fuel in accordance with the ASTM standard. Different purification methods such as component distillation, leaching (washing) and dry cleaning methods are used. The most common method for purifying biodiesel is leaching which requires water and time. The essence of the leaching method is the use of water to increase the concentration of biodiesel. So, in this step, the method of leaching was used to remove the biodiesel impurities, including catalyser, alcohol, soap and glycerine. For this purpose, each litre of oil was mixed with half a litre of distilled water and allowed to stand for 30 minutes to obtain a homogeneous and milky mixture. The milky mixture was next transferred to the funnel to separate the water and the biodiesel phases. After 48 hours, the biodiesel was clearer than the previous one. This process was repeated in three stages. After the purification of biodiesel, its important characteristics were measured in the Bioenergy Laboratory of

Tarbiat Modares University. The clarity of the waste water from the leaching is a good measure for the completion of the work as seen in Figure 2c [29]. In order to ensure the separation of methanol, the phase was washed three times with distilled water at 50°C [30]. After the completion of the leaching process and in order to capture biodiesel, it was placed in the oven at 60-70°C for 5-6 hours. As the temperature rises, molecules of water sticks together more easily and quickly and become larger droplets. Due to the difference in density between water and biodiesel, water is deposited and separated from biodiesel (Figure 2d). Upon the completion of these steps, if the biodiesel specifications were consistent with the standards such as B, it may be used as biodiesel fuel, both 100 DIN V and 51606 ASTM D6751-09, 14214-08.

4. Biodiesel properties

The specifications of the produced biodiesel were evaluated based on the standard tests in the ASTM table and are presented in Table 2. Based on Table 3 and equation (3), the amount of methyl ester in the biodiesel was 90.18%.

Table 2. Biodiesel specifications according to ASTM standard

No	Test Name	unit	Result biodiesel	Limit range	Test Method
1	Iron (Fe)	ppm	20.4		ASTM D6595
2	Chromium (Cr)	ppm	0		ASTM D6595
3	Aluminium (Al)	ppm	0.4		ASTM D6595
4	Copper (Cu)	ppm	0.2		ASTM D6595
5	Lead (Pb)	ppm	0.9		ASTM D6595
6	Tin (Sn)	ppm	0.4		ASTM D6595
7	Nickel (Ni)	ppm	0		ASTM D6595
8	Titanium (Ti)	ppm	0		ASTM D6595
9	Silver (Ag)	ppm	0		ASTM D6595
10	Molybdenum (Mo)	ppm	0		ASTM D6595
11	Silicon (Si)	ppm	3.5		ASTM D6595
12	Sodium (Na)	ppm	2.2		ASTM D6595
13	Boron (B)	ppm	0.5		ASTM D6595
14	Vanadium (V)	ppm	1.1		ASTM D6595
15	Zinc (Zn)	ppm	0.3		ASTM D6595
16	Phosphorus (P)	ppm	0		ASTM D6595
17	Calcium (Ca)	ppm	13.3		ASTM D6595
18	Barium (Ba)	ppm	0		ASTM D6595
19	Magnesium (Mg)	ppm	0.8		ASTM D6595
20	Kin. Viscosity @40°C	cSt	5	1.9-6	ASTM D445
21	Density - @15 °C	Kg/m3	883	max 900	ASTM D4052
22	Cloud Point	°C	12	min -7	ASTM D2500
23	Flash Point (Closed Cup)	°C	190	min 130	ASTM D93
24	TAN	mg KOH/g	0.74	max 0.8	ASTM D974
25	Water & Sediment	vol.%	0.05	max 0.05	ASTM D96 - D2273
26	Copper Corrosion	100 °C	1a		ASTM D130
27	Sulphated Ash	wt%	0.02	max 0.02	ASTM D874
28	Sulphur	ppm	172 ppm		ASTM D4294
29	Cetane Index	0	47.7	min 47	ASTM D976
30	Ramsbottom Carbon Residue	%wt	0.05		ASTM D524

The chromatogram of TSO methyl ester shows the presence of derivatives of C16:0 (palmitic acid), C18:0 (stearic acid), C18:1 (oleic acid), C18:2 (linoleic acid), C18:3 (linoleic acid), C20:0 (eicosenoic acid), C22:1 (behenic acid) and C22:2 (erucic acid) (Figure 5). The chromatogram of PSO biodiesel confirmed the formation of methyl ester [31]. Based on Table 3 and equation (3), the amount of methyl ester in the biodiesel was 90.18%.

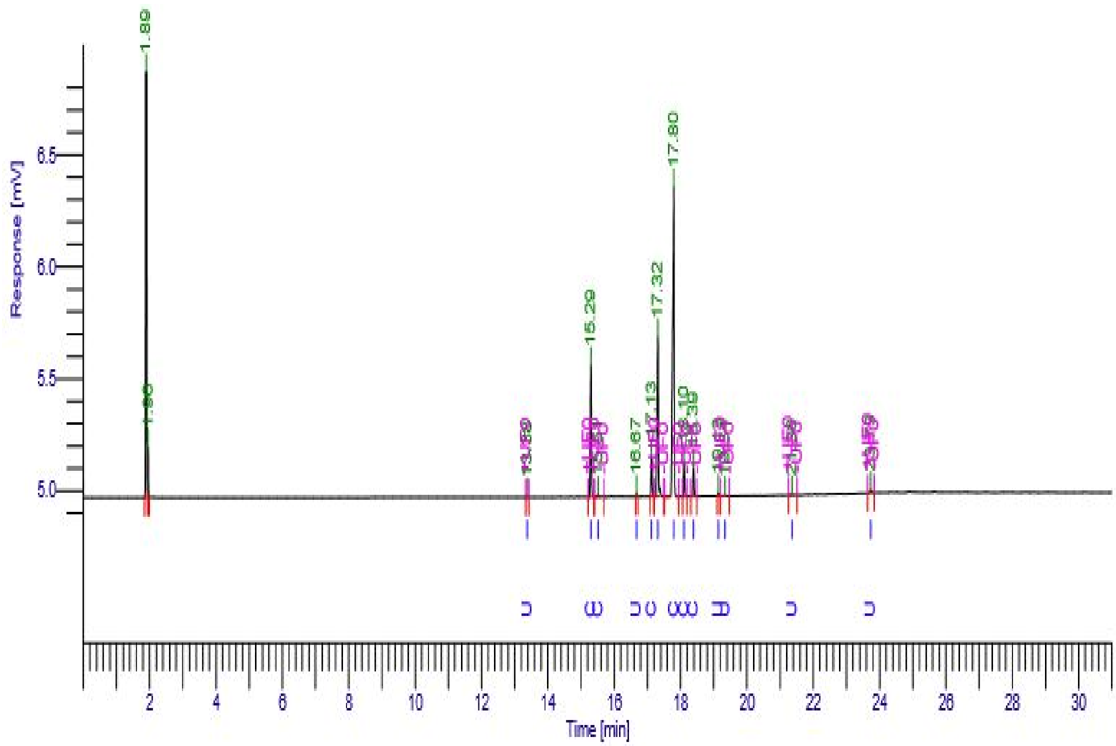


Figure 5. Chromatogram of TSO methyl ester

$$C = \left(\frac{\text{A total} - \text{A is}}{\text{A is}}\right) \times \left(\frac{Wis}{\text{Ws}}\right) \times 100 \quad (3)$$

Where: A is= A internal standard= (A) C19, W is=2.11 mg and W sample=58.7 mg

Table 3. Composition and molar mass weight of the TSOB

Peak	Component Name	Time (min)	Area (uVsec)	Height (uv)	Area (%)
3	un Known38	13.377	10.11	5.71	0.11
4	C16:0	15.293	1143.29	588.75	12.89
5	C16:1	15.512	23.41	11.07	0.26
6	un Known33	16.670	28.76	14.63	0.32
7	C18:0	17.130	434.93	177.47	4.9
8	C18:1	17.316	1875.68	711.66	21.15
9	C18:2	17.799	4632.33	1382.6	52.24
10	C19:0	18.101	339.92	158.45	3.83
11	C18:3	18.388	273.27	130.08	3.08
12	un Known37	19.134	32.8	14.86	0.37
13	un Known39	19.340	14.7	4.2	0.17
14	un Known40	21.364	9.22	3.61	0.1
15	un Known43	23.272	49.75	12.19	0.56
			8868.16	3215.29	100

5. Engine emissions testing

In this research, the effects of different engine loads (no load, 50% load and full load) and a minimum rpm of 1800 rpm, 2150 rpm and 2500 rpm were evaluated for engine emissions using different biodiesel / diesel ratios (0% BD, 5% BD, 10% BD, 20% BD (LOMBARDINI 3LD510 engine). The MAHA-MGT5 machine was used to measure pollution and greenhouse gas of the engine. This machine was able to determine CO, CO_2, and HC values using the infra-red technology, and also the values of O_2 and NOx gases using the chemical sensors.

5.1 Specifications of 3LD510 LOMBARDINI engine

The 3LD510LOMBARDINI engine used for the test is shown in Figure 6. The specifications of the engine are shown in Table 4.

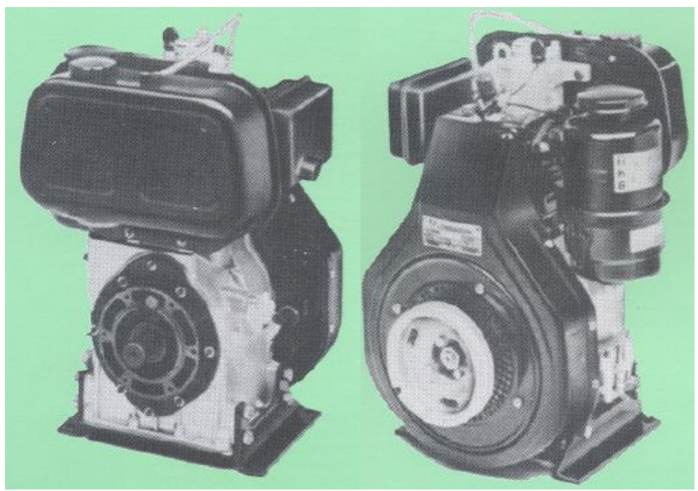


Figure 6. LOMBARDINI 3LD510 engine tested [32]

Table 4. Specifications of the 3LD510LOMBARDINI engine [32]

Model	LD510LOMBARDINI3
manufacturing factory	LOMBARDINI Italy Company
Number of cylinders	1
Cylinder Course	90mm
Cylinder diameter	85mm
Total cylinder volume	510cc
Maximum power	9KW
Maximum torque	33NM

The results of analysis of variance of pollutants and greenhouse gases (Table 5) showed that different loads, speeds and different ratios of fuel had a significant effect on the amount of CO, CO_2, HC, NOx, and O_2 gases ($p<0.01$). Also, using Duncan’s multi-range test, the highest and lowest mean values were determined.

Table 5. Results of variance analysis of the effect of %Blend, Load, Speed

Source	DF	Mean Square				
		CO correct	CO_2	HC correct	O_2	NO
BD	3	24.81**	31.95**	2219040.95**	2.96**	64319.98**
Load	2	669.09**	775.16**	28165218.00**	1532.40**	630839.47**
Speed	2	8.55**	92.00**	1307963.50**	94.08**	9824.30**
BD*Load	6	20.55**	9.80**	688864.33**	15.10**	53651.38**
BD*Speed	6	29.60**	40.40**	791808.76**	60.26**	15896.44**
Load*Speed	4	19.33**	9.02**	694088.35**	15.12**	43066.10**
BD*Load*Speed	12	15.74**	20.71**	307292.29**	35.83**	14144.06**
Error	1988	0.00**	0.00**	1602.66**	0.00**	40.66**

** There is a significant difference, at a probability level of 0.01. * There is a significant difference, at a probability level of 0.05

5.2 Engine emissions results and analysis

Figure 7 shows that with the increasing load in the range of 0, 50% and 100%, the amount of NOx increases and has an increasing trend. Figure 8 shows that with the increase in speed, NOx emission rate increases with the highest average value related to the fuel with 20% biodiesel. It means that in average speed B20 releases NOx 53% more than B0. Higher oxygen content in biodiesel enhances the formation of NOx, which is generally accepted. Labeckas and Slavinskas [33] investigated the relationship between NOx values and mass percent of fuel oxygen on a 4-stroke, 4-cylinder, WC, DI, NA diesel engine experimentally. NOx formation increases as load is increased [34], which is the result of higher combustion temperature caused by the higher engine load.

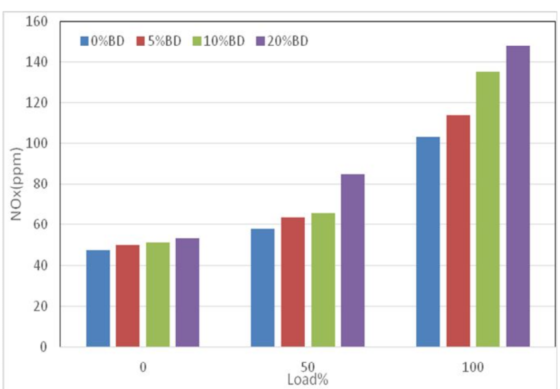


Figure 7. NOx changes over load changes

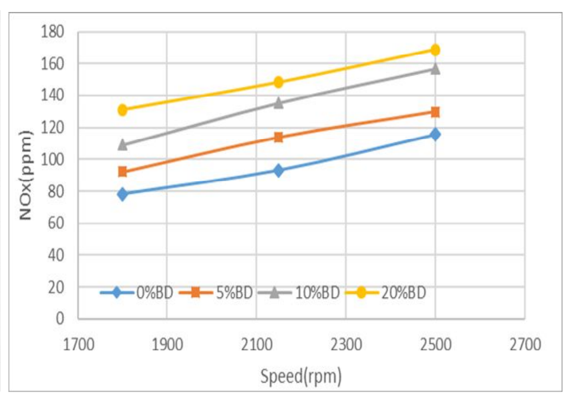


Figure 8. NOx changes over speed changes

Figure 9 shows that, by increasing the load at 0, 50% and 100%, the amount of CO decreases. The remarkable thing is that, at the fuel ratio of 10%, there are the least carbon monoxide emissions. Figure 10 shows that, as the speed increases, the amount of CO emissions decreases 35%, and the highest average value is related to the fuel, which has 20% biodiesel.

The extra oxygen content of biodiesel promotes the complete combustion, and thus leads to the reduction in CO emissions [35]. Biodiesel has a higher cetane number, which results in the lower possibility of formation of rich fuel zone and thus reduces the CO emissions. This viewpoint was indicated in [36].

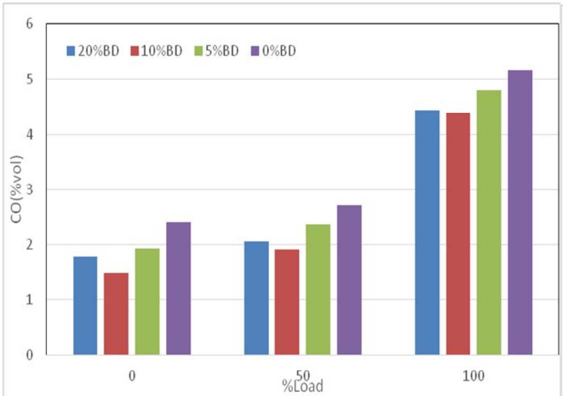


Figure9. CO changes over load changes

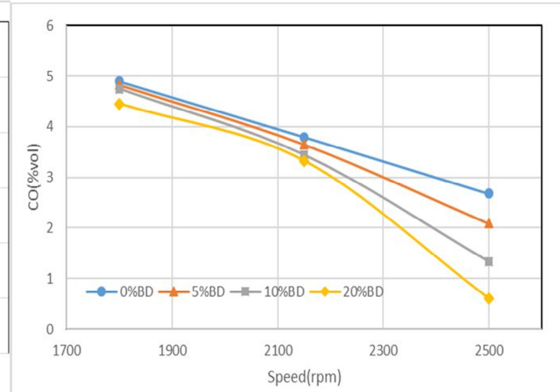


Figure10. CO changes over speed changes

Figurer 11 shows that by increasing the load in the range of 0, 50% and 100%, the amount of CO_2 greenhouse gas decreases. It is noteworthy that, at the fuel ratio of 10%, the lowest carbon dioxide emissions are achieved in the range of 0 and 50%. Figure 12 shows that by increasing speed, the amount of CO_2 emissions increases and the lowest average value is related to the fuel that has 5% biodiesel equal 43% of B20.

Because the contribution rate of traffic on CO_2 emissions is as high as 23% [37], some authors have studied CO_2 emissions of biodiesel. Ozsezen et al. [38] reported that biodiesel resulted in lower CO_2 emissions than diesel during the complete combustion caused by the lower carbon to hydrogen ratio.

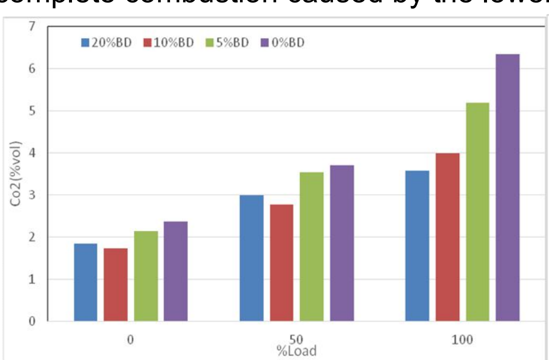


Figure11. CO_2 changes over load changes

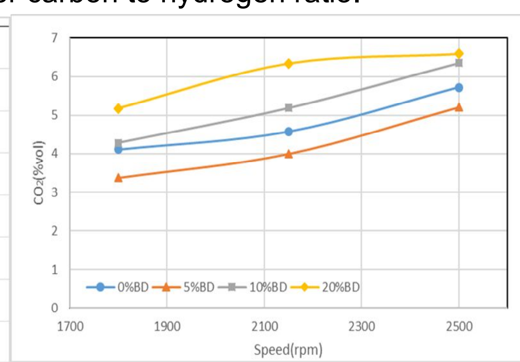


Figure12. CO_2 changes over speed changes

Figure 13 shows that by increasing the load in the range of 0, 50% and 100%, the amount of HC decreases. It is noteworthy that the lowest HC emissions occur at the fuel ratio of 5%. Figure14 shows that by increasing speed, the amount of HC emissions decreases, and the lowest average value is achieved with the fuel that has 20% biodiesel which is 13% less than B10.

The feedstock of biodiesel and its properties have an effect on HC emissions, especially for the different chain length or saturation level of biodiesels. The advance in injection and combustion of biodiesel favours the lower HC emissions [34].

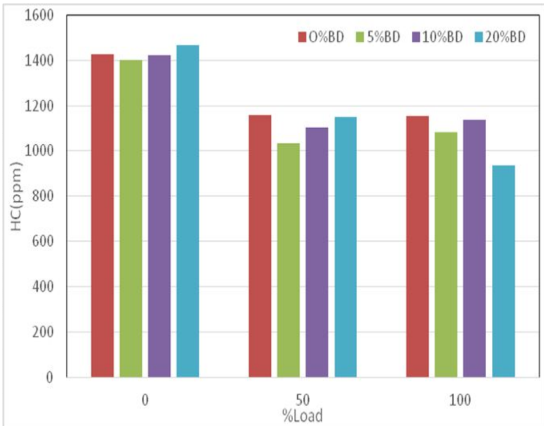


Figure 13. HC changes over load changes

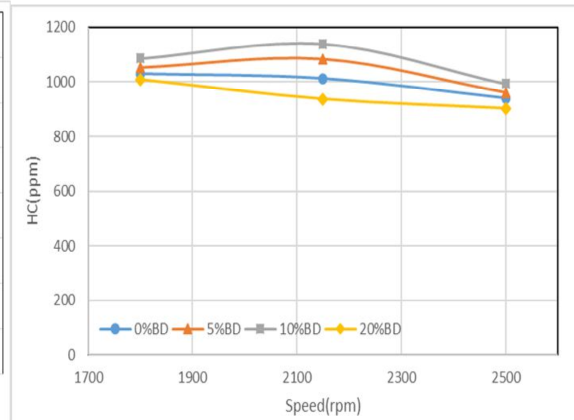


Figure 14. HC changes over speed changes

Figure 15 shows that by increasing load in the range of 0, 50% and 100%, the value of O_2 decreases. The lowest O_2 was found at the fuel ratio of 20%. Figure 16 shows that, by increasing speed, the amount of oxygen in the output decreases, and the lowest average value is related to the fuel that has 20% biodiesel that is 10% of B0. By increasing torque, O_2 decreases slightly for each biodiesel fuel [39]. Huzayyin et al. [40] concluded that O_2 is reduced for biodiesel by increasing engine temperatures and more complete combustion due to the increased engine load. Also, Kumar et al. [41] concluded that the percentage of O_2 decreases by increasing torque.

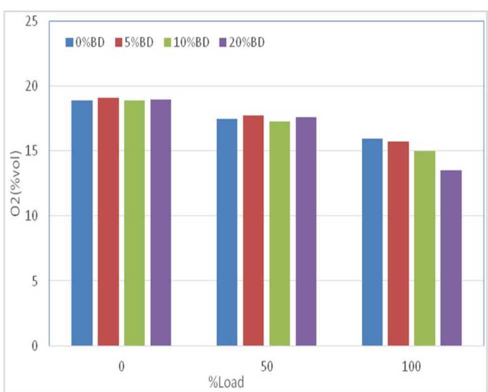


Figure 15. O2 changes over load changes

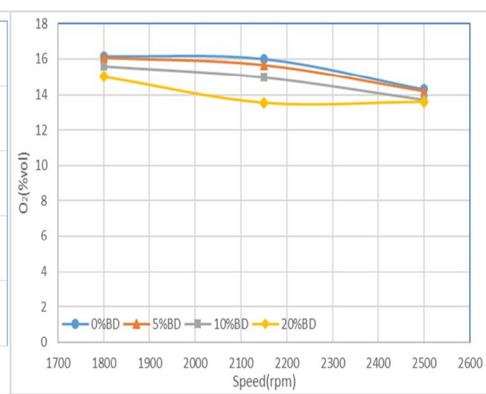


Figure 16. O2 changes over speed changes

5.3 Comparison of experimental and predicted emissions using Artificial Neural Network (ANN) model

The prediction of emissions was performed by a multilayer perceptron network, which was chosen because it is one of the most elementary forms of neural network structures. This network has three layers: one is input layer, the other is hidden layer and the last one is the output layer. Input data sets and corresponding target sets are used to train and test neural networks. The next step consisted of ANN training. The learning rule of an ANN, also called the training algorithm, is a procedure for modifying the weights of a network, ωij, to decrease the error between the desired target values and the experimental output. Input and output pairs are offered to the network and then the error between the network output and actual value are minimized by adjusting weights. To develop an ANN model, the available experimental data set was divided into two sets, one was used for training the network (80% of the data), and the generalisation capability of the network was verified by the remaining data [42]. The mathematical background of the ANN, training and testing procedures were presented by Kumar et al. [43]. By completing the training, predictions from a new set of data can be done by using the already trained network. The input parameters are engine load, percentage of blending diesel and biodiesel and engine speed, and the output parameters are, CO, CO_2, HC, O_2 and NO_x emissions. The Neural Networks Toolbox of MATLAB 2017b was used to develop the network. In this simulation, we used The Tangent-sigmoid transfer function in the hidden layer (first layer) and output layer (second layer). The neuron number in the input layer of the network was determined by the number of system inputs and its number of outputs characterizes the neuron number in the output layer of the network. Thus, input layer of network had three neurons and the output layer had five neurons. Ten neurons were used in the hidden layer. The range of both the input and output values which are used by Neural network should be between 0.1 and 0.9 in order to increase the accuracy of prediction. The following formula can adjust the range of input and output data to be in between 0.1 and 0.9.

$$\frac{Value - Min}{Max - Min} \times (High - Low) + Low \tag{4}$$

This equation is a commonly used method for the unification of test and target data. Where, minimum is the minimum value of the data set, maximum is the maximum value of the data set, high is the maximum normalised data which equals to 0.9, and low is the minimum normalised data which equals to 0.1. Back propagation (BP) learning algorithm, which is the most common in science and engineering applications was used in this study. Weight and bias values of the network are updated according to Levenberg–Marquardt (Train LM) optimisation algorithm by the back propagation training function [44], [45]. The Marquardt-Levenberg (ML) algorithm, which is a nonlinear least-squares algorithm applied to the learning of the multilayer perceptrons, was applied and chosen to establish the weight assignment. In summary, the ML algorithm is a modified Gauss-Newton method that minimises the error function using the Jacobian matrix and the Hessian of the objective function, but without having to compute the Hessian [46].

The performance index of Train LM algorithm is the mean squared error (MSE) [43] and it is formulated as given below:

$$MSE = \sum_{i=1}^{n} \left(y_i - y_k \right)^2 \tag{5}$$

Where y_i is the predicted value of the *i* Th pattern, y_k is the target value of the *i* th pattern and N is the number of pattern.

Figure 17 shows the correlation coefficient of the value obtained and the target value of the prediction obtained by using the Levenberg-Marquardt algorithm. Both of them have a value of 0.99, demonstrating the network capacity to generalize and simulate new ester data of fatty acid and predict the iodine value. Figures18-19 are the snapshots of mean square error plot and Error Histogram.

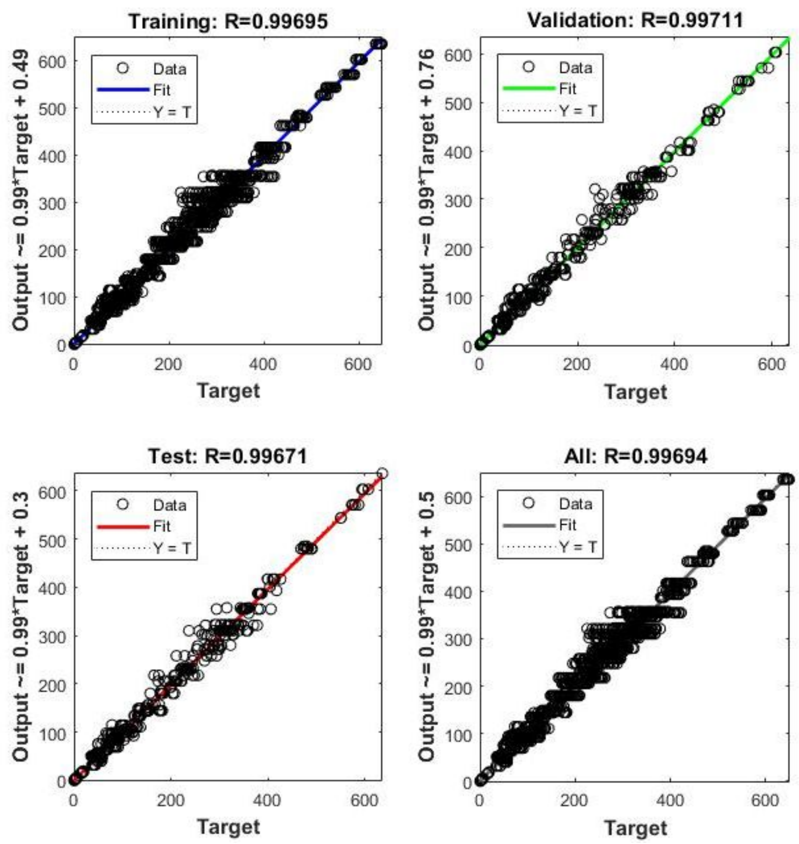
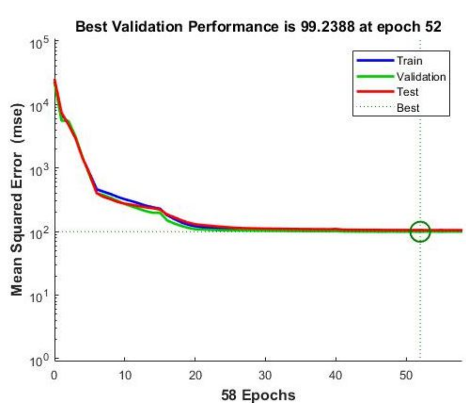


Figure 17. R values of training, validation and test data



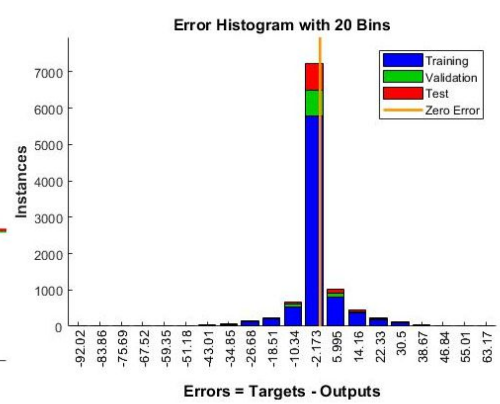


Figure 18. Snapshot of mean square error plot Figure 19. Snapshot of Error Histogram

Various graphs were obtained to compare experimental and predicted emissions values. The coincidence of experimental and predicted values indicates that the training has been done on a good scale. The target values 0%, 5%, 10% and 20% of fuel and 0%, 50%and100% load in 1800, 2150 and 2500 rpm were studied according to the training process of ANN and the results are shown in Figures 20-24. It can be seen from these Figures that the ANN model predicts engine emissions of tomato seed biodiesel fairly well.

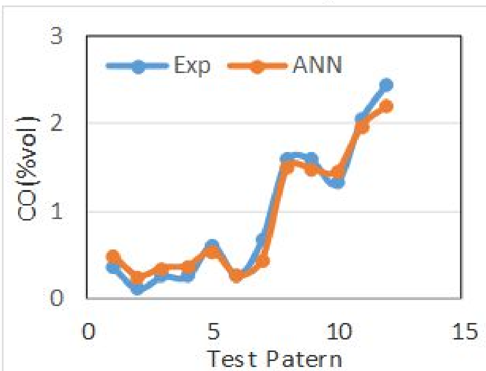


Figure 20. Comparison of experimental CO experimental emission with ANN CO

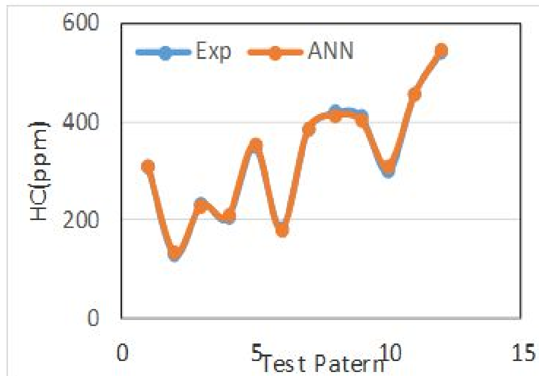


Figure 21. Comparison of HC emission with ANN HC

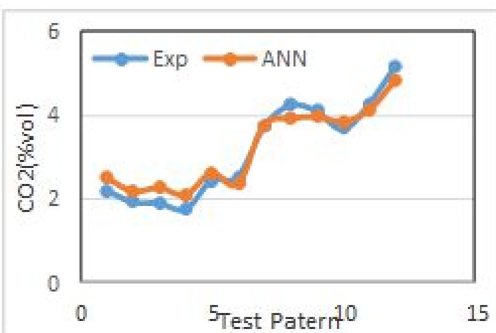


Figure 22: Comparison of experimental CO_2 emission with ANN CO_2.

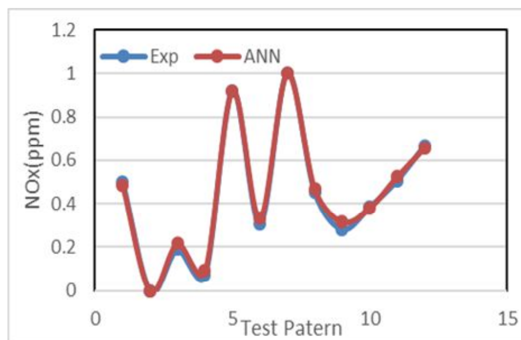


Figure 23: Comparison of experimental NOx emission with ANN NOx.

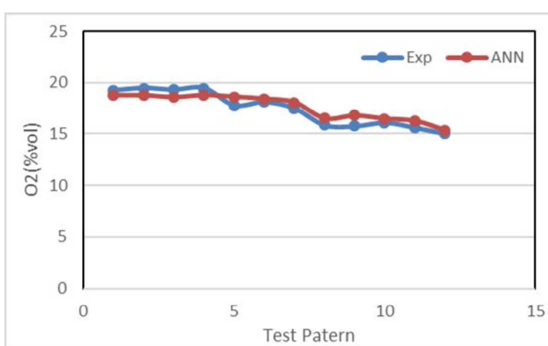


Figure 24. Comparison of experimental O_2 emission with ANN O_2

For the above figures, different legends and lines for Exp and ANN were used since the current two legends (i.e.circle and line) looked the same in a black printout.

6. Conclusions

The results showed that the diesel and biodiesel mixture of tomato seed oil can be used to reduce pollutants produced by the engine. According to the results, the best fuel for the most pollution reduction is B20. These results show that B20 at 100% load releases NOx around 43% more than B0. And B0 releases CO 28% more than B20 respectively at 100% load. At the same loads and percentage of biodiesel the same happened for CO_2 but the percentage was 45% more. HC results showed that B20 in 100% load released 5% less than B0 and O_2 for B20 was 4% less than B0 at the same loads as HC load and percentage of biodiesel. A back propagation (BP) neural network model with a 3–10–5 (number of input layer–hidden layer–output layer neurons) configuration was developed to predict the specific fuel emissions of CO, CO_2, O_2, HC and NOx of a diesel engine. This new approach can be considered as an alternative and practical technique to evaluate the engine parameters. ANNs are reasonable for the prediction of engine parameters due to their capability to learn and generalize a broad range of experimental conditions. This makes the ANN model a great instrument to solve the complicated engineering problems, especially those related to the engine emissions.

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تولید بیودیزل از هسته گوجه فرنگی و آزمایش آلایندگی و شبیه سازی آن با شبکه عصبی

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تلفن: ۱۱۸۲ ۳۱۶ ۹۱۷ ۹۸+

چکیده

در این تحقیق، از روغن بذر گوجه‌فرنگی برای تولید سوخت بیودیزل استفاده شد. در ابتدا برای کاهش درصد اسیدهای چرب آزاد، روغن در دماهای ۴۰، ۵۰ و ۶۰ درجه سانتیگراد با مخلوط اسید سولفوریک و متانول صنعتی با نسبت مولی‌های مختلف روغن واکنش داده شد. بهترین بازده تبدیل در دمای ۶۰ درجه سانتیگراد و نسبت مولی ۱ به ۹ بدست آمد. در مرحله ترانس استریفیکاسیون، بیودیزل با استفاده از واکنش مخلوط هیدروکسید پتاسیم تولید شد. سپس ویژگی‌های عملکردی و گازهای آلاینده سوخت دیزل معمولی و مخلوط سوخت‌های بیودیزل در حالت سرعت و بارهای مختلف اندازه‌گیری و مقایسه شد. این آزمایش‌ها در موتور دیزلی تزریق مستقیم ۹ کیلووولت انجام شد. نتایج تجزیه و تحلیل واریانس با استفاده از نرم افزار SPSS نشان داد که اختلاف معنی داری در سطح احتمال $R < 0.01$ بین تولید آلاینده‌هایی مانند NOx ، CO، HC و سایر گازهای اگزوز مانند CO_2 و O_2 در سرعت‌های مختلف و بارها وجود دارد. نتایج آزمایش‌های چندگانه Duncanنیز نشان‌داد که کمترین میزان انتشار بوسیله سوخت ترکیبی B20تولید شده است. مدل شبکه عصبی مصنوعی (ANN) نیز برای پیش‌بینی انتشار گازهای گلخانه‌ای استفاده شده است که نشان می دهد مطابقت بسیار خوبی با مقادیر R برابر با ۰/۹۹ برای داده‌های آموزش و آزمایش وجود دارد.