



**REPUBLIC OF TURKEY
ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY
UNIVERSITY**

**INSTITUTE OF GRADUATE SCHOOL
DEPARTMENT OF MECHANICAL ENGINEERING**

**EXPERIMENTAL AND THEORETICAL INVESTIGATION OF THE
EFFECT OF AMMONIA ADDITIVE ON ENGINE EMISSION AND
PERFORMANCE PARAMETERS**

**ÖMER BÖYÜKDİPİ
MASTER OF SCIENCE**



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**SUPERVISOR
Assoc. Prof. Dr. GÖKHAN TÜCCAR**

ADANA 2021

ABSTRACT

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In the scope of this study, the effects of the NH_3 (Ammonia) as a fuel additive on the engine emission, performance, and vibration parameters were experimentally investigated. The sunflower, peanut, hazelnut, and waste oil biodiesel were produced as primary fuel. All produced biodiesel varieties were blended with NH_3 additive at volumetric ratios of 5%, 10%, and 15%. In the first part of the study, Diesel-RK was used as a combustion simulation programme to observe numerically the effects of NH_3 additive on the engine emission and performance parameters. The combustion simulations were generated according to the thermal properties and characteristic of all fuel mixtures. The engine emission (Oxides of Nitrogen (NO_x), Particulate Matter (PM) and Smoke Opacity) and performance (Power, Torque, and Indicated Mean Effective Pressure (IMEP)) parameters were evaluated. In the second part of the study, the engine vibration was experimentally investigated to observe the effects of the NH_3 additive for all fuel mixtures. All mixtures were combusted under no-load conditions in varying engine speed (1200-2400 rpm) by using the Mitsubishi Canter 4D31 diesel engine. Experimental vibration data were recorded with the accelerometer sensor placed on the engine block for all fuel mixtures. The ANNs model was generated to predict the experimental vibration data. In this sense, the predicted vibration data were compared with the experimental vibration data. In the generation part of the ANNs model, the x-axis vibration (m/s^2), y-axis vibration (m/s^2), RMS (m/s^2), time (second), and engine speed (rpm) were selected as input parameters to predict the vibration in the z-axis. In this case, the z-axis vibration (m/s^2) was considered as the target parameter.

As a result of the combustion simulations of the Diesel-RK programme, when the NH_3 additive was gradually increased in the fuel mixture, NO_x emission dramatically decreased for all fuel mixtures. On the contrary to this decrement, a particular increment was observed in PM and smoke opacity. Moreover, the NH_3 additive negatively affected the engine power, torque and IMEP parameters. In the experimental studies, a slight z-axis vibration increment was observed for the sunflower and waste oil biodiesel blended with 5%, 10%, and 15% NH_3 additive. On the other hand, 5% NH_3 additive positively affected and caused to decrease the z-axis vibration data for the hazelnut and peanut biodiesel- NH_3 additive mixtures.

Keywords: Combustion, NH_3 additive, Biodiesel, Artificial neural networks (ANNs), Engine vibration, Exhaust emission, Engine performance

ÖZET

AMONYAK KATKI MADDESİNİN MOTOR EMİSYONU VE PERFORMANS PARAMETRELERİ ÜZERİNDEKİ ETKİSİNİN DENEYSEL VE TEORİK ARAŞTIRILMASI

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Bu çalışma kapsamında, yakıt katkısı olarak NH_3 'ün (Amonyak) motor emisyonu, performansı ve titreşim parametreleri üzerindeki etkileri deneysel olarak araştırılmıştır. Birincil yakıt olarak ayçiçeği, yer fıstığı, fındık ve atık yağ biyodizeli üretilmiştir. Bu çalışmada, üretilen tüm biyodizel çeşitleri NH_3 katkısı ile %5, %10 ve %15 hacim oranlarında harmanlanmıştır. Çalışmanın ilk bölümünde, NH_3 katkısının motor emisyonu ve performans parametreleri üzerindeki etkilerini sayısal olarak gözlemlemek için yanma simülasyon programı olarak Diesel-RK kullanılmıştır. Yanma simülasyonları, tüm yakıt karışımlarının termal özelliklerine ve karakteristiklerine göre oluşturulmuştur. Motor emisyonu (Azot Oksitleri (NO_x), Partikül Madde (PM) ve Duman Opaklığı) ve performans (Güç, Tork ve Gösterilen Ortalama Etkili Basınç (IMEP)) parametreleri değerlendirildi. Çalışmanın ikinci bölümünde, tüm yakıt karışımları için NH_3 katkısının etkilerini gözlemlemek için motor titreşimi deneysel olarak incelenmiştir. Tüm karışımlar, Mitsubishi Canter 4D31 dizel motor kullanılarak değişen motor devrinde (1200-2400 rpm) yüksüz koşullarda yakılmıştır. Tüm yakıt karışımları için motor bloğuna yerleştirilen ivmeölçer sensörü ile deneysel titreşim verileri kaydedilmiştir. YSA modeli, deneysel titreşim verilerini tahmin etmek için oluşturulmuştur. Bu anlamda tahmin edilen titreşim verileri deneysel titreşim verileri ile karşılaştırılmıştır. YSA modelinin oluşturulması kısmında x eksenini titreşimi (m/s^2), y eksenini titreşimi (m/s^2), RMS (m/s^2), zaman (saniye) ve motor hızı (rpm) z eksenindeki titreşimi tahmin etmek için giriş parametreleri olarak seçilmiştir. Bu durumda, z eksenini titreşimi (m/s^2) hedef parametre olarak kabul edildi.

Diesel-RK programının yanma simülasyonları sonucunda, yakıt karışımında NH_3 katkısı kademeli olarak artırıldığında, NO_x emisyonu tüm yakıt karışımları için önemli ölçüde azalmıştır. Bu azalmanın aksine PM ve duman opaklığında belirli bir artış gözlenmiştir. Ayrıca NH_3 katkısı motor gücü, tork ve IMEP parametrelerini olumsuz etkilemiştir. Deneysel çalışmalarda %5, %10 ve %15 NH_3 katkısı ile harmanlanmış ayçiçeği ve atık yağ biyodizeline hafif bir z ekseni titreşim artışı gözlemlenmiştir. Öte yandan, %5 NH_3 katkısı fındık ve fıstık biyodizel- NH_3 katkı karışımları için z ekseni titreşim verilerini olumlu etkilemiş ve azalmasına neden olmuştur.

Anahtar Kelimeler: Yanma, NH_3 katkısı, Biyodizel, Yapay sinir ağları (YSA), Motor titreşimi, Egzoz emisyonu, Motor performansı



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NOMENCLATURE

ANNs	: Artificial Neural Networks
ASTM	: American Society for Testing and Materials
AV	: Acid Value
BDC	: Bottom Dead Center
BSCO	: Brake Specific Carbon Monoxide
BSHC	: Brake Specific Hydrocarbon
CO	: Carbon Monoxide
CO ₂	: Carbon Dioxide
CI	: Compression Ignition Engine
CIS	: Commonwealth Of Independent States
CH ₃ OH	: Methanol
DME	: Dimethyl Ether
EGR	: Exhaust Gas Recirculation
EU	: Europe
FVB	: Foeniculum Vulgare Oil
H ₂	: Hydrogen
HC	: Hydrocarbon
HHO	: Hydroxyl Gas
ICE	: Internal Combustion Engine
IMEP	: Indicated Mean Effective Pressure
IV	: Iodine Value
KOH	: Potassium Hydroxide
LA	: Latin America
Mtoe	: Million Tons of Oil Equivalent
ME	: Middle East
N ₂	: Nitrogen
NA	: Northern America
NaOH	: Sodium Hydroxide
NO _x	: Oxides of Nitrogen

PM	: Particulate Matter
RCCI	: Reactivity Controlled Compression Ignition
RME	: Root Mean Error
RMS	: Root Mean Square
RMSE	: Root Mean Square Error
SCR	: Selective Catalytic Reduction
TDC	: Top Dead Center



1. INTRODUCTION

The most important factor affecting the progression and development of countries is to meet their energy needs. The world's energy demand increases significantly due to the growth of populations and industrialization of developing countries. In 2020, the world's energy need has been expected to increase 25 to 180,000 GWh/year because of predictable reasons [1]. Nowadays, most of the energy consumed by humans is obtained from primary energy sources. These energy sources can be identified as petroleum, natural gas, coal, biomass, flowing water, wind, and solar radiation. After the industrial revolution, the consumption of primary energy resources significantly increased until 2020. According to the annual primary energy consumption forecast from today to 2040, this increase is going to continue gradually. The forecast about total primary energy consumption requirement was given in Table 1.

Table 1. Total primary energy consumption requirement [2]

Region	Unit	2020	2021	2022	2023	2024	2025	2030	2035	2040
World	Mtoe	14,2	14,4	14,6	14,86	15,03	15,16	15,86	16,623	17,48
Europe	Mtoe	1,858	1,852	1,842	1,831	1,818	1,800	1,712	1,658	1,650
Asia	Mtoe	6,31	6,50	6,69	6,870	7,031	7,162	7,772	8,294	8,770
Africa	Mtoe	749	765	783	802	821	840	957	1,106	1,301
ME	Mtoe	777	777	774	767	757	746	727	725	742
NA	Mtoe	2,56	2,55	2,59	2,538	2,522	2,500	2,406	2,359	2,347
LA	Mtoe	874	889	904	920	936	953	1,047	1,150	1,258
CIS	Mtoe	955	962	970	981	994	1,007	1,082	1,162	1,246
Pacific	Mtoe	149	150	152	154	156	157	163	169	172

Within the scope of this information, the energy consumption potential of the world becomes a critical problem for today and the future. Moreover, global warming will cause more serious problems every year for the environment and people as the primary energy sources irregularly were consumed. As known, carbon monoxide (CO) gases causes global warming because of being a primary greenhouse gas. Therefore, the primary method to overcome these problems is to reduce the CO concentration in the atmosphere. Nowadays, the consumption of

petroleum-derived fuels causes an increment in the CO concentration of the atmosphere. In addition to that, all motor vehicles, industrial processes, energy usage, production, and distribution are the most important factors that increase CO concentration in the atmosphere. The forecast of CO concentration provides decisive information for energy consumption policies in protection against global warming. The forecast about total carbon monoxide emission was given in Table 2.

Table 2. The forecast of the total CO emission [2]

Region	2020	2025	2030	2035	2040
World	36,265	37,763	38,177	38,617	39,549
Europe	3,959	3,67	3,313	3,075	2,94
Asia	18,444	20,456	21,399	22,016	22,738
Africa	1,345	1,536	1,78	2,094	2,515
ME	2,081	1,964	1,887	1,825	1,79
NA	5,816	5,323	4,793	4,496	4,285
LA	1,848	1,95	2,028	2,102	2,2
CIS	2,363	2,467	2,591	2,639	2,72
Pacific	408	398	387	372	361

As shown in Table 2, CO emissions are expected to gradually decline in Europe, ME, NA and Pacific regions from now until 2040. On the contrary of this situation, the concentration of CO is gradually expected to increase for the sum of all regions. In line with this forecast, a lot of research especially have been made about the fuel and fuel additive study fields to overcome problems that are revealed in the previous section.

After the invention of internal combustion engines, an increment was observed in the concentration and diversity of exhaust emission gases in the atmosphere. This diversity has increased the concentration of a gas highly toxic and harmful to the ozone layer, such as oxides of nitrogen (NO_x), in the atmosphere.

NO_x gas especially exists at high temperatures as a combustion product when nitrogen reacts with oxygen gases in the air during combustion. Therefore, there are many factors that cause

an increment in NO_x emissions. The greatest sources of NO_x emission can be described as energy production and applications, high motor vehicle traffic in large cities, industrial processes, agriculture and other sources. The information about NO_x emissions in the EU was given in Figure 1 according to the sector group.

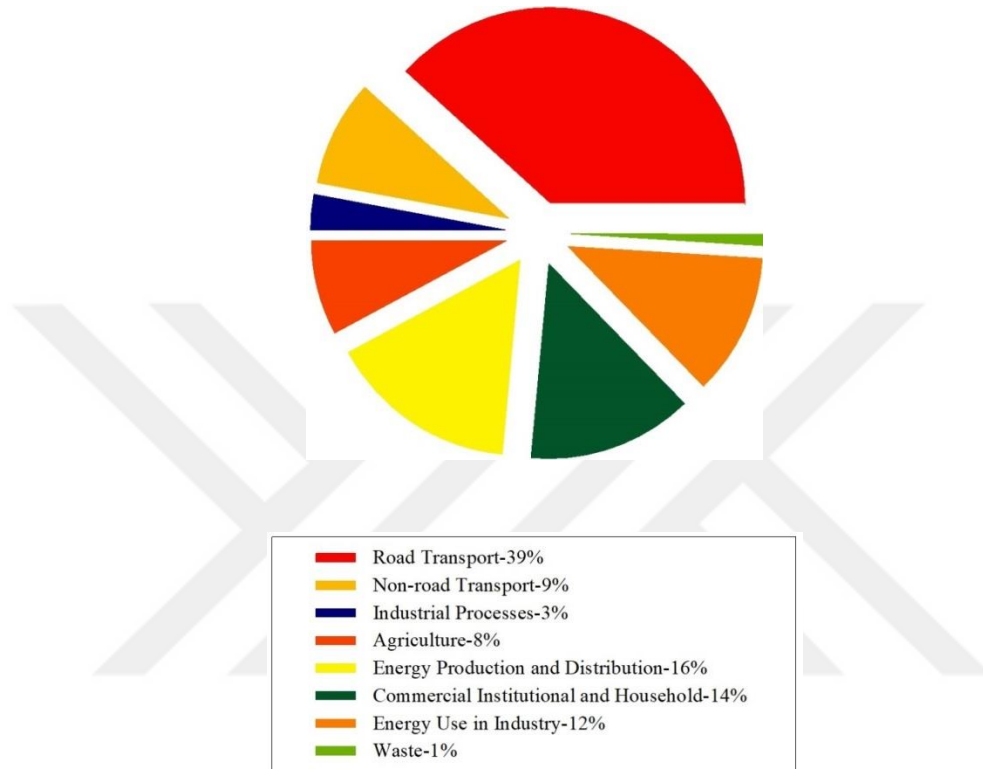


Figure 1. NO_x emissions in the EU according to sector group, 2018

As seen in Figure 1, the production of the emission gases is occurred in many different ways by people. Therefore, some regulations have been made to decrease the negative effect of exhaust emission gases on the environment. European emission standards are one of the most effective emission control arrangements among other regulations. In accordance with this purpose, European emission standards have been implemented for many years and as a result of this, the exhaust emission gases were regulated all over the world by using such emission control arrangements. The comparison of petrol and diesel engines NO_x emission standards according to different Euro classes was given in Figure 2.

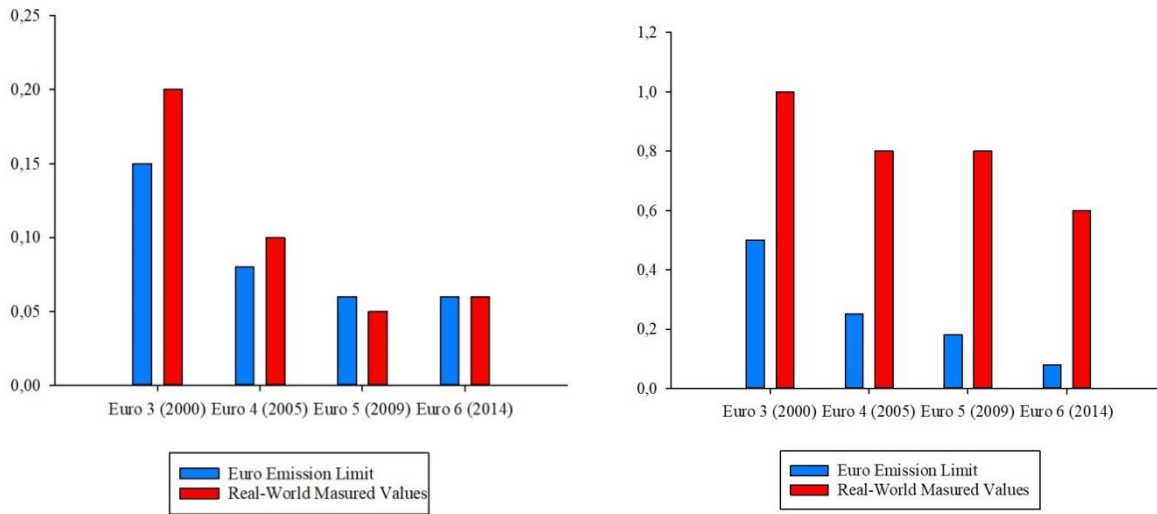


Figure 2. Comparison of NO_x emission standards according to different Euro classes a) petrol engines b) diesel engines [3]

As seen in Figure 2, the concentration limit of NO_x emissions in g/km was gradually decreased to overcome the effects of greenhouse gases from Euro 3 (2000) until Euro 6 (2014) regulations. Especially, diesel engines produce NO_x at the critical level. Therefore, a significant reduction was observed in NO_x emissions of diesel engines by using European emission standards.

In this sense, many emission control systems are improved to limit the amount of NO_x emission in diesel motor vehicles. These emission control systems are selective catalytic reduction (SCR), exhaust gas recirculation (EGR), and catalytic converter. SCR systems are one of the most effective applications for exhaust gases. In SCR systems, AdBlue is sprayed into the exhaust gases before it reaches the catalyst. Therefore, high temperature transforms AdBlue into NH₃. Then, they react with each other and turn into two elements (nitrogen and water vapour) that are not harmful to the atmosphere while ammonia (NH₃) and the antagonist nitrogen oxides penetrate the catalyst. As a result of this process, a significant decrease in NO_x emission has been observed due to the chemical and physical properties of NH₃.

Previous studies have proven that NH₃ has the potential to reduce the direct or indirect effects of exhaust emission gases in this study field. Besides, NH₃ is recognized as an important alternative to the world's increasing energy needs by many sectors. Therefore, NH₃ has a

determinant effect in the reduction of NO_x and other exhaust emission gases. NH_3 has many advantages such as lower emission, better engine performance, lower cost and safer storage. Therefore, the liquid NH_3 was used as a fuel additive by mixing with diesel and biodiesel fuels in the scope of this study. This study aims to decrease the concentration of NO_x , carbon dioxide (CO_2) and other emission gases in the atmosphere.

NH_3 is a colourless gas with a characteristically pungent smell. Moreover, it has a lower density according to air. Liquid NH_3 freezes at low temperature because of having strong molecule bondings. NH_3 basically can be described as a hydrogen carrier and transportation fuel due to having a high hydrogen ratio. NH_3 doesn't contain any carbon atoms. Therefore, it directly does not emit greenhouse gases as a result of burning. In this sense, information about the benefits of NH_3 as fuel was given in Figure 3.

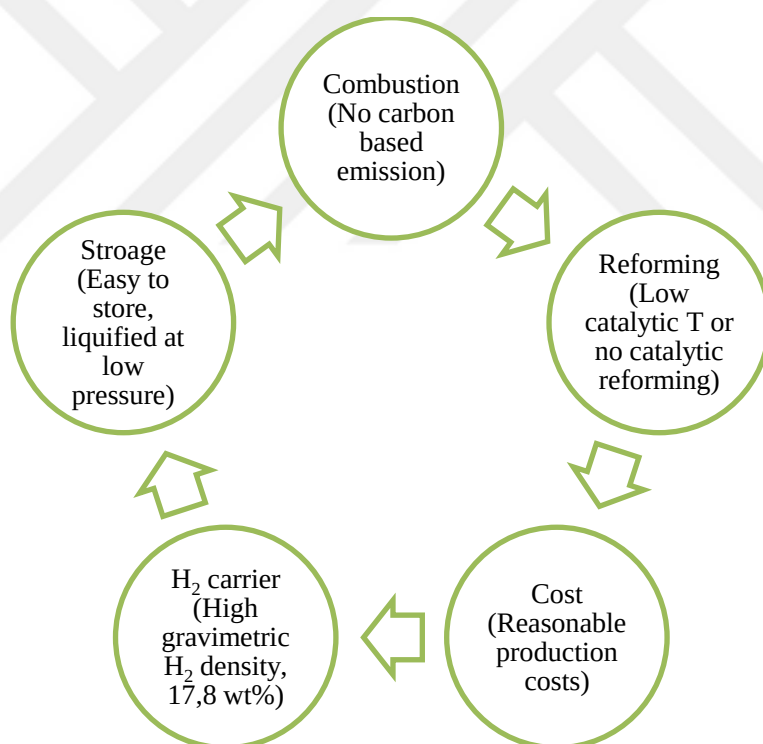


Figure 3. Benefits of NH_3 as fuel [4]

Although NH_3 as fuel has a lot of benefits, there are some deficiencies in the usage of NH_3 . Therefore, the limitations of NH_3 as fuel were given in Figure 4.

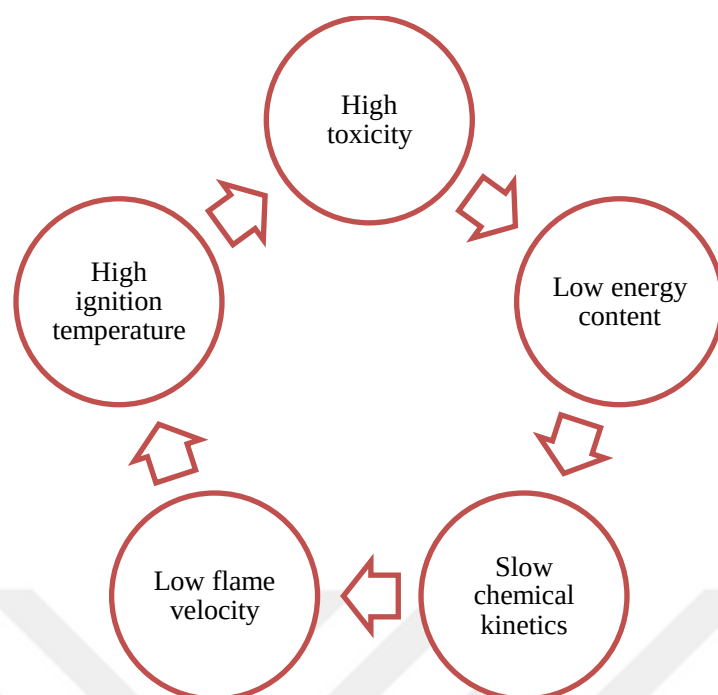


Figure 4. Limitations of NH_3 as fuel

The chemical properties of NH_3 were compared with other hydrocarbon fuels to reveal the advantage of NH_3 during combustion. Therefore, information about the thermal properties and combustion characteristics of NH_3 and hydrocarbon were given in Table 3.

Table 3. Thermal properties and fundamental combustion characteristics of NH_3 and hydrocarbon [5]

Fuel	NH_3	H_2	CH_4	C_3H_8
Boiling temperature ($^{\circ}\text{C}$)	-33.4	-253	-161	-42.1
Condensation pressure (atm)	9.90	N/A	N/A	9.40
Lower heating value (MJ/kg)	18.6	120	50.0	46.4
Flammability limit	0.63-1.4	0.1-7.1	0.5-1.7	0.51-2.5
Adiabatic flame temperature ($^{\circ}\text{C}$)	1800	2110	1950	2000
Max. laminar burning velocity (m/s)	0.07	2.91	0.37	0.43
Min.auto ignition temperature $^{\circ}\text{C}$	650	520	630	450

NH_3 has a very high potential in terms of being used as a fuel. In this sense, the usage areas of NH_3 as fuel was given in Figure 5. On several occasions in the past, anhydrous NH_3 has been considered and has actually been used as a fuel for combustion engines.

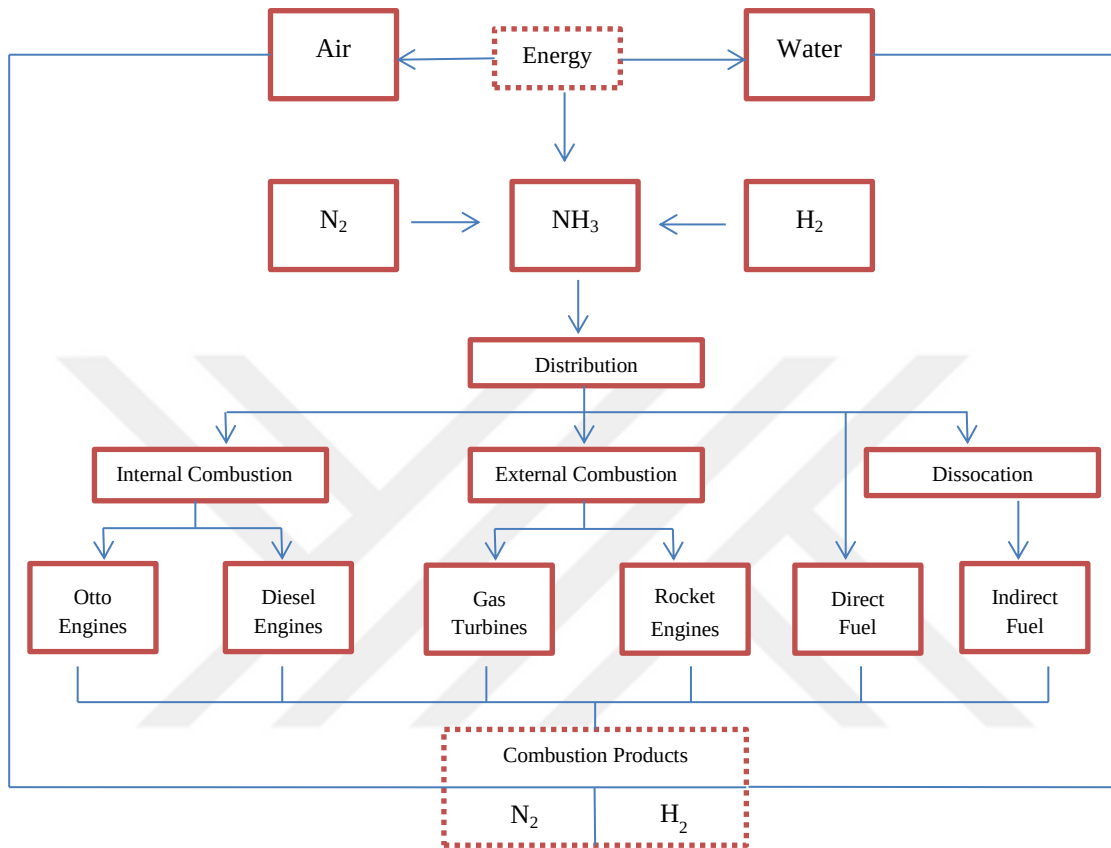


Figure 5. Use of NH_3 as a fuel [6]

During World War II, NH_3 was occasionally used in Europe with remarkable success as a fuel for public transportation [6]. At this point, there are some reasons for the usage of NH_3 as a fuel. These reasons can respectively be described that NH_3 can significantly reduce emission gases in the atmosphere due to being non-carbonaceous fuel and a hydrogen carrier. Therefore, CO doesn't occur among the combustion products when NH_3 was burned as fuel in the internal combustion engines. On the other hand, conventional fuels dramatically increase the content of combustion products in the atmosphere. This situation causes the greenhouse effect worldwide. NH_3 does not constitute any soot in the internal combustion engines although conventional fuels cause lots of soot inside of the cylinder. NH_3 has a high octane number and low flammability limit according to other fuels. The cost of NH_3 is economically more affordable among other fuels as mentioned in the previous section. In the 1990s, NH_3

prices were between 200-400 \$/t price range. Nowadays, NH_3 prices approximately have been above 700 \$/t [7]. Autoignition limit temperature has the determinant factor among these advantages. NH_3 has a high auto-ignition temperature limit among different fuels due to having strong bonds between molecules. This chemical property of NH_3 ensures a lot of advantage in the usage of NH_3 as a fuel. The storage conditions of liquid NH_3 are easier and safer than other fuel at the pressurized tanks due to having a high flammability limit.

NH_3 has a wide range of uses among chemicals due to having a lot of advantages in terms of its chemical structure. It is used extensively in the fertilizer and chemical industry. The wide range of the usage of NH_3 is given in Figure 6. On the other hand, NH_3 has a high potential for usage in energy applications. The usage of NH_3 in the energy field is usually indirect. This usage rate gradually shows an increment every year in the energy sector. The usage of NH_3 in energy applications can be diversified as fuel cells, refrigeration systems, generators, boilers, compression ignition engines, spark-ignition engines and gas turbines.

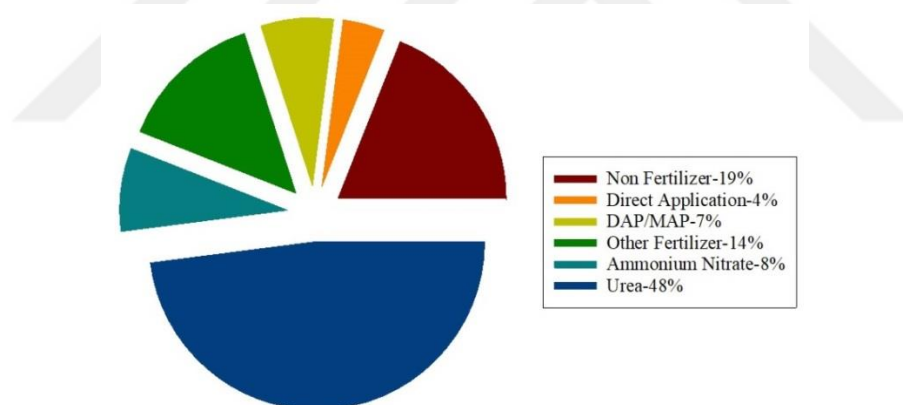


Figure 6. Usage areas of NH_3 [8]

NH_3 production has critical importance due to the high-level usage of NH_3 as mentioned in the previous section. In line with this information, NH_3 can be synthesized from natural gas, coal, fuel oil, naphtha, etc. The information about the raw materials of NH_3 was given in Figure 7. Natural gas has critical importance as it constitutes 72% of NH_3 production as seen in Figure7. There are a lot of used production methods as well as the raw materials of NH_3 in energy sectors. NH_3 production methods can be described as Haber-Bosch, thermochemical, and solid state. Besides, the chemical properties of NH_3 such as lower heating value, energy

content and auto-ignition temperature can differ according to the variety of raw materials and production method of NH_3 .

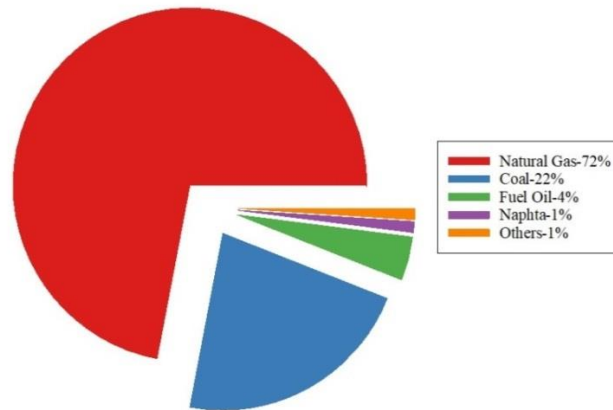


Figure 7. Raw materials of NH_3 [9]

Although there are some disadvantages about the usage of NH_3 as a fuel, it can be a powerful alternative energy source and it can replace conventional fuels by using appropriate methods. Therefore, NH_3 can be used as a fuel in a lot of power systems. All power systems were given in Figure 8.

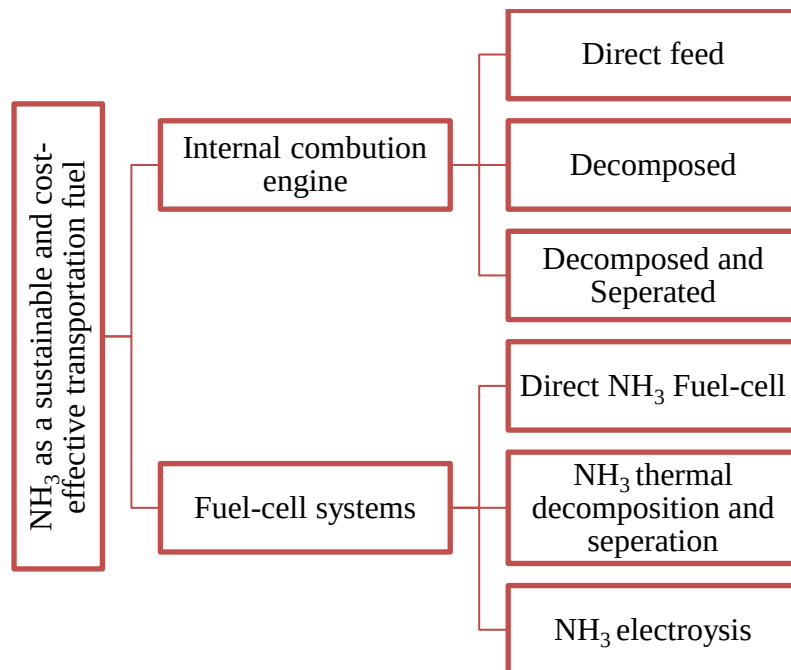


Figure 8. Power systems fuelled with NH_3 [10]

Diesel RK Programme is a commercial simulation software that computes and optimizes the combustion, engine performance and emission parameters. This software can simulate and optimize working processes of two- and four-stroke internal combustion engines by using all types of boosting. In the scope of this programme, the engine emission and performance parameters can be analyzed and evaluated in a wide range. Besides, there are numerically many optimization applications to support experimental studies in this program. These applications can be described as knock prediction, valve timing, EGR, fuel consumption, engine performance and emission optimizations.

The most important factor that directly affects engine life and rides comfort is the engine vibration parameter. Engine vibration basically can be described as a mechanical phenomenon whereby oscillations occur about an equilibrium point. Although the automobile industry tries to prevent excessive vibration, there are a lot of reasons that cause to increase in the vibration frequency. These reasons can be diversified as the weak spark, clogged injectors, worn engine mounts, and fuel types. In addition to that, the unbalanced forces can increase the intensity of the vibration. Therefore, suspension systems are improved to eliminate the unbalanced forces that create vibration in the automobile industry.

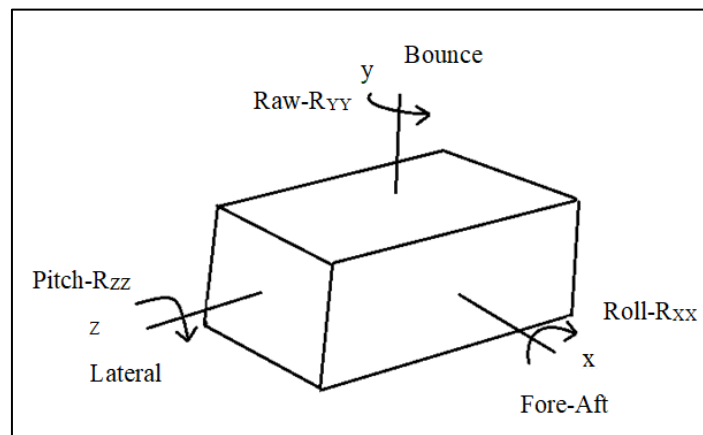


Figure 9. Engine freedoms

The engine freedoms in the x, y, and z-axis were given in Figure 9. The unbalanced forces can be determined to calculate the vibration frequency according to 6 parameters (force-aft, bounce, lateral, roll-R_{xx}, raw-R_{yy}, and pitch-R_{xx}). As mentioned in the previous section, an investigation has been made on the fuel factor that causes the engine vibration in the scope of

this study. In this sense, the combustion characteristic of NH_3 has a very decisive role in terms of vibration parameter. When NH_3 is burned in the internal combustion engine, the combustion produces a flame that has with a relatively low propagation rate. Combustion may show an inconsistent behavior under high engine speed operating conditions due to this low combustion rate of NH_3 . An internal combustion engine that uses NH_3 requires a secondary combustion promoter to eliminate the disadvantages of NH_3 . Therefore, the usage of NH_3 as a fuel additive instead of the main fuel can positively reflect on the vibration parameter.

The experimental studies can cause both time loss and high costs in some researches. Many simulation programs are used to eliminate these problems. Especially, artificial intelligence applications are a method that makes a difference in this field. Therefore, Artificial Neural Networks (ANNs) is extensively used in academic studies. ANNs are basically inspired by the way the biological neural system works, such as the brain process information [11]. Within the scope of this study, the purpose of ANNs is to constitute a data set by using vibration results and to increase the originality of the study by comparing these data sets with experimental results. Moreover, cost and time can be saved by using suitable model. The ANNs models that reach high accuracy levels are one of the important factors that increase the quality of the study. Therefore, the ANNs models that have approximately 90% accuracy value are evaluated in the scope of this study.

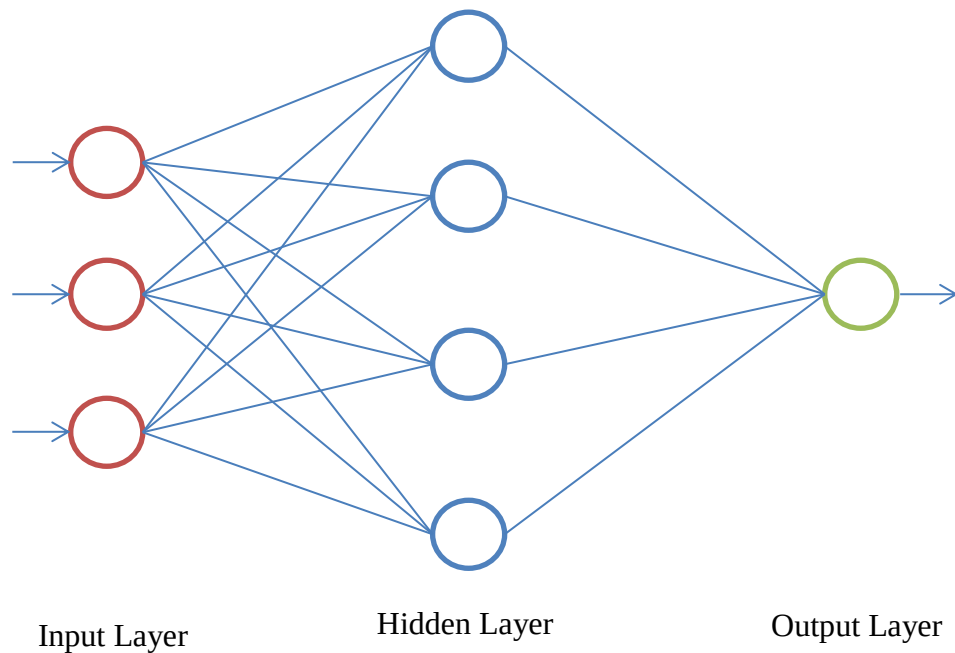


Figure 10. Basic neural network structure

The flow chart of the basic neural network structure was given in Figure 10. ANNs models consist of 3 layers. These layers are input, hidden, and output layers. In the generation of ANNs models, the parameters that have not related to each other were taken as input parameters. ANNs simulation results were also considered as output parameters. In addition to that, a certain range of input parameters has been accepted as the test parameter In order to reveal the accuracy of the model.

As mentioned in the previous section, it was revealed that there are some deficiencies in the usage of NH_3 as the main fuel and therefore it should be used as a fuel additive. In this sense, different types of biodiesel were used as the main fuel due to being green fuel in the scope of this study. Biodiesel basically can be produced from vegetable oil by using the transesterification method. Biodiesel has been a strong alternative to diesel fuels over the years. It is biodegradable and non-toxic, has low emission and environmentally beneficial [12]. On the other hand, feedstock and cost are the determinant factors that limit biodiesel production. The cost of biodiesel that is produced from waste oils is close to the cost of diesel fuels.

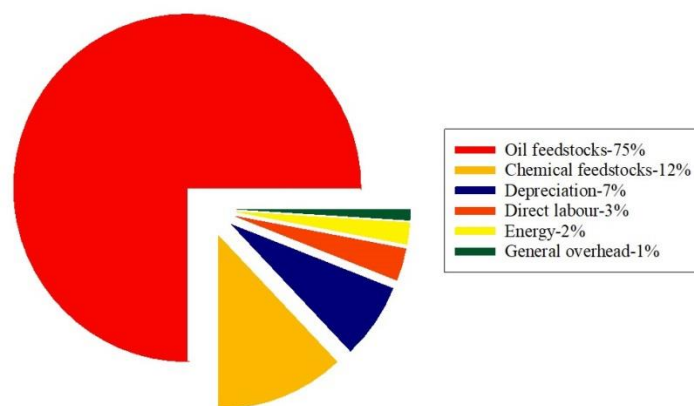


Figure 11. The general cost of the production of biodiesel [13]

The information about the general cost of the production of biodiesel was given in Figure 11. In the scope of this study, 4 different types of biodiesels as a main fuel were produced from the sunflower, hazelnut, peanut, and waste oils. Despite the high cost of feedstocks of this biodiesel that are produced, the total cost of biodiesel remained below the standard price. The main reason for this situation is the application of the transesterification method.

NH_3 can constitutively be defined as the fuel of the future due to having high hydrogen content and not containing any carbon atoms as mentioned in the previous sections. Therefore, this study numerically and experimentally aims to observe the effects of NH_3 additive on engine vibration, emission, and performance parameters. Diesel-RK programme was used to analyze the emission and performance parameters. In this sense, combustion simulations were generated for different fuel and NH_3 additive ratios. In the generation section of combustion simulations, the sunflower, peanut, hazelnut, and waste oil biodiesel were assumed as main fuels. In addition to that, the NH_3 additive ratio was gradually increased as 5%, 10%, and 15% in biodiesel fuels. All combustion simulations were evaluated according to NH_3 additive ratios. When the previous studies about NH_3 in the literature are examined, it has been revealed that it provides a significant decrease in emission parameters and also positively affects some engine performance parameters.

In the scope of this study, another parameter is the engine vibration that is experimentally investigated. Therefore, the production of 4 different types of biodiesel that are mentioned in the previous section was carried out for vibration experiments. All vibration data was recorded during experiments for different types of fuel mixtures. In this sense, simulation models were generated to compare with the experimental vibration data by using ANNs. These ANNs models have a high percentage of accuracy in terms of the consistency of the study. All simulation comparisons were evaluated according to NH_3 additive ratios. Although there are several studies that used NH_3 as the main fuel in the literature, no study was observed that uses NH_3 as a fuel additive and experimentally examines the vibration, emission and performance parameters within our knowledge. Therefore, there are some deficiencies about this research subject in the literature. The pros and cons of NH_3 as a fuel additive were evaluated for all these parameters by using different main fuels. Besides, the originality and validity of the study in the literature have been aimed to increase by comparing the experimental results with the results of the generated ANNs model.

2. LITERATURE REVIEW

There are a lot of study areas to eliminate the problems caused by global warming as a result of the increase in emission gases. Recently, fuel additive studies are one of the most notable study topics and have a high potential against the world energy demand problem. Therefore, fuel additive studies not only find solutions to these problems but also meet the energy needs of the world to a large extent. In addition to that, fuel additive has many advantages that improve engine performance and combustion. Fuel additive studies have a wide area in the literature. Therefore, the fuel additive studies that contribute to the development of the literature are respectively mentioned in the following sections.

M. Kasper et al. [14] investigated the influence of fuel additives on the formation of carbon during combustion. They revealed that the fuel additive ferrocene leads to the formation of condensation nuclei in the combustion zone before the formation of carbonaceous particles. Howard et al. [15] investigated the usage of metallic and non-metallic fuel additives to decrease soot emissions from practical combustion systems. The obtained result showed that metal additives significantly reduced the soot content in the exhaust of practical flames. N. Rahmat et al. [16] investigated innovative and potential technologies for glycerol transformation into fuel additives. They revealed that glycerol-based additive has certain qualities suitable for gasoline, biodiesel and diesel fuels. M. Gürü et al. [17] improved the diesel fuel properties by using additives in this study. They used organic compounds of Mn, Mg, Cu and Ca metals as diesel fuel additives. A. Keskin et al. [18] investigated influences of tall oil biodiesel with Mg and Mo based fuel additives on diesel engine performance and emission. They revealed a significant reduction in CO emissions and smoke opacity. Moreover, low NO_x and CO₂ emissions were obtained due to the fuel additive. A. Cornejo et al. [19] investigated oxygenated fuel additives in diesel/biodiesel blends to analyze the effect on engine performance and greenhouse gases (GHG) emissions. This research revealed that some gas emissions can be reduced with oxygenated fuel additives. A. Keskin et al. [20] investigated the effects of metallic based fuel additives on performance and exhaust emission parameters of the diesel engine. The obtained results showed that some engine performance improved by adding metallic based fuel additives. In

addition to that, the reduction was observed in specific fuel consumption, CO and CO₂ emission parameters. McCormick et al. [21] investigated the effects of fuel additives on the emission parameters. They revealed that fuel additive has a decrement effect on NO_x concentration. On the other hand, it negatively affects the PM parameter for some fuel additive. Splitter et al. [22] investigated the efficiency and emissions of reactivity controlled compression ignition (RCCI) combustion by using a fuel additive. They observed and analyzed the effects of fuel additive on performance and emission parameters. Ganesh et al. [23] investigated the effect of nano-fuel additive on emission parameters. They revealed that nano-fuel additives have a decrement effect on emissions parameters in the scope of this study.

In line with these studies, fuel additive has critical importance to solve the engine exhaust emission and performance problems and is a feasible and proven method. Although some studies have been done about the usage of NH₃ as a fuel additive, there is a lack for engine performance, vibration and emission parameters in the literature. The studies that are used NH₃ as a fuel additive are respectively revealed in the following section,

Ryu et al. [24] investigated the effects of NH₃ and dimethyl ether (DME) mixtures on the combustion and emissions parameters in a compression ignition engine. They revealed result that high NH₃ content can be applied in diesel engines when a suitable injection system is selected for NH₃ additive. In addition to that, the exhaust control system was used to reduce emission gases in this study. Şahin et al. [25] investigated to observe the effects of NH₃ on the engine performance and exhaust emissions parameters by using NH₃ fumigation method. The obtained results revealed that NH₃ can be used as a fuel additive in diesel engines. Reiter et al. [26] investigated the effects of NH₃-diesel fuel mixtures on the combustion and emissions parameters in the compression-ignition engine. The obtained results showed that if the amount of NH₃ in the diesel fuel does not exceed 60%, the significant reduction can be obtained in the NO_x emission parameter. The lower flame temperature and the amount of NH₃ can cause the reduction of NO_x emission parameter in the compression-ignition engine. R. Sivasubramanian et al. [27] investigated the effects of the mustard methyl ester with NH₃ additive on the emissions parameters of compression ignition engines. A significant reduction was obtained in emission parameters as a result of this study. Ryu et al. [28] developed a direct injection system for using gaseous NH₃ in a

spark-ignition engine and investigated the effects of NH_3 -gasoline mixtures on the engine performance and emission parameters. The obtained results showed that the NH_3 additive decreased the brake specific carbon monoxide (BSCO) for all combinations. On the other hand, the NH_3 additive dramatically increased brake specific hydrocarbon (BSHC) due to the reducing of NH_3 combustion temperature and the NH_3 additive caused the increment of NO_x emissions parameter in this study. Gross et al. [29] investigated the effects of NH_3 -DME mixtures combinations on the combustion and emission parameters in a compression-ignition engine. The obtained results revealed that when the NH_3 was added to DME fuel, the combustion pressure and temperature decreased in compression ignition engine. Therefore, CO and HC emission parameters showed a certain increment but on the other hand, soot emission remained so low according to other emission parameters. H. Kobayashi et al. [30] investigated NH_3 combustion on a large scale and analyzed the effects of NH_3 combustion on emission and performance parameters. Moreover, the utilization and challenges of NH_3 were explained in the scope of this study.

Main fuel variety (diesel, biodiesel, and etc.) has critical importance to determine the effects of NH_3 additive on engine performance, vibration and exhaust emission parameters. Besides, the main fuel variety is one of the most parameters that increase the accuracy and validity of the study. As explained in the previous sections, biodiesel (sunflower, hazelnut, peanut and waste oil biodiesel) as the main fuel was produced from vegetable oil by using the transesterification method in this study. NH_3 as a fuel additive was added in a certain proportion (5%, 10%, and 15%) to overcome the disadvantages of biodiesel fuels. The literature review was made about the types of biodiesel that is used as the main fuel. This literature review revealed that biodiesel was used as an effective main fuel in internal combustion engines. The studies that investigate biodiesel as the main fuel are respectively given in the following section.

G. Knothe et al. [31] investigated the biodiesel fuels on a large scale. They analyzed the development of biodiesel according to different perspectives. Moreover, this study has the potential to guide other studies in the biodiesel literature. L. Lin et al. [32] investigated the opportunities and challenges against the usage of biodiesel fuels. They concluded that the usage of renewable fuels should be increased to reduce greenhouse gases in the atmosphere. In this sense, they revealed that the most suitable fuel to achieve this goal is biodiesel.

Tüccar et al. [33] investigated methyl ester of microalgae oil as fuel in a diesel engine. They revealed that microalgae biodiesel reduced NO_x and CO emissions. Besides, they experimentally analyzed the power and torque parameters. Yesilyurt [34] investigated the energetic and exergetic performance parameters by using peanut oil biodiesel and diesel fuel in compression ignition engines. The obtained results revealed that biodiesel can be produced from peanut oil and peanut oil biodiesel has a similar effect with diesel fuel on energetic and exergetic performance parameters. M. Akcay et al. [35] investigated the effect of hydrogen addition on the engine performance, and exhaust emission parameters by using diesel fuel-waste oil biodiesel as a main fuel. This study revealed that hydrogen enrichment of the intake air has positive effects on the engine performance and exhaust emission parameters when diesel, diesel-waste oil biodiesel were used as a main fuel. C. Dueso et al. [36] investigated the behaviour of sunflower oil biodiesel with a natural antioxidant addition produced from bio-oil extraction in a diesel engine. This study revealed that there are no significant differences between neat sunflower biodiesel and same biodiesel with the bio-oil additive in an internal combustion engine. I. Çelikten et al. [37] investigated the alternation of the performance and exhaust emission parameters of a diesel engine by using diesel, rapeseed oil and hazelnut oil methyl ester blends. Diesel fuel gave better results for engine performance parameters according to biodiesel fuels. On the other hand, lower CO and smoke emission results were obtained when the biodiesel was used in this study.

Software that numerically analyzes combustion is very important for the optimization and development of internal combustion engines. The effects of fuel and fuel additive on emission and performance parameters can clearly be observed by using such software. As mentioned in the previous section, Diesel-RK can basically be described as the optimizing and simulating programme that analyzed the emission, performance, and etc. In the literature, there are several studies that investigate these parameters by using the Diesel-RK Programme.

Kuleshov [38] constituted a model to predict air-fuel mixing, combustion and emission parameters for a diesel engine by using the Diesel-RK Programme. This model contains all operating ranges. Al-Dawody et al. [39] investigated that the combustion, performance and emission parameters of soybean biodiesel-diesel mixtures in Diesel-RK Programme. Datta et al. [40] investigated that the engine emission and performance parameters of diesel-biodiesel-

methanol mixtures in the Diesel-RK Programme. Kuleshov and Grekhov et al. [41] multidimensionally optimized the diesel engine in the Diesel-RK Programme. They used the multi-zone fuel spray combustion and NO_x formation models in the optimization process.

Besides the engine emission and performance parameters, the vibration parameter has a decisive importance in terms of the originality of the study. Moreover, engine vibration is one of the oldest parameters that is studied in the literature. Therefore, many studies about vibration parameter in the literature are respectively given in the following section.

T. Ramachandran et al. [42] investigated internal combustion engine vibrations and mountings. They researched different vibration measurement techniques and mountings to decrease the engine vibrations. S. Javed et al. [43] investigated the vibration parameter in a diesel engine by using biodiesel fuel and different fuels blends. Moreover, they generated an ANNs model to predict RMS velocity. D.P. Satsangi and N. Tiwari [44] experimentally analyzed the combustion, noise, vibrations, performance and emissions parameters in the genset engine by using diesel/n-butanol blends. Tüccar [45] investigated the effects of hydroxy gas enrichment on the vibration, noise and emission parameters by using *Foeniculum vulgare* oil biodiesel (FVB) and diesel fuel. More desirable vibration results were recorded for FVB in the scope of this study. Moreover, a decrement was shown in CO emissions. On the other hand, NO_x emission increased with FVB and HHO utilization.

The comparison of the experimental results with the results of the ANNs model is a fairly new concept in the fuel additive literature. Therefore, there are few studies in the literature that are supported by ANNs models. In this sense, the ANNs model has been generated in order to eliminate this lack in the literature. Studies that investigate the ANNs model are respectively given in the following section.

Uludamar et al. [46] investigated vibration of a hydroxyl (HHO) gas generator installed diesel engine according to different diesel-biodiesel blends. In addition to that, they used a ANNs model to predict and validate the experimental results. D. Boruah et al. [47] basically investigated the engine performance of internal combustion engines by using ANNs. They revealed that ANNs is an applicable model due to having high accuracy ratio for internal combustion engine performance parameter. A. Bhaskar Garg et al. [48]

observed the effects of ANNs on the internal combustion engine performance and emission parameters. They created three sets of prediction model to compare with the experiment results and found the best model for all dataset. Uslu [49] predicated engine emissions and performance parameters of a single-cylinder diesel engine by using ANNs model. They constituted high accurate ANNs model when the experimental results were compared with algorithm results. Çelebi et al. [50] experimentally investigated noise, vibration and emission parameters in an unmodified diesel engine by using the ANNs model. It was revealed that an increment was observed in CO₂ and NO_x emissions and the ANNs model was generated to predict the vibration parameter.



3. MATERIALS AND METHODS

In the scope of this study, different types of biodiesel fuels (sunflower, hazelnut, peanut and waste oil biodiesel) were produced from vegetable oils by using the transesterification method as explained in the previous section. These biodiesel fuels have been blended with NH_3 additive in certain proportions (5%, 10% and 15%). These mixture fuels can respectively be described as S100, S95A5, S90A10, S85A15, P100, P95A5, P90A10, P85A15, N100, N95A5, N90A10, N85A15, and W100, W95A5, W90A10, W85A15. All mixtures were burned in the Mitsubishi Canter 4D31 diesel engine. The Mitsubishi Canter 4D31 diesel engine was simulated at no load condition during the experiment. The engine speed gradually was increased with 300 rpm increment from 1200 rpm until 2400 rpm. In addition to that, the vibration parameter was recorded by using the accelerometer sensor. All experimental data were recorded for all mixture fuels according to explained parameters in the previous section. The ANNs models were generated to predict the vibration data for all NH_3 additive ratios. The simulation results were compared with the experimental results. The effects of NH_3 as a fuel additive experimentally and numerically were evaluated on the vibration, emission, and performance parameters.

3.1. Test Engine

All experimental researches were carried out on a four-stroke, four-cylinder Mitsubishi Canter 4D31 diesel engine experimental setup in the machine theory and dynamics laboratory of Adana Alparslan Türkeş Science and Technology University. The test engine was operated with the sunflower, peanut, hazelnut, and waste oil biodiesel blended with 5%, 10%, and 15% NH_3 additive ratios to observe the effects of NH_3 as a fuel additive on the vibration parameter.

The layout of the Mitsubishi Canter 4D31 diesel engine (1) Eddy Current Dynamometer, 2) Mitsubishi Canter 4D31, 3) Accelerometer sensor, 4) Fuel Tank, 5) Intake Manifold, 6) Exhaust Manifold, 7) Exhaust Emissions, and 8) Engine Control software) was shown in Figure 12. The technical specifications of the Mitsubishi Canter 4D31 diesel engine were tabulated in Table 4.

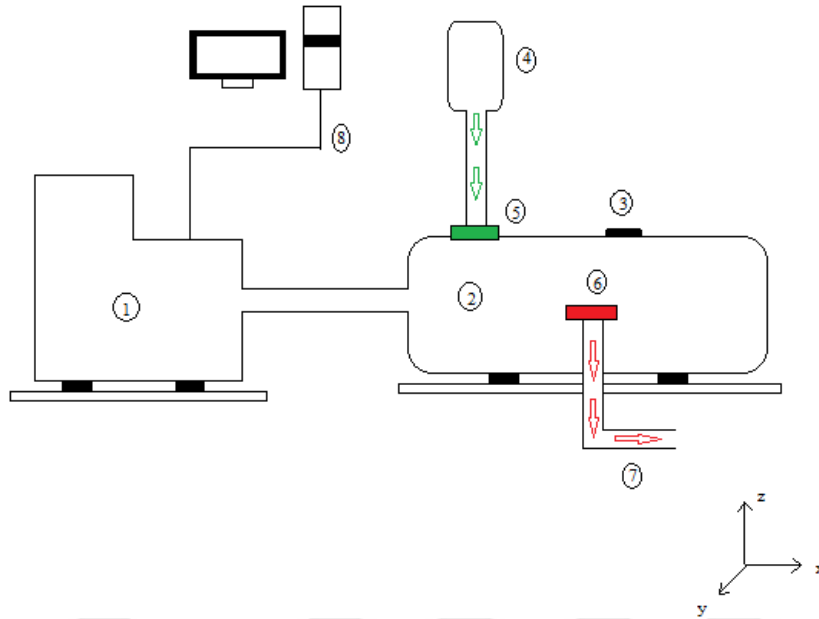


Figure 12. The layout of Mitsubishi Canter 4D31 diesel engine

Table 4. Technical specifications of Mitsubishi Canter 4D31 diesel engine [45]

Brand	Mitsubishi Canter
Model	4D31
Configuration	In line 4
Type	Direct injection diesel with glow plug
Displacement	3298cc
Bore	100
Stroke	105
Power	91 HP @ 3500 rpm
Torque	223 Nm @ 2200 rpm
Oil Cooler	Water cooled

The selection of the test engine type has critical importance to observe correctly the effect of NH_3 as a fuel additive on all exhaust emission, performance, and vibration parameters. Therefore, the diesel engine (Mitsubishi Canter 4D31) was selected as the test engine for the vibration experiments due to having some advantages. These advantages can be described as diesel engines have high overall efficiency and have lower CO emission. On the other hand, they can produce more NO_x emissions according to petrol engines. Besides, the importance of the vibration parameter has increased more due to the old engine model.

3.2. Biodiesel

In accordance to ASTM, the term biodiesel assigned for monoalkyl esters of long-chain fatty acids resulting from edible oils, non-edible oils and waste oils, which produced from the transesterification process of triglycerides using methanol and catalyst [51]. As mentioned in the previous sections, the energy deficit of the world continues to increase every year depending on industrialization and the increase in consumption. Therefore, our dependence on petroleum and many energy sources which are its derivatives has gradually increased in order to eliminate this energy deficit. Therefore, biodiesel has been a wide field of study for a lot of energy sectors due to having advantages according to other fuel types. In this sense, biodiesel has different generations in terms of its raw materials, production methods, and having the energy content.

3.2.1. Biodiesel Generations

Biodiesel has many generation groups since it has a wide history. These generations can be classified as 1st, 2nd, 3rd and 4th generations. This classification was made according to a lot of determinant factors. These determinant factors have been divided into generations with continuous development in the literature over many years. The information about the classification of biodiesel production for different generations was given in Figure 13.

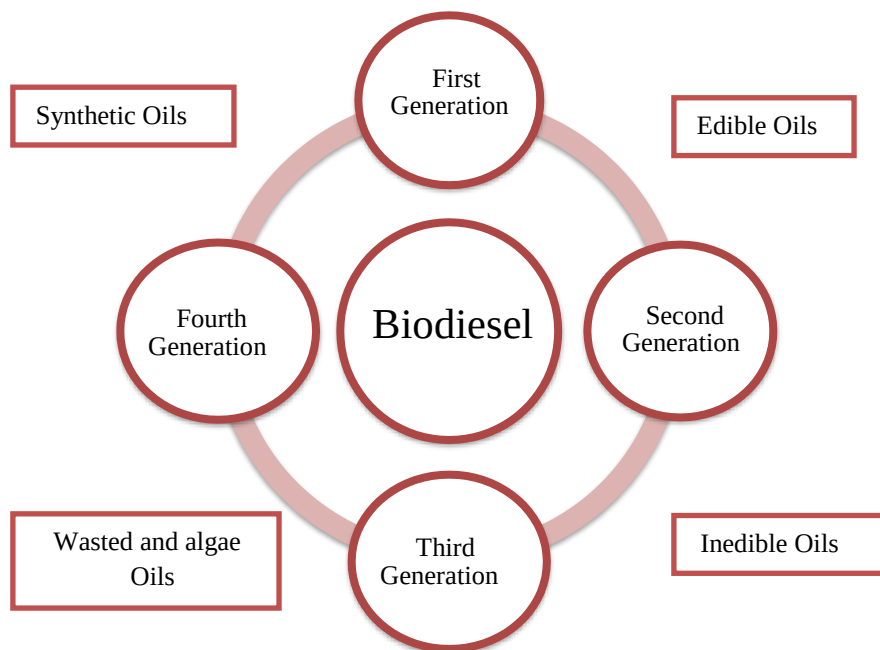


Figure 13. The classification of the biodiesel production for different generations [52]

First-generation biodiesels can be produced from edible feedstocks. These edible feedstocks are rapeseed oil, soybean oil, coconut oil, corn oil, palm oil, mustard oil, olive oil, rice oil, etc. [53]. This generation has some disadvantages according to other generations due to being the feedstock of expensive food products. Therefore, different feedstocks were searched for biodiesel production.

Second generation biodiesels can be produced from non-edible feedstocks, example of non-edible feedstocks are neem oil, jatropha oil, nagchampa oil, karanja oil, calophyllum inophyllum oil, rubber seed oil, mahua indica oil, etc. [54,55]. Second-generation biodiesels have lower emission values. Moreover, it has cheaper feedstocks according to the cost of first-generation biodiesel.

Third-generation biodiesels can be produced from microalgae and waste oils are termed [56]. Higher fuel efficiency and lesser greenhouse effect can be shown as the main benefits of third-generation biodiesels according to others.

Fourth-generation biodiesels can be described as photobiological solar fuels and electro-fuels. It is a new study field for biodiesel production in literature. In addition to that, the feedstocks of fourth-generation biodiesel are widely available, inexhaustible, and cheap [51].

3.2.2. Biodiesel Feedstocks

The feedstock has always been a determinant and critical factor in biodiesel researches for years. As explained in the previous section, biodiesel feedstock can be classified into different generations. Biodiesel production was carried out by using different feedstocks during the experimental stage of the study. Therefore, the selection of feedstock has an important place in terms of the scope of the study. Besides, the feedstock of biodiesel must be examined the produced biodiesel to be sustainable and applicable in every aspect.

Biodiesel production from vegetable oils has a long history. In this section, the sunflower, hazelnut, peanut, and waste oil was investigated due to being the feedstocks of produced biodiesel. There is no shortage of feedstocks as sunflower, hazelnut and peanut oils regularly are consumable by people. Besides, they are in the first generation biodiesel class. When sunflower feedstock was compared with other feedstock, sunflower feedstock is one of the

most used feedstocks in the world in terms of quantity due to having easy cultivation and wide usage properties. Therefore, sunflower feedstock is cheaper and more common feedstock according to other feedstocks in the literature. On the other hand, hazelnut and peanut feedstocks are quite expensive due to growing difficulties and low production capacity. This situation causes the production of hazelnut and peanut biodiesel to be limited.

Waste oil feedstock is in the third generation biodiesel class. The rate of waste is increasing every year in every area depending on the increment in the human population around the world. Many applications are made to prevent this situation and biodiesel production from waste oil is one of these applications. Waste oil feedstock, which is very critical in terms of recycling, has many advantages according to other feedstock types. It has a feasible infrastructure as well as lower emission, cost and high energy content.

3.2.3. Benefits and Limitations of Biodiesel

Biodiesel basically can be described as a non-toxic and green fuel due to having organic fats. Nowadays, biodiesel constitutes a powerful alternative due to having some advantages against petroleum and diesel fuels. On the other hand, there are also many disadvantages such as feedstock cost, infrastructure problem and etc. The information about the benefits of biodiesel was tabulated in Table 5.

Table 5. Benefits of the usage of biodiesel [57]

Benefits of biodiesel
Biodiesel is produced from renewable resources
Biodiesel positively affects the engine life due to not having sulfur.
Since biodiesel is a carbon-free fuel, it causes a significant decrease in carbon dioxide emissions
Biodiesel reduces the dependence of countries on foreign fuel suppliers.
Biodiesel is a biodegradable and non-toxic fuel.
The negative effect of biodiesel is less on the quality of air according to other fuels.
Biodiesel can be stored easily due to high flammability limit temperature.

All limitations about the usage of biodiesel were given in Table 6. The advantages and disadvantages of biodiesel were evaluated in a wide range in this study.

Table 6. Limitations of the usage of biodiesel [57]

Limitations of biodiesel
The combustion quality of biodiesel may differ in different fuels.
Some biodiesel varieties are more expensive than conventional fuels due to their feedstock costs.
Biodiesel can be harmful for the rubber houses of engine in long-term usage.
Biodiesel can create serious food shortage depending on the its feedstock.
Biodiesel can cause clogging in the engine due to collecting the dirt in the fuel filters.
Biodiesel slightly can increase the quantities of NO _x .
Biodiesel does not have sufficient infrastructure due to its limited usage according to petroleum derived fuels.

3.2.4. Biodiesel Properties

After the biodiesel production process is completed, the chemical and physical properties of the fuel should be examined according to a lot of parameters. Therefore, all characteristic properties of pure oils and produced biodiesels were investigated and compared with each other to reveal the differences between them. In this sense, the effects of different kind of biodiesel fuels can clearly be observed on emission, performance, and vibration parameters.

The pure oils and produced biodiesel were characterized in accordance with a viscosity at 40 °C, density at 15 °C, iodine value (IV), acid value (AV), cetane number, heating value, flash point, carbon residual, and sulfur content parameters. The information about these parameters for produced biodiesel and pure oils were respectively given in Table 7 and Table 8.

All chemical and physical parameters can be briefly explained as follows; a decrement was observed in the density of pure oils after they were converted to biodiesel. The kinematic viscosity parameter has critical importance due to indicating the ability of the fuel to atomize into small droplets in the combustion chamber [58]. IV can be described as a measure of the unsaturation of oils and fats [59]. AV measures free fatty acids and is a parameter that directly affects storage, quality and etc. [60]. Cetane number is a determinant parameter due to describing the combustion quality of the fuel. The heating value parameter is directly proportional to the chain and saturation degree of biodiesels. Flashpoint basically can be

described as the lowest ignition temperature. Carbon residual and sulfur content parameters can directly affect the amount and content emission of the gases.

Table 7. The chemical characteristics of pure oils [61]

Feedstock	Viscosity at 40 °C (mm ² / s)	Density at 15 °C (g/cm ³)	Iodine value	Acid value (mgKOH/g)	Cetan e num.	Heating value (MJ/kg)	Flash point (°C)	Carbon residual	Sulfur content (wt %)
Sunflower [62,63,64]	34.01	918	129.5	0.302	38.1	39.56H	256	0.275	0.01%
Hazelnut [64,65]	24.0	945	94.32	0.95	52.9	39.9	325	0.21	0.025%
Peanut [66]	39.8	895	116.2	-	36.2	39.8	234.8	0.22	0.01%
Waste Oil [67, 68]	35.3	900	95.85	2.04	61	39.96	275	-	-

Table 8. The chemical characteristics of biodiesels produced from pure oils [61]

Biodiesel	Viscosity at 40 °C (mm ² / s)	Density at 15 °C (g/cm ³)	Iodine value	Acid value (mgKOH/g)	Cetan e num.	Heating value (MJ/kg)	Flash point (°C)	Carbon residual	Sulfur content (wt %)
Sunflower [51, 64,69,70]	4.26	869	128.7	0.357	45.7	34.71 L, 40.6H	180.3	-	-
Hazelnut [65]	4.81	896	109	0.351	62.95	39.58	172.7	-	7 ppm
Peanut [51]	4.69	878	67.45	-	58.24	35.33	176	-	-
Waste Oil [71]	4.57	855	-	-	52.2	40.50	126	-	-

3.3. Procedure of Biodiesel Production

In the experimental section of the study, biodiesel production from vegetable oil is carried out in the laboratory of Adana Alparslan Türkeş Science and Technology University. The sunflower, hazelnut, peanut, and waste oil biodiesel were produced according to the following procedure; the preparation process of vegetable oils, the transesterification process, the

separation process, the washing process, the drying process and the filtration process. The flow chart of the biodiesel production process was given in Figure 14.

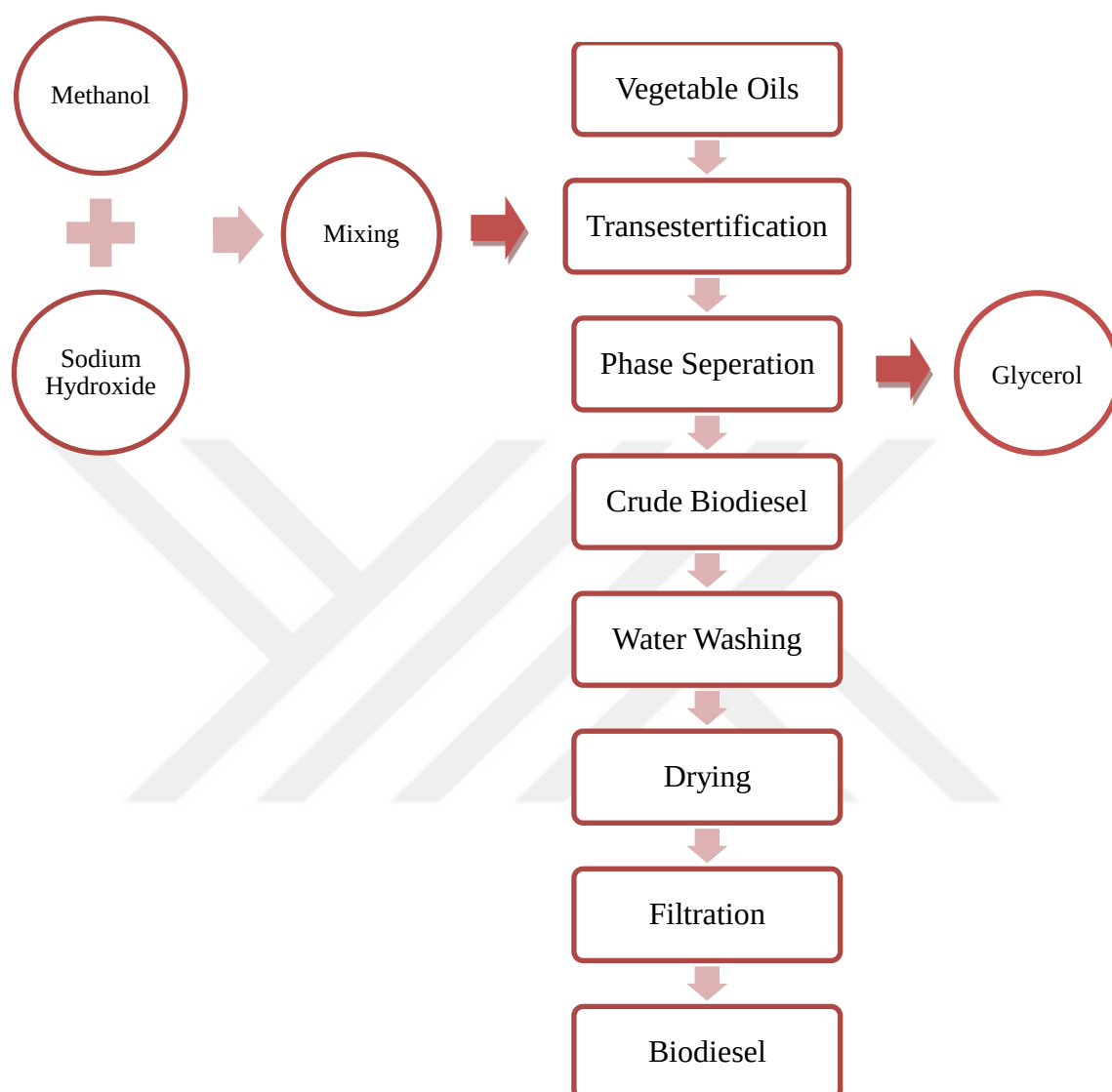


Figure 14. Procedure of biodiesel production

The tools and equipment that are used in this experimental research respectively are as follows; vegetable oil (sunflower, hazelnut, peanut, and waste oil), monohydric alcohol (methanol) (CH_3OH), basic catalyst (caustic soda) (NaOH), magnetic stirrer and heater, precision balance, tape measure, separatory funnel, beaker, and washing bottle.

3.3.1. Preparation of Vegetable Oils

The selection of pure oils is a critical part of the production of biodiesel. The sunflower, hazelnut, peanut, and waste oil were selected as pure oils. As mentioned in the previous

section, these pure oils are in the first and third generations. The biodiesel production process starts with this step; the weight and volume of the feedstocks were measured to determine the ratio of NaOH and CH₃OH for a catalyst mixture. The images about the preparation of the vegetable oils were given in Figure 15.

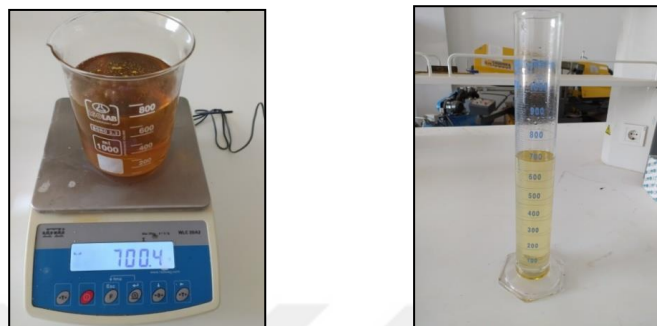


Figure 15. Volume and weight measuring of pure oil

Due to the fact that the catalyst mixture decreases the pure oil temperature, the temperature of pure oil was kept constant at approximately 64 °C and 470 rpm by a magnetic heater and stirrer. The catalyst mixture was prepared by mixing NaOH and CH₃OH. This mixture contains 20% CH₃OH and 5‰ NaOH of the weight of pure oil. This mixture was prepared to catalyst the transesterification reaction. The information about catalyst mixture was given in Figure 16.

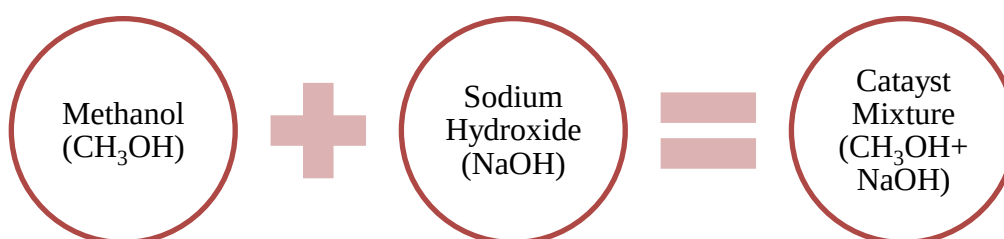


Figure 16. The mixture of NaOH and CH₃OH

3.3.2. Transesterification

After the preparation of the catalyst mixture, it is added to pure oil to initiate the transesterification process. This situation causes the temperature of the pure oil to drop from 64 °C to 60 °C. This temperature value has a critical importance for the transesterification process to take place at optimum efficiency. Most of the reaction takes place within the first 5

minutes. It must be carried out for 1 hour at 60 °C and 470 rpm in order to achieve 100% efficiency.

Different biodiesel production methods have been used in the scope of biodiesel literature. These methods can be defined as; direct use and blending, transesterification, thermal cracking (Pyrolysis), and microemulsion methods. The transesterification process was used as a production method due to having some advantages in this study. Transesterification is a conventional, low cost and simpler method according to thermal cracking and microemulsion methods in the production of biodiesel. The transesterification method can be described as consisting of a reaction between a vegetable oil or animal fat and short-chain alcohol (methanol or ethanol), by using a specific catalyst for obtaining ethyl esters (biodiesel) and glycerol [72]. The catalytic transesterification processes involve the reaction of a triglyceride (fat or oil) with alcohol to constitute the esters and glycerol with a catalyst. A triglyceride has a glycerin molecule as its base with three long-chain fatty acids attached [73]. This process consists of three reversible reactions. In each step, glycerides are transformed into glycerol, and one ester is produced [74]. The mechanism of transesterification reaction was respectively given in Figure 17.

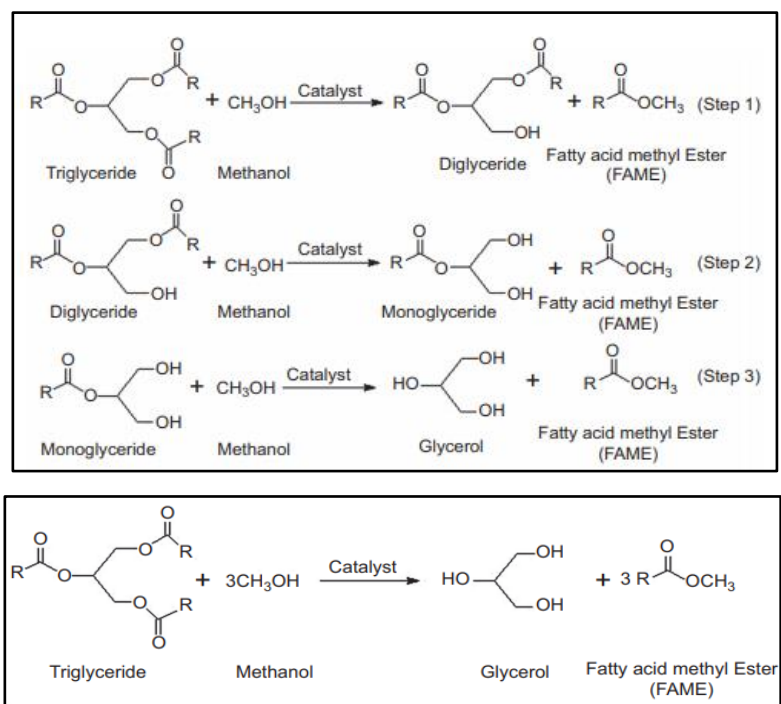


Figure 17. Reaction steps of transesterification process by using CH_3OH - NaOH mixture [75]

After the transesterification reaction was completed, the glycerol and biodiesel phases formed separately from each other within 8 hours. The information about the conversion of fatty acid into biodiesel is given in Figure 18.

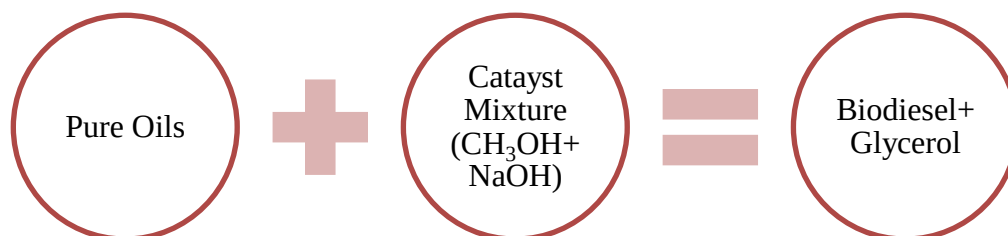


Figure 18. Conversion of fatty acid into biodiesel

Biodiesel production options can be diversified on the basis of the transesterification. These options have some pros and cons according to the type of used catalysis. NaOH, potassium hydroxide (KOH), and their derivations are the most common homogenous alkaline catalysts due to having some advantages such as short reaction time and high biodiesel yield [76,77,78]. In this study, CH₃OH - NaOH was used as a catalysis mixture to carry out the transesterification reaction. Different catalysis options were given in Figure 19.

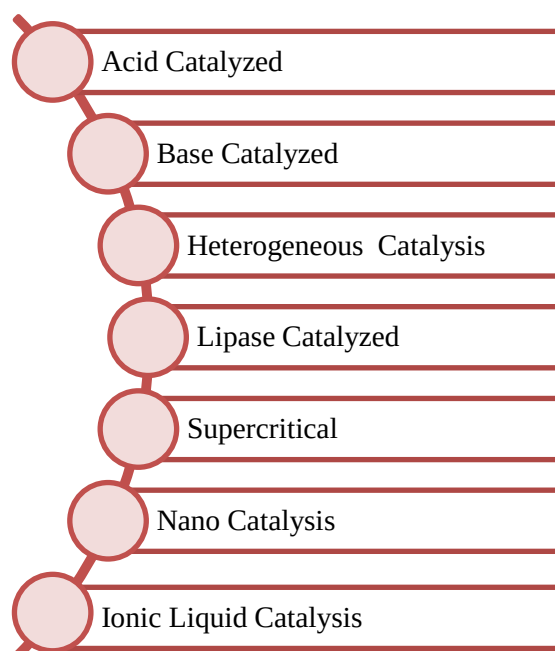


Figure 19. Transesterification process types [73]

3.3.3. Separation and Washing Process

In the production of biodiesel, separation and washing processes are determinant factors for improving the quality and efficiency of biodiesel. After the transesterification process, vegetable oil is transferred into the separatory funnel to remove glycerol from biodiesel. Biodiesel and glycerol sections were clearly observed in a short time after the completion of the transfer process. Biodiesel in the separatory funnel must be kept waiting for 8 hours to minimize the amount of glycerol in biodiesel. After 8 hours, the accumulated glycerol in the bottom layer is removed by the tap of the funnel. The steps of the separation process were given in Figure 20.

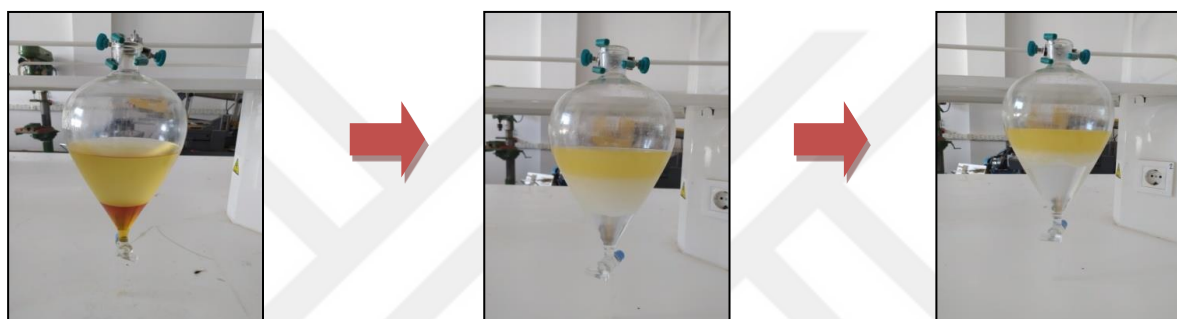


Figure 20. Separation process

Despite the removal of the separated glycerol due to the density difference, there may still be a small amount of glycerol in the biodiesel. Therefore, the washing process is started in order to completely remove the glycerol from the biodiesel. The washing process plays an important role on the combustion and chemical properties of biodiesel. The procedure of the washing process is as follows; some water is added to the biodiesel and the rinsing process is done. After a certain period of time, water and glycerol react as a result of this process and foam is formed in the bottom layer. The foam is removed by the tap of the funnel. This process ends when the amount of glycerol in the biodiesel is depleted and only water remains in the bottom layer.

3.3.4. Drying Process

After the completion of the separation and washing process, a drying process must be made as the last step of the production process. Water droplets can adversely affect the combustion efficiency of biodiesel production. Therefore, the drying process is carried out to remove the water droplets formed in the biodiesel due to the washing process. The drying process takes

place as follows; the magnetic stirrer stirs the biodiesel at approximately 100 °C and 470 rpm for 1 hour to evaporate the water droplets in the biodiesel. The drying process was given in Figure 21.

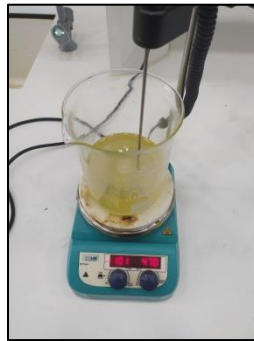


Figure 21. Drying process

3.3.5. Filtration Process

Biodiesel purity is one of the determining factors due to affecting directly the quality and efficiency of the biodiesel. Therefore, the filtration process must be made to remove undesirable substances. After the biodiesel production process is completed, some undesirable substances that occur during the production may accumulate in the bottom layer of biodiesel. This process is made as follows; the biodiesel is leached by filtration paper and impurities are removed. The filtration process was given in Figure 22.



Figure 22. Filtered biodiesel

3.4. Internal Combustion Engine

An internal Combustion Engine (ICE) can basically be defined as a heat engine that converts chemical energy in a fuel into mechanical energy. It was invented in the 1860s and had been the most complex and engineering-based invention ever invented by humanity until this date.

Therefore, it has a wide historical background. Nowadays, the improvement of ICE gradually continues in every application areas. The historical development of the ICE is as follows; steam engines, lenoir engines, otto-langen engines, otto four-stroke engines, two-stroke engines, diesel four-stroke engines and wenkel engines.

3.4.1. Working Principle of Four-Stroke ICE

The working mechanism of ICE is based on a similar basis. In this sense, there are four sections for the working mechanism of the diesel engine. These are suction, compression, expansion or power and exhaust strokes. These strokes can respectively be described as follows [79];

1. In suction stroke, the air is introduced into the cylinder by the intake valve. At this time, the exhaust valve is closed.
2. In compression stroke, the air in the cylinder is compressed until the clearance volume by the piston. At this time, the intake and exhaust valves are closed.
3. In expansion or power stroke, the fuel is injected into the cylinder at the end of the compression stroke. The combustion occurs at the constant pressure and product gases expand doing work. At this time, the intake and exhaust valves are closed during the stroke.
4. In exhaust stroke, the piston moves from the top dead centre (TDC) until the bottom dead centre (BDC) due to the product gases. Product gases pushed out of the cylinder by the exhaust valve. At this time, the intake valve is closed and the exhaust valve is open during the stroke.

The imagine about the four-stroke of a compression ignition engines (CI) was given in Figure 23.

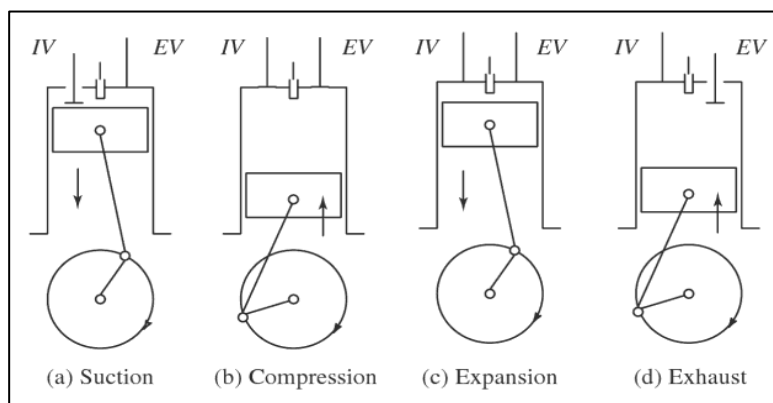


Figure 23. Four-stroke of a CI engine [79]

$1 \rightarrow 0$ or $0 \rightarrow 1$ processes are represented to analyze the suction and exhaust strokes in Figure 21 [79]. In diesel cycle, the process sequence was given in Table 9 and change trend of p-V and T-s diagrams during the combustion processes was given in Figure 24.

Table 9. The process sequence of p-V and T-s diagrams

Process 1 $\rightarrow$ 2	Isentropic compression
Process 2 $\rightarrow$ 3	Constant pressure heat addition
Process 3 $\rightarrow$ 4	Isentropic expansion
Process 4 $\rightarrow$ 1	Constant volume heat rejection

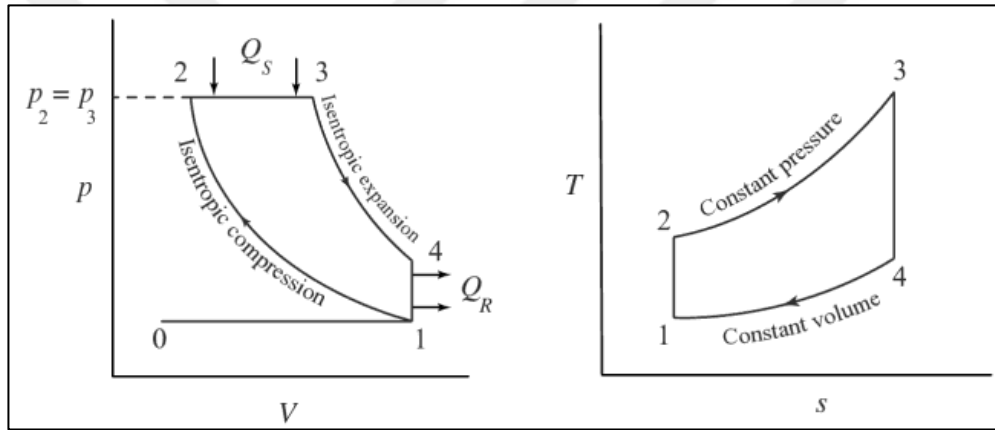


Figure 24. p-V and T-s of a diesel cycle [79]

3.4.2. Thermal Efficiency and Net Work Output

The thermal efficiency is one of the most important parameter that gives informations about the engine performance. Besides, different biodiesel fuel types and NH_3 additive ratios have a significant thermal effect in terms of the efficiency of the engine. Therefore, thermal efficiency is an important factor in the evaluation of performance parameters in the scope of this study. The thermal efficiency formulation of a diesel engine was proven according to p-V and T-s cycles.

$$n_{\text{Diesel}} = \frac{Q_S - Q_R}{Q_S} \quad (1a)$$

$$= \frac{mC_p(T_3 - T_2) - mC_v(T_4 - T_1)}{mC_p(T_3 - T_2)} \quad (1b)$$

$$= 1 - \frac{C_v(T_4 - T_1)}{C_p(T_3 - T_2)} \quad (1c)$$

$$= 1 - \frac{1}{\gamma} \left(\frac{T_4 - T_1}{T_3 - T_2} \right) \quad (1d)$$

Considering the process $1 \rightarrow 2$

$$T_2 = T_1 \left(\frac{V_2}{V_1} \right)^{(\gamma-1)} = T_1 r^{(\gamma-1)} \quad (2)$$

Considering the constant pressure process $2 \rightarrow 3$

$$\frac{V_2}{T_2} = \frac{V_3}{T_3} \quad (3a)$$

$$\frac{T_3}{T_2} = \frac{T_3}{T_2} = r_c \quad (3b)$$

$$T_3 = T_2 r_c \quad (3c)$$

$$T_3 = T_1 r^{(\gamma-1)} r_c \quad (3d)$$

Considering the process $3 \rightarrow 4$

$$T_4 = T_3 \left(\frac{V_3}{V_4} \right)^{(\gamma-1)} \quad (4a)$$

$$= T_3 \left(\frac{V_3}{V_2} \times \frac{V_2}{V_4} \right)^{(\gamma-1)} \quad (4b)$$

$$= T_3 \left(\frac{r_c}{r} \right)^{(\gamma-1)} \quad (4c)$$

$$T_4 = T_1 r^{(\gamma-1)} r_c \left(\frac{r_c}{r} \right)^{(\gamma-1)} = T_1 r_c^\gamma \quad (4d)$$

Thermal efficiency of a diesel engine;

$$n_{Diesel} = 1 - \frac{1}{\gamma} \left[\frac{T_1 (r_c^\gamma - 1)}{T_1 (r^{(\gamma-1)} r_c - r^{(\gamma-1)})} \right] \quad (5a)$$

$$= 1 - \frac{1}{\gamma} \left[\frac{(r_c^\gamma - 1)}{(r^{(\gamma-1)} r_c - r^{(\gamma-1)})} \right] \quad (5b)$$

$$= 1 - \frac{1}{r^{(\gamma-1)}} \left[\frac{(r_c^\gamma - 1)}{\gamma (r_c - 1)} \right] \quad (5c)$$

The net work output is another determinant parameter in terms of the proven thermal efficiency in the previous section. The net work output formulation was proven by using parameters in the combustion cycles.

$$W = p_2 (V_3 - V_2) + \frac{p_3 V_3 - p_4 V_4}{\gamma - 1} - \frac{p_2 V_2 - p_1 V_1}{\gamma - 1} \quad (6a)$$

$$= p_2 V_2 (r_c - 1) + \frac{p_3 r_c V_2 - p_4 r V_2}{\gamma - 1} - \frac{p_2 V_2 - p_1 r V_2}{\gamma - 1} \quad (6b)$$

$$= V_2 \left[\frac{p_2 (r_c - 1)(\gamma - 1) + p_3 r_c - p_4 r - (p_2 - p_1 r)}{\gamma - 1} \right] \quad (6c)$$

$$= V_2 \left[\frac{p_2(r_c - 1)(\gamma - 1) + p_3 \left(r_c - \frac{p_4}{p_3} r \right) - p_2 \left(1 - \frac{p_1}{p_2} r \right)}{\gamma - 1} \right] \quad (6d)$$

$$= p_2 V_2 \left[\frac{(r_c - 1)(\gamma - 1) + (r_c - r_c^\gamma - r^{(1-\gamma)}) - (1 - r^{(1-\gamma)})}{\gamma - 1} \right] \quad (6e)$$

$$= \frac{p_1 V_1 r^{(\gamma-1)} [\gamma(r_c - 1) - r^{(1-\gamma)}(r_c^\gamma - 1)]}{\gamma - 1} \quad (6f)$$

Other related engine performance parameters can be diversified as indicated thermal efficiency, brake thermal efficiency, mechanical efficiency, volumetric efficiency, mean effective pressure, mean piston speed, specific power output, specific fuel consumption, fuel-air ratio, calorific value of the fuel [79].

3.4.3. Combustion in CI Engine

As described in the previous section, the combustion process begins with the injection of fuel into the cylinder in CI engines. The injected fuel mixes with the air and the ignition process instantaneously takes place. This process can be classified into 4 stages to observe the combustion characteristic. The image of the combustion stages in CI engines was given in Figure 25.

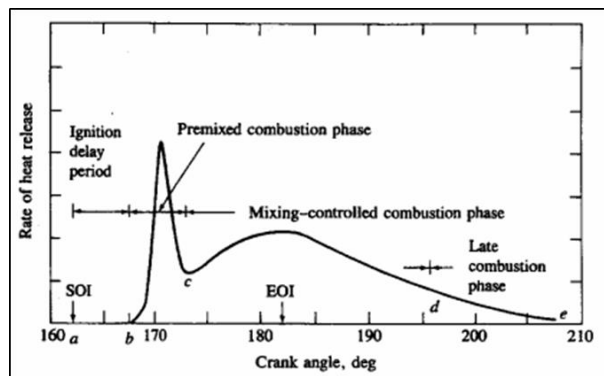


Figure 25. Combustion stages in CI engines [80]

These 4 stages can respectively be described as follows [80];

- In the ignition delay time (ab), the fuel that is injected into the cylinder evaporates in a short time and mixes with the pressurized air.
- In the pre-mixed combustion phase (bc), in a few crank angles, the mixture (fuel+air) combusts in the flammability limit during the ignition delay period.
- Mixing-controlled combustion phase (cd), the burning rate is controlled by the rate at which mixture becomes available for burning with consuming of premixed gas. The burning rate is controlled primarily by the fuel-air mixing process.
- Late combustion phase (de), heat release continues at a lower rate for expansion stroke. Therefore, fuel completely may not have burned. A fraction of the fuel energy is present in soot and other combustion products.

3.4.4. NH₃ Combustion

The NH₃ as a fuel additive can be combined with the other conventional fuels. In this sense, the combustion of the NH₃ was investigated to reveal its effects on the engine emission, performance, and vibration parameters.

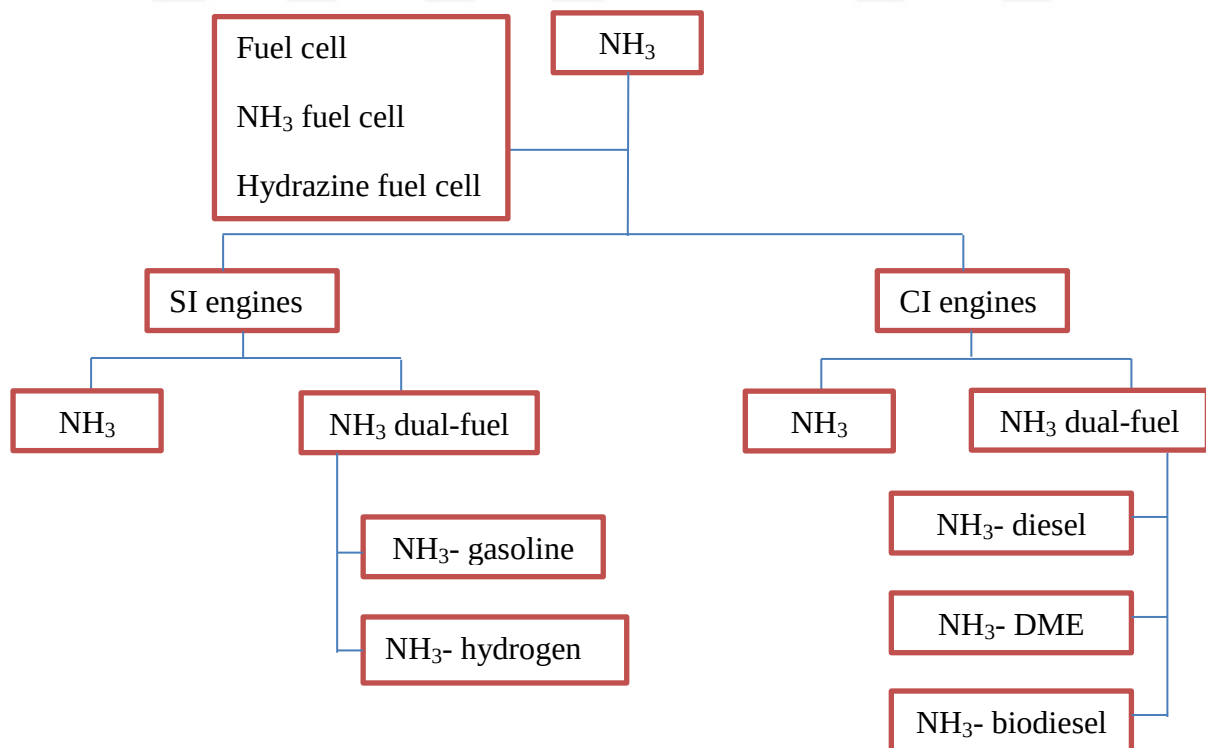


Figure 26. The classification of the NH₃ as a fuel additive [81]

The information about the classification of the NH_3 as a fuel additive was given in Figure 26. The NH_3 has a wide usage field in the fuel cell of electric vehicles as seen in Figure 26. Moreover, the NH_3 can be blended with gasoline and hydrogen fuels for spark ignition engines. On the other hand, it can be used as dual fuel blended with diesel, DME, and biodiesel for compression ignition engines. The NH_3 don't produce CO_2 , CO , and hydrocarbons due to being non-carbonaceous fuel at the end of the combustion. This advantage is a determinant factor against the other conventional fuels. The NH_3 has higher autoignition and low flame speed according to other fuel types. Therefore, the combustion quality was negatively affected. In addition to that, the fuels blended with NH_3 additive caused to decrease the oxygen content in the combustion and therefore, the combustion is worsen due to low oxygen content. The upper and lower

3.5. Diesel-RK Programme

3.5.1. Pre-Processing

In the scope of this study, an internal combustion engine was simulated in Diesel-RK Programme according to the technical specifications of the Mitsubishi Canter 4D31 diesel engine. All combustion simulations were made for different types of biodiesel and NH_3 additive ratios in this programme. The engine performance and emission parameters were numerically analyzed to observe the effects of NH_3 additive. Besides, all these parameters were compared between each other for varying biodiesel types and additive ratios.

Pre-processing of Diesel- RK programme consists of 5 main sections. These sections are the creation of a diesel engine, designing of the combustion chamber, determination of injection strategies, selection of the fuel types and determination of operating modes.

Firstly, a diesel engine was created for combustion simulations as mentioned in the previous part. The images captured from the Diesel-RK programme are respectively given as a flowchart in Figure 26.

1) Engine
Mitsubishi Canter 4D31 diesel engine

Working Cycle
☒ Four-Stroke Cycle
☐ Two-Stroke Cycle

Fuel and Method of Ignition
☒ DI Diesel
☐ Petrol, SI, Carburation
☐ Petrol, SI, Injection into Inlet Port Valve port
☐ Gas, Spark Ignition
☐ Gas, SI with Prechamber

2) Basic Engine Design
☒ In-Line
☐ V-Engine
☐ Opposed Engine (Boxer)
☐ Radial

Number of Cylinders 4

Cooling System
☒ Liquid Cooling
☐ Air Cooling

3) Ambient Parameters on a Sea Level
 - Pressure, p_o [bar] 1
 - Temperature, T_o [K] 288

Application
☒ Overland and on the sea
☐ Aviation
☐ Submarine

4) Cylinder Bore, D, [mm] 100
 Piston Stroke, S, [mm] 105
 Nominal Engine Speed, [rpm] 1500
 Compression Ratio 15

5) ☐ Super- or Turbocharged Engine
 Compressor Pressure Ratio 2

☐ Intercooling

Cylinder Head Design
☐ Two Valves
☒ Four Valves

Injection Pressure, [bar] Less than 500

Figure 27. The creation of a diesel engine in Diesel-RK programme

After the simulation of the diesel engine was created, the fuel injection velocities were determined according to the different crank angle. The image that is captured about injection velocity was given in Figure 27.

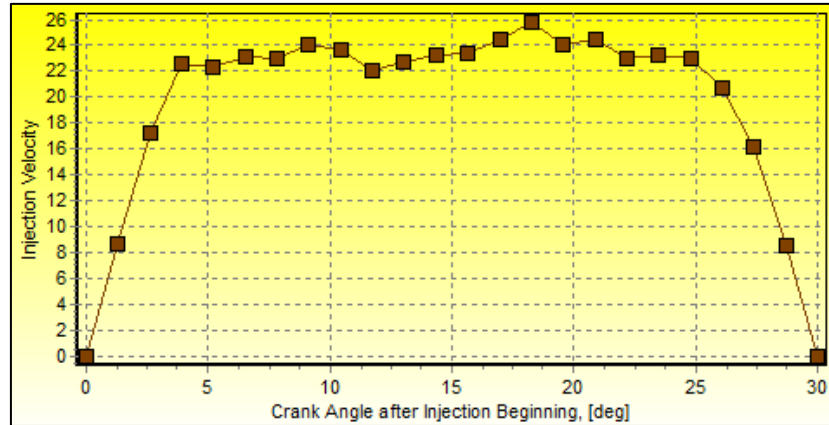


Figure 28. Injection velocity-Crank angle

Diesel-RK has a wide fuel library in the selection of the fuel type. There are a lot of fuel types such as diesel, biofuels, petrol, natural gas, propane+buthane, biogas, producer gas, and coal gas in this library. Moreover, a new type of fuel can be created by changing the chemical and physical properties of the fuel. After the selection of the fuel type, the operating conditions were determined at the end of the pre-processing section. The engine speed was gradually increased with 300 rpm increment from 1200 rpm until 2400 rpm. The image that is captured about the operating conditions of a diesel engine was given in Figure 28.

Mode of Performance (#1 = Full Load)	☒ #1	☒ #2	☒ #3	☒ #4	☒ #5
Engine Speed, [rpm]	1200	1500	1800	2100	2400
Air Fuel Equivalence Ratio in the Cylinder	2	2	2	2	2
Injection / Ignition Timing, [deg B.TDC]	10	10	10	10	10
Ambient Pressure, [bar]	1	1	1	1	1
Ambient Temperature, [K]	288	288	288	288	288
Inlet Pressure Losses (before compressor), [bar]	0,02	0,02	0,02	0,02	0,02
Differential Pressure in exhaust (tail) system, [bar]	0,04	0,04	0,04	0,04	0,04

Figure 29. The operating conditions of a diesel engine

3.6. Engine Vibration Analysis

Within the scope of this study, the vibration of the engine body was examined according to different variable parameters. These variable parameters can be described as biodiesel variety

and different NH_3 ratios (5%, 10%, and 15%). According to vibration results, negative or positive effects of variable parameters on vibration were observed. In the experimental setup, eddy current dynamometer and engine block is the main vibration producer. Therefore, the parts of the engine block have critical importance in the measuring of vibration. The experiment setup of the Mitsubishi Canter 4D31 diesel engine was shown in Figure 29.



Figure 30. Mitsubishi Canter 4D31 diesel engine setup

The vibration of the motor was measured according to different variable parameters thanks to the application device fixed to the motor body. This device has software that can measure vibration with high precision. Therefore, it can be used in academic studies. This software logs the accelerometer sensor data. At the same time, it saves minimum and maximum values measured for each of the parameters by using a delicate accelerometer sensor. Vibration measurement was made according to 6 different parameters. These parameters are x (longitudinal) (m/s^2), y (lateral) (m/s^2), z (vertical) (m/s^2), RMS (m/s^2), time (second), and engine speed (rpm). RMS (m/s^2) was calculated as the square root of the arithmetic mean of the squares of the vibration values in the x , y , and z -axis.

$$x_{RMS} = \sqrt{\frac{1}{n}(x_1^2 + x_2^2 + \dots x_n^2)} \quad (7)$$

3.6.1. Accelerometer Sensor

An accelerometer sensor is a device that measures and records vibration data on a diesel engine. This sensor is fixed to collect the vibration data on the engine block. The measurement process was instantaneously carried out during the experiment according to 3 different axes (x, y, and z-axis). All information about the technical properties of the accelerometer sensor was given in Table 10.

Table 10. Technical properties of accelerometer sensor

Vibration Sensor Name	BMI160_ ACCELEROMETER
Vendor	BOSH
Version	50528789
Resolution	0.0023928226 m/s ²
Max Range	78.4532 m/s ²
Power	0.18 mW

Before vibration measurement during the experiments, the accelerometer sensor was calibrated to obtain accurate data according to the environmental conditions. The image of accelerometer sensor was given in Figure 30.

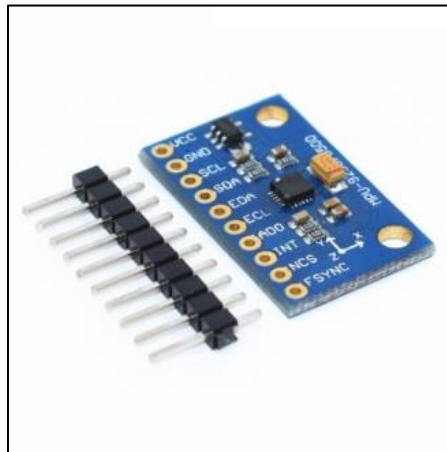


Figure 31. Accelerometer sensor

3.7. Artificial Neural Networks (ANNs)

Artificial neural networks (ANNs), basically can be described as a set of technologies often encompassed with artificial intelligence that attempts to simulate the function of the human

brain [82]. ANNs is modelled on the transmission and learning of information in the human brain depending on the flow system. The functioning mechanism of the ANNs system can be explained as follows; there are 3 basic sections in the information flow of the system structure. These are the input layer, hidden layer, and output layer. The most important factor in ensuring this functioning is the neurons that provide signal transmission in these layers. Therefore, the ANNs model is a system that can be developed and tested depending on the relation between neurons. This development process can be divided into 2 stages. These are the training/learning stage and the test/verification stage [83]. In the first stage, the network is trained to make a sensible output estimate according to input data. In the other stage, the experiment dataset is validated with the predicted data. The network training process is stopped when the test error reaches the limit point [84]. The error formulas used in the operations within the scope of this process are given below;

$$R^2 = 1 - \left(\frac{\sum_{i=1}^n (t_i - o_i)^2}{\sum_{i=1}^n (o_i)^2} \right) \quad (8)$$

$$MRE (\%) = \frac{1}{n} \sum_{i=1}^n \left| 100 \frac{t_i - o_i}{t_i} \right| \quad (9)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (t_i - o_i)^2} \quad (10)$$

These error formulas (RMSE and MRE) are used to observe and validate the predictive performance of the models in ANNs. Where 'n' is number of dots in the data set, 'o' is estimated output value and 't' is real output [83]. The information flow chart of the ANNs model was given in Figure 31.

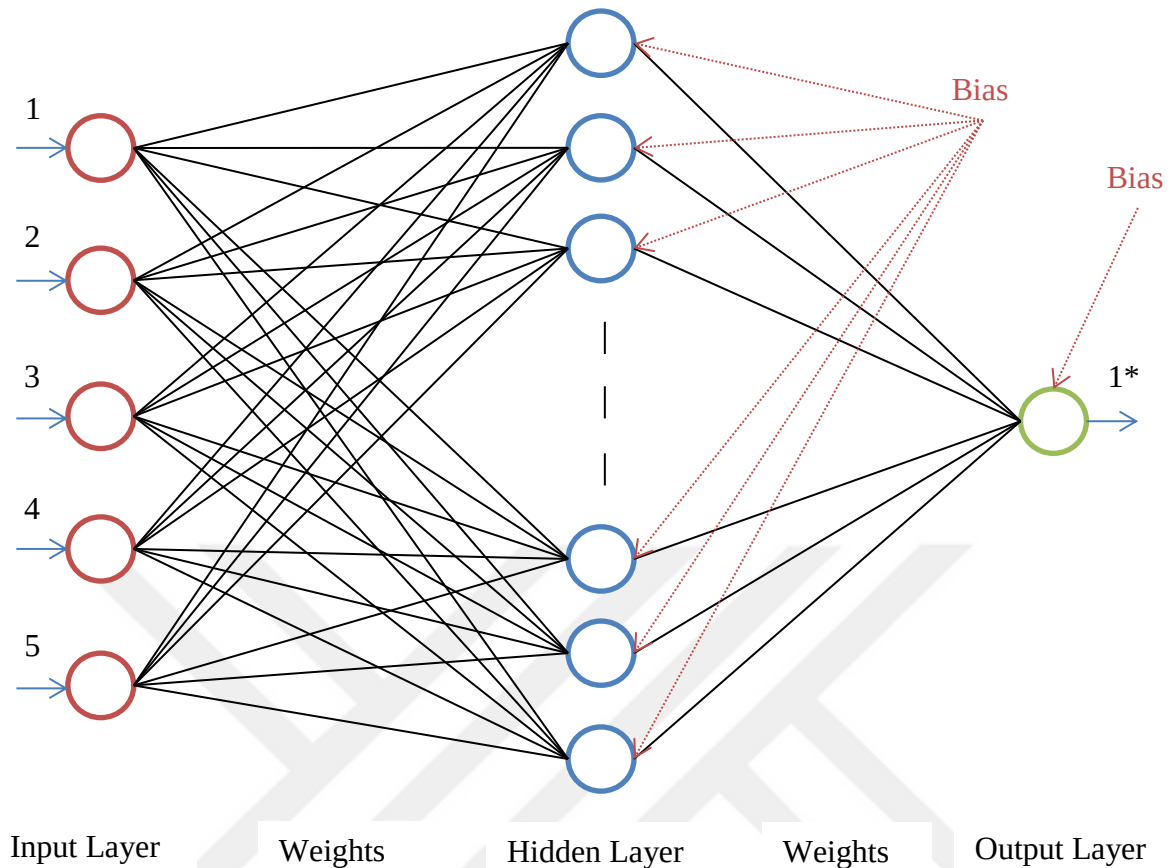


Figure 32. Information flow chart of ANNs model

Table 11. Input and output parameters

1) x-axis vibration data (m/s^2)	
2) y-axis vibration data (m/s^2)	
3) RMS vibration data (m/s^2)	1*) z-axis vibration data (m/s^2)
4) Engine speed (m/s)	
5) Time (second)	

All input and output parameters were tabulated in Table 11 to generate the ANNs model. As mentioned in the previous section, the selection of parameters has critical importance for input and output layers. Therefore, the x-axis vibration (m/s^2), y-axis vibration (m/s^2), RMS (m/s^2), time (second), and engine speed (rpm) were selected as input parameters to predict the vibration in the z-axis. In this case, the z-axis vibration (m/s^2) was considered as the target parameter. Moreover, a certain range in the output vibration data was determined as test data to control the accuracy of the generated ANNs model.

Besides, the ANNs model was generated according to the parameters shown in Table 12 to predict the experimental vibration data.

Table 12. The parameters of generated ANNs model

Network Type	Feed-forward backprop
Training Function	TRAINGDx
Adaption Learning Function	LEARNGDM
Performance Function	MSE
Number of Layers	2
Number of Neurons	10
Transfer Function	TANSIG

4. RESULTS AND DISCUSSIONS

4.1. Engine Emission Parameters

4.1.1. Nitrogen Oxides (NO_x)

NH_3 additive directly affects the physical properties, oxygen capacity and reaction temperatures of the main fuel. Moreover, it has a higher cetane number according to biodiesel fuels. NH_3 has no carbon content and is a hydrogen carrier. In this sense, it is theoretically known that NH_3 has a positive effect on NO_x emission due to these advantages. As seen in Figure 32 and Figure 33, NO_x emissions decreased in combustion simulations when NH_3 additive is gradually increased for all biodiesel fuels. The highest and lowest NO_x concentration was respectively observed for hazelnut biodiesel- NH_3 and sunflower biodiesel- NH_3 mixtures according to other fuel types.

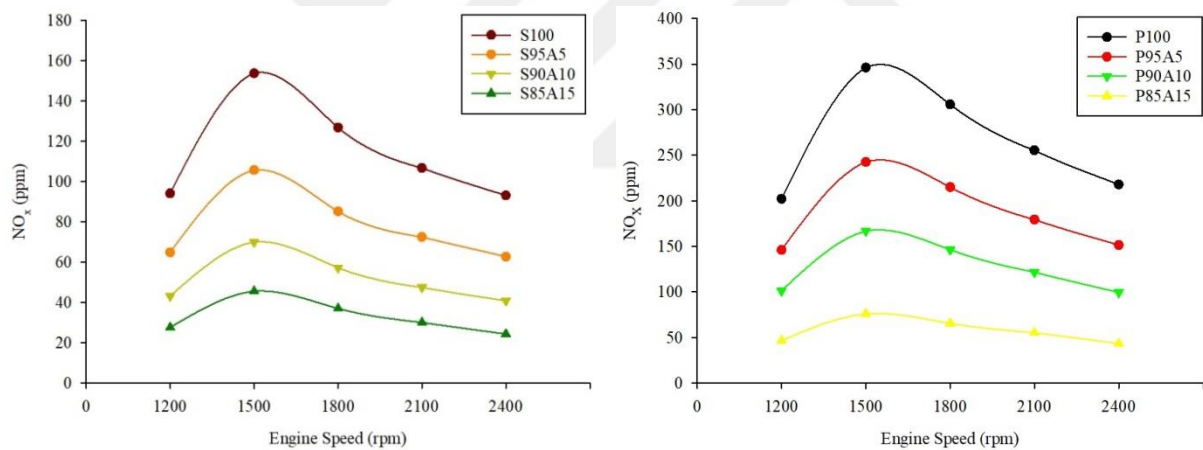


Figure 33. NO_x emission (ppm) - Engine speed (rpm) for sunflower and peanut biodiesels

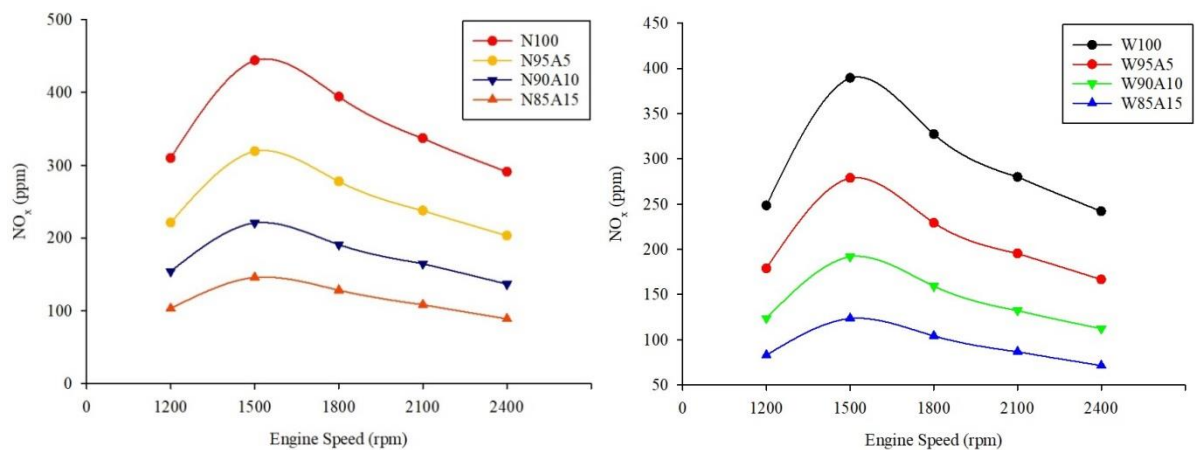


Figure 34. NO_x emission (ppm) - Engine speed (rpm) for hazelnut and waste oil biodiesels

4.1.2. Particulate Matter (PM)

Particulate matter can be described as the sum of organic and inorganic matters that are extremely detrimental in the exhaust gas. Incomplete combustion is one of the main reasons for the formation of PM. Besides, the oxygen content of the fuel mixtures can directly affect the changing trend of PM parameter during combustion. As seen in Figure 34 and Figure 35, when NH_3 additive is gradually increased, PM increased during combustion for all fuel mixtures. In this sense, it has been clearly observed that NH_3 worsens combustion. The highest PM concentration was observed at 1200 rpm for all fuel mixtures. PM concentration remained stable with the engine idling for all fuel types. PM concentration of sunflower biodiesel- NH_3 mixture is high due to having a lower oxygen content compared to other fuels. According to the combustion simulation results, it was revealed that there is an inverse relationship between PM and NO_x parameters.

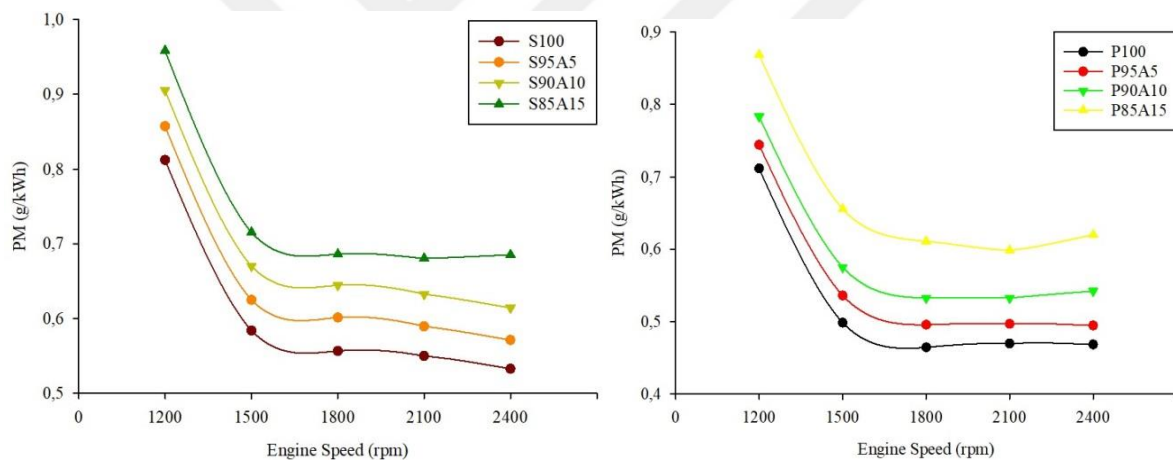


Figure 35. PM (g/kWh) - Engine speed (rpm) for sunflower and peanut biodiesels

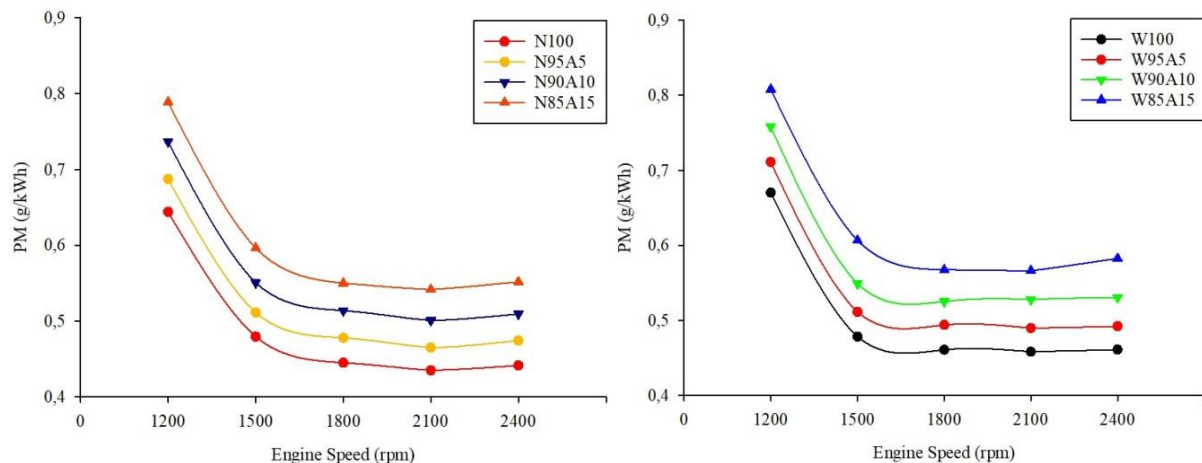


Figure 36. PM (g/kWh) - Engine speed (rpm) for hazelnut and waste oil biodiesels

4.1.3. Smoke Opacity

Smoke opacity can be described as the presence of water vapour, hydrocarbons, and solid particles in the exhaust gas. The main reason for the increment in smoke opacity values is poor oxidation. Besides, NH_3 additive can reduce the pressure and temperature in the cylinder. This situation negatively affects the combustion characteristic of the fuel mixtures. As seen in Figure 36 and Figure 37, the increment was observed in the smoke opacity parameter for all fuel mixtures when NH_3 additive is gradually increased according to varying engine speed. The highest and lowest smoke opacity was respectively observed for sunflower and hazelnut biodiesel. There is a directly proportional relationship between PM and smoke opacity parameters on the contrary of NO_x parameter. Besides, a significant reduction was observed between 1200 rpm and 1500 rpm for all fuel types.

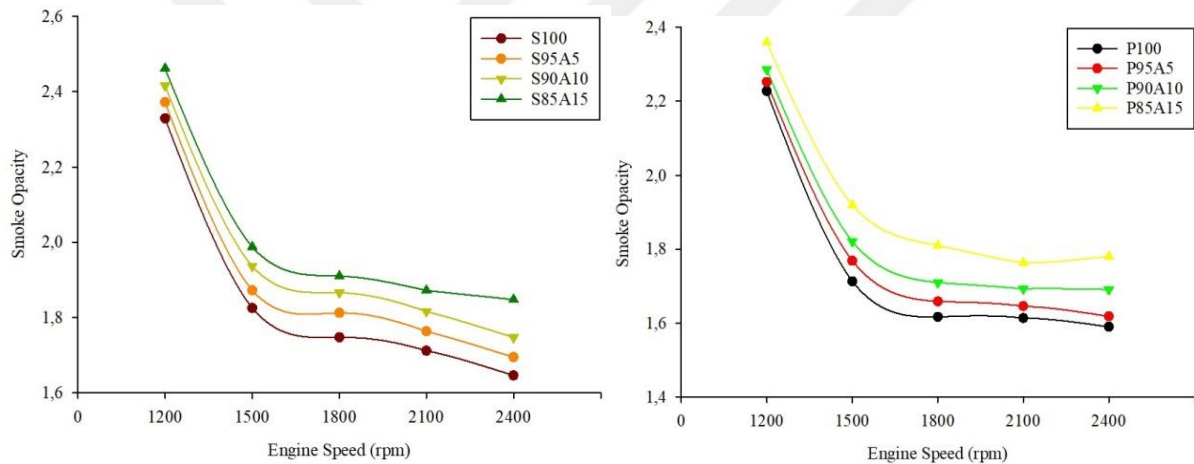


Figure 37. Smoke opacity - Engine speed (rpm) for sunflower and peanut biodiesels

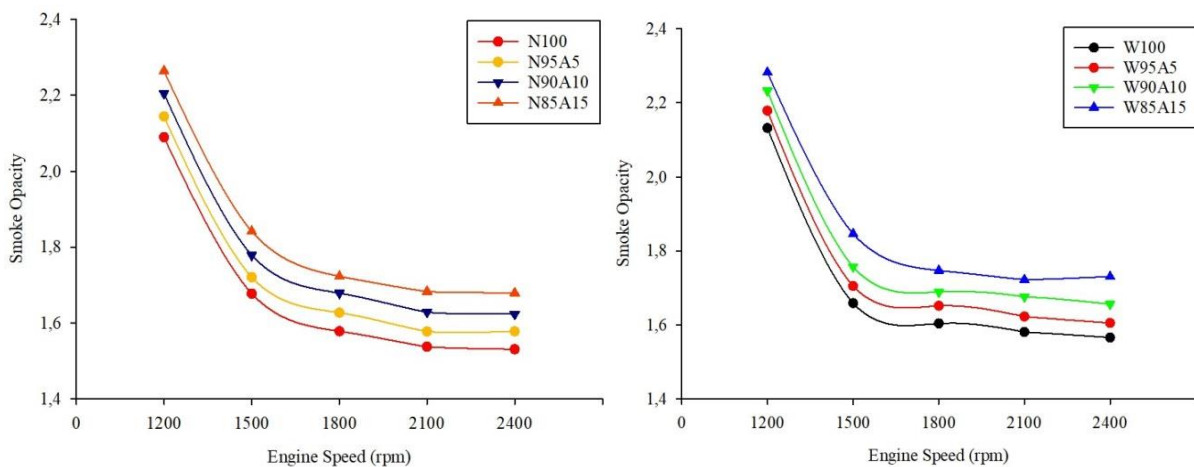


Figure 38. Smoke opacity - Engine speed (rpm) for hazelnut and waste oil biodiesels

4.2. Engine Performance Parameters

4.2.1. Engine Torque

Torque can basically be described as a rotating force produced by a crankshaft of the engine. As mentioned in the previous section, the combustion pressure and temperature inside the cylinder are determinant factors that directly affect the engine performance. As seen in Figure 38 and Figure 39, a significant change was not observed in all fuel mixtures for varying engine speed. On the other hand, a decrement was observed in all combustion simulations when NH_3 additive is gradually increased for all fuel mixtures. The highest and lowest torque values were respectively observed for hazelnut and sunflower biodiesels. As a result of the combustion simulations, it has been revealed that NH_3 additive negatively affects the engine torque. Moreover, the engine produces less net work depending on the decrement in torque parameter.

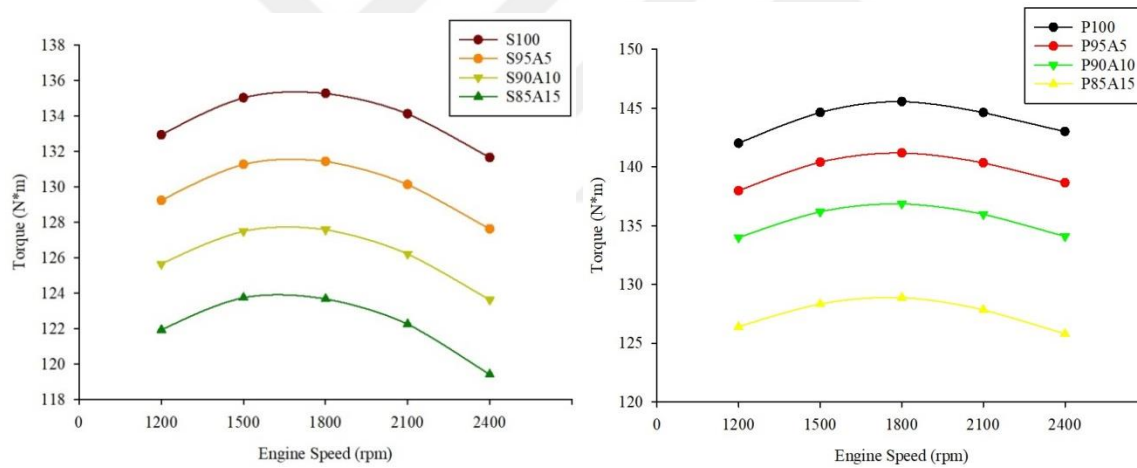


Figure 39. Torque (N*m) - Engine speed (rpm) for sunflower and peanut biodiesels

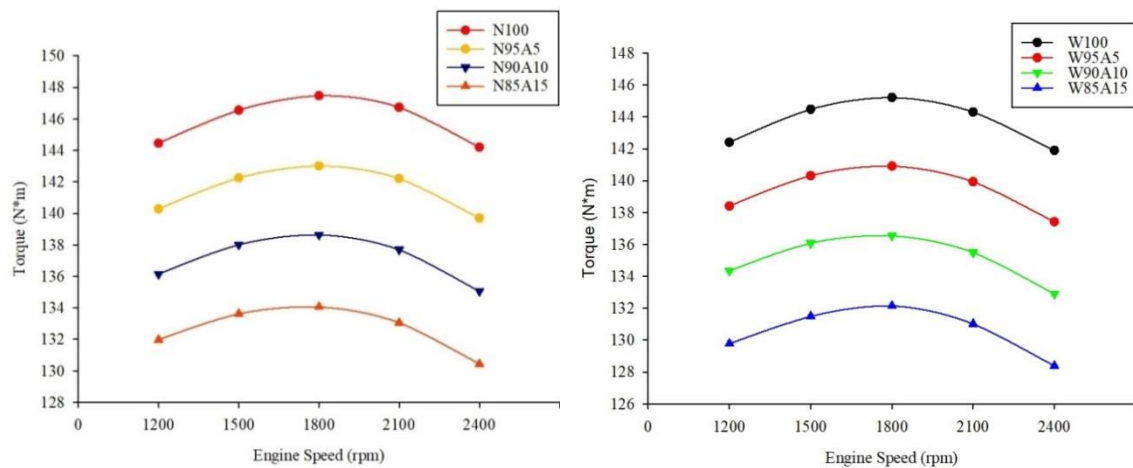


Figure 40. Torque (N*m) - Engine speed (rpm) for hazelnut and waste oil biodiesels

4.2.2. Engine Power

The engine power can basically be described as the product of the angular velocity of the crankshaft and the engine torque. The thermal efficiency of the engine decreases due to the NH_3 additive worsens combustion. Therefore, the NH_3 additive partially caused a decrease in engine power for all fuel mixtures. As seen in Figure 40 and Figure 41, a small decrement was observed in the engine power for all fuel types depending on the increment of NH_3 additive. Besides, the engine power gradually increased according to varying engine speed. The lowest engine power was observed in sunflower biodiesel according to other types of fuel mixtures. On the other hand, a noticeable difference was not observed between other fuels for engine power.

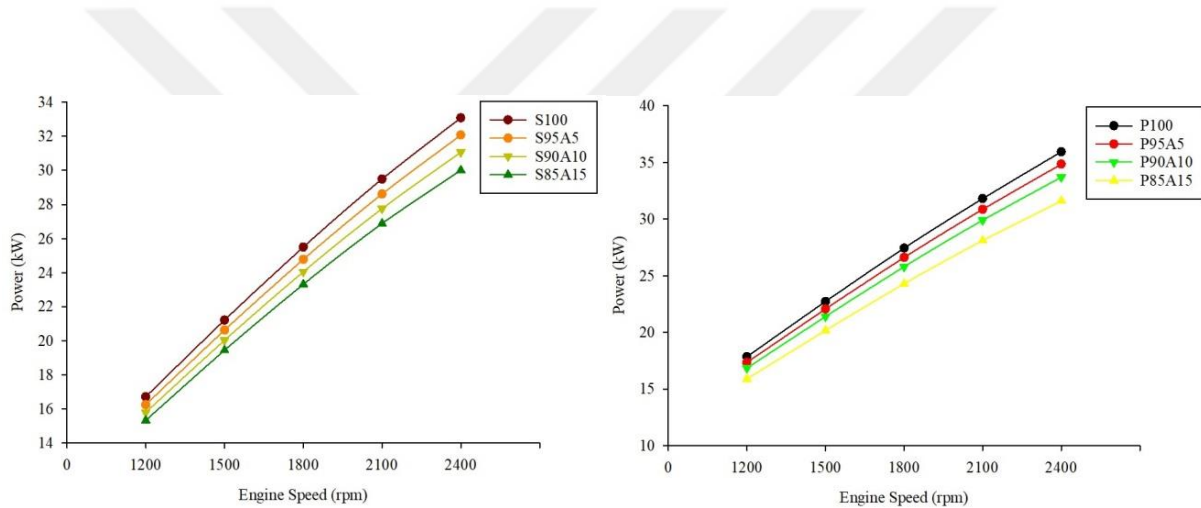


Figure 41. Power (kW) - Engine speed (rpm) for sunflower and peanut biodiesels

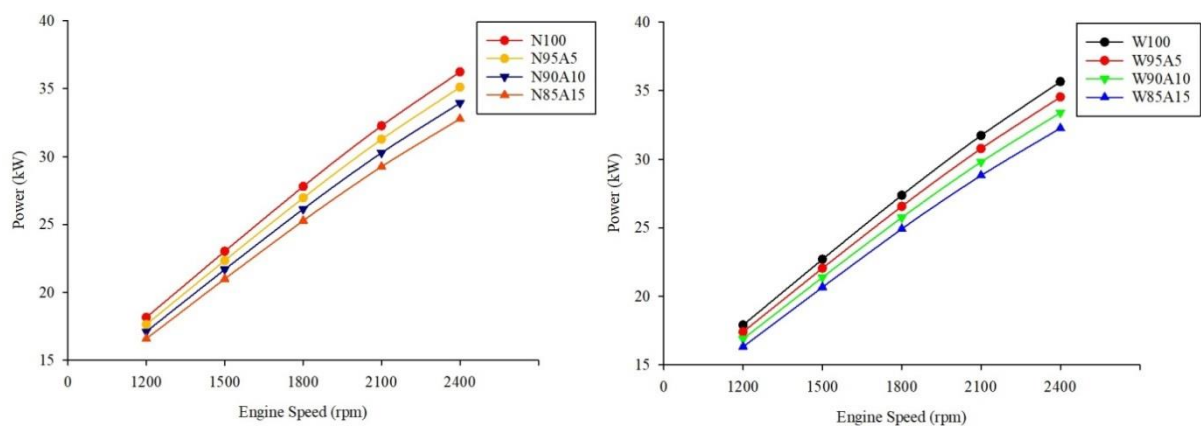


Figure 42. Power (kW) - Engine speed (rpm) for nut and waste oil biodiesels

4.2.3. Indicated Mean Effective Pressure (IMEP)

IMEP can basically be described as the gas pressure energy that is developed in one engine cycle divided by the cylinders displacement parameter [85]. It is an essential parameter to evaluate and analyze the engine torque and power. Moreover, it can give information about the effects of NH_3 additive on the mechanical efficiency according to different kinds of biodiesel. As seen in Figure 42 and Figure 43, IMEP gradually decreased for all fuel mixtures when NH_3 additive in biodiesel was increased. IMEP showed an increasing trend depending on the increment of the engine speed. The highest and lowest IMEP were respectively observed for hazelnut and sunflower biodiesel. The pressure in the cylinder decreased due to the low heating value of the NH_3 as a fuel additive. In this sense, it has been revealed that NH_3 additive negatively affects IMEP as seen in all combustion simulations.

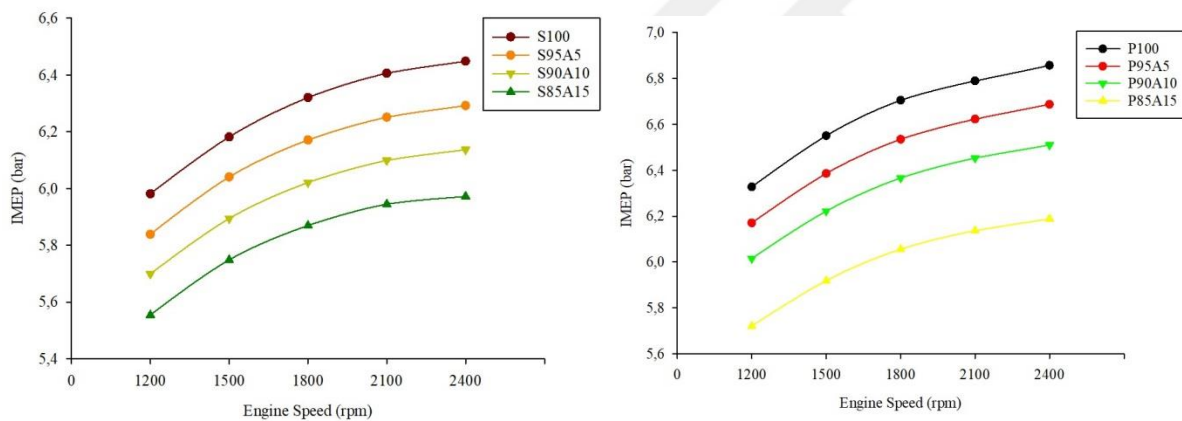


Figure 43. IMEP (bar) - Engine Speed (rpm) for sunflower and peanut biodiesels

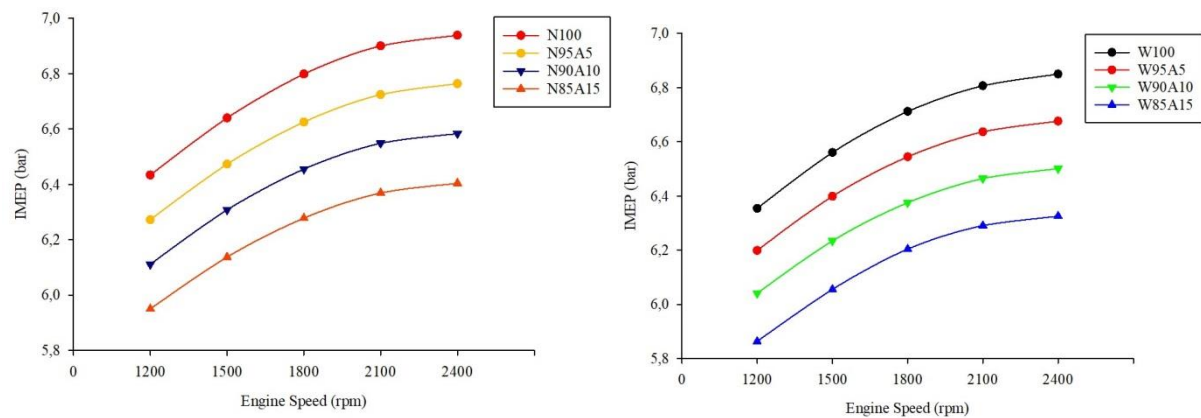


Figure 44. IMEP (bar) - Engine Speed (rpm) for hazelnut and waste oil biodiesel

4.3. Engine Vibration Parameter

In the experimental section, the NH_3 ratio in biodiesel was increased by 5%, 10% and 15%. Mitsubishi Canter 4D31 diesel engine was simulated under no-load conditions between 1200 rpm and 2400 rpm with 300 rpm increment. Vibration data were recorded during the experiment by placed accelerometer sensor on the engine block for all NH_3 ratios. As mentioned in the previous section, the ANNs models were constituted to compare with the experimental vibration results.

4.3.1. Vibration and ANNs results of sunflower- NH_3 mixtures

In the scope of this study, the sunflower biodiesel was blended with 5%, 10%, and 15% NH_3 additive and the ANNs models were generated to predict the experimental engine vibration for all fuel mixtures. The comparison of the experimental and simulation vibration data was respectively given in Figure 44, Figure 45, Figure 46, and Figure 47 for all NH_3 additive ratios.

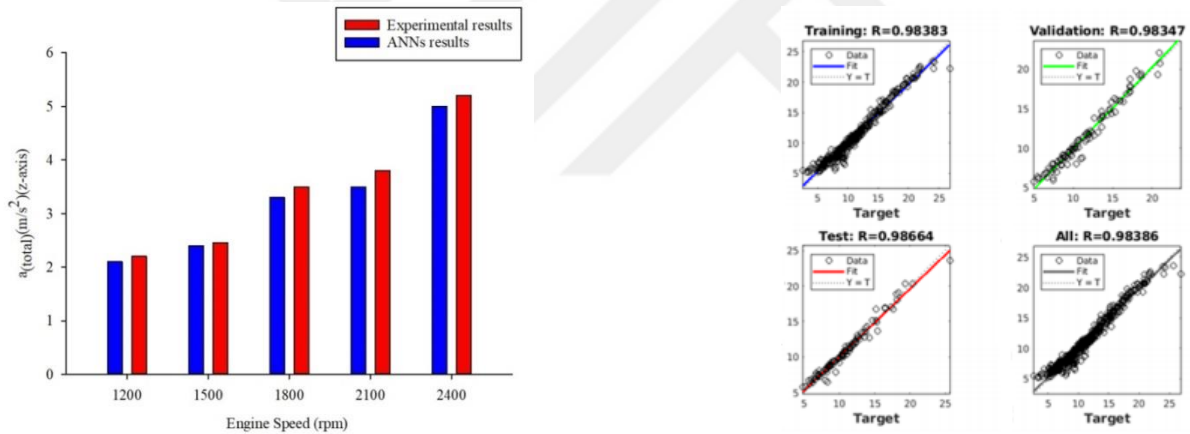


Figure 45. $a_{\text{total}}(\text{m/s}^2)$ - Engine Speed (rpm) and ANNs model R error values for S100

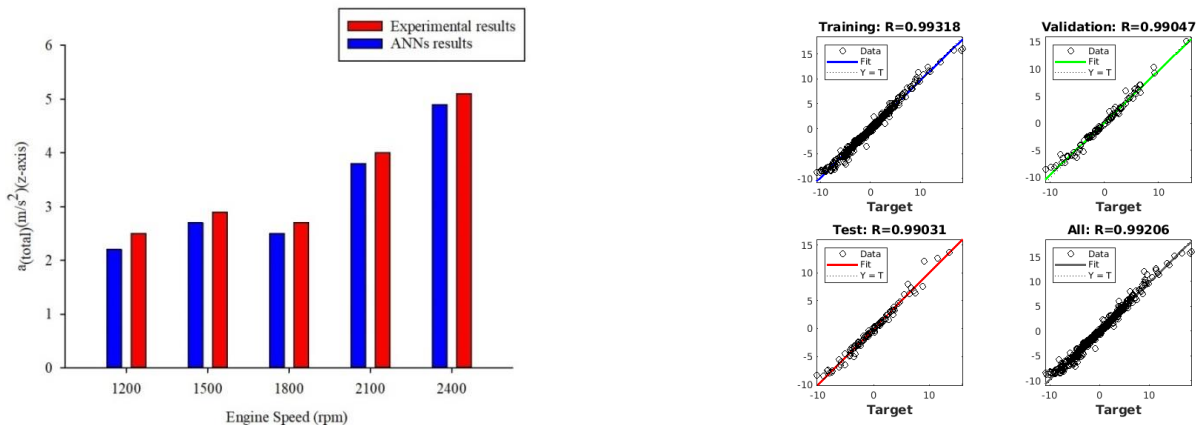


Figure 46. $a_{\text{total}}(\text{m/s}^2)$ - Engine Speed (rpm) and ANNs model R error values for S95A5

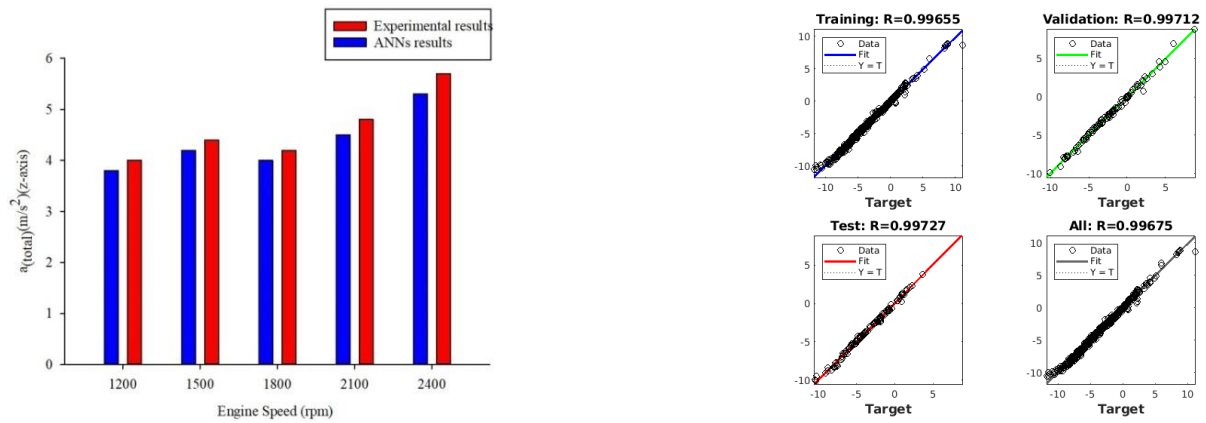


Figure 47. a_{total} (m/s²) - Engine Speed (rpm) and ANNs model R error values for S90A10

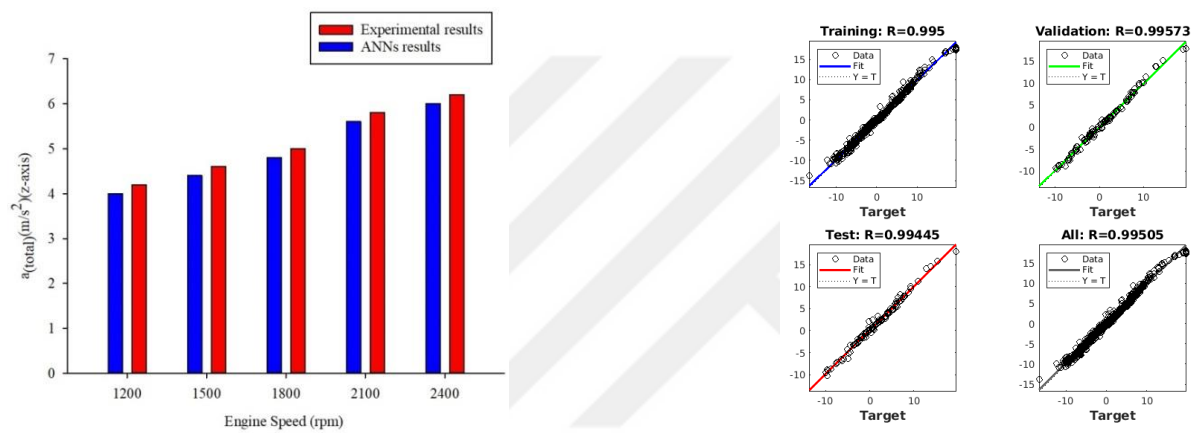


Figure 48. a_{total} (m/s²) - Engine Speed (rpm) and ANNs model R error values for S85A15

All regression formulations that are used to predict the vibration data were given in Table 13.

Table 13. Regression formulations for sunflower-NH₃ mixtures

NH ₃ additive	Regression formulations in ANNs models
No NH ₃	$z(\text{m/s}^2) = -8,97 - 0,00347 \text{ Time (second)} + 0,9241 \text{ x-axis (m/s}^2) + 0,646 \text{ y-axis (m/s}^2) - 0,0568 \text{ RMS (m/s}^2) + 0,00022 \text{ Engine speed (m/s)}$
5% NH ₃	$z(\text{m/s}^2) = -8,19 - 0,00444 \text{ Time (second)} + 0,7252 \text{ x-axis (m/s}^2) + 0,663 \text{ y-axis (m/s}^2) + 0,0059 \text{ RMS (m/s}^2) + 0,00057 \text{ Engine speed (m/s)}$
10% NH ₃	$z\text{-axis (m/s}^2) = -4,88 + 0,01857 \text{ Time (second)} + 0,7401 \text{ x-axis (m/s}^2) + 1,117 \text{ y-axis (m/s}^2) - 0,3375 \text{ RMS (m/s}^2) - 0,00270 \text{ Engine speed (m/s)}$
15% NH ₃	$z\text{-axis (m/s}^2) = -9,07 + 0,00349 \text{ Time (second)} + 0,9423 \text{ x-axis (m/s}^2) - 0,462 \text{ y-axis (m/s}^2) + 0,1383 \text{ RMS (m/s}^2) - 0,00072 \text{ Engine speed (m/s)}$

Besides, as a result of the comparison of the fuel mixtures, the highest z-axis vibration data was tabulated in Table 14 depending on the engine speed and the accuracy value of the generated ANNs model.

Table 14. The z-axis vibration data and its accuracy values for sunflower-NH₃ mixtures

Engine speed (rpm)	Fuel type	Accuracy values	Highest z-axis vibration data
2400 rpm	S100	98.386%	5.18 m/s ²
2400 rpm	S95A5	99.206%	5.05 m/s ²
2400 rpm	S90A10	99.675%	5.58 m/s ²
2400 rpm	S85A15	99.505%	6.12 m/s ²

All vibration data in the z-axis and RMS of vibration data for varying engine speed were respectively given in Figure 48 and Figure 49.

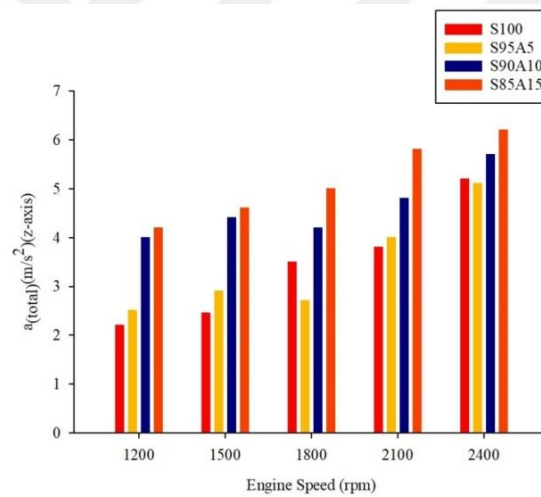


Figure 49. All vibration data in z-axis for varying engine speed

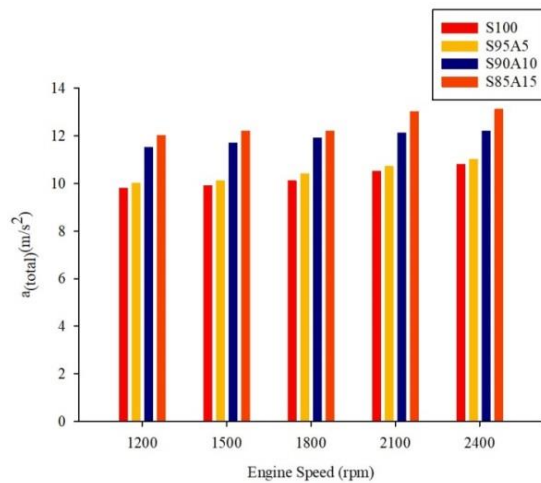


Figure 50. RMS of vibration data for varying engine speed

NH₃ additive negatively affected z-axis vibration data. When the NH₃ additive ratio was gradually increased, an increment was observed in vibration data as seen in Figure 49. 15% NH₃ additive ratio caused the highest increment when it was compared with the other NH₃ additive ratios. Besides, the engine vibration data followed an increasing path depending on the varying engine speed. Therefore, the highest vibration data was recorded as 6.12 m/s² at 2400 rpm for S85A15 fuel mixture. The images of vibration frequency were captured from the accelerometer sensor during the experiment. These images were given in Figure 50 for the x, y, and z-axis.

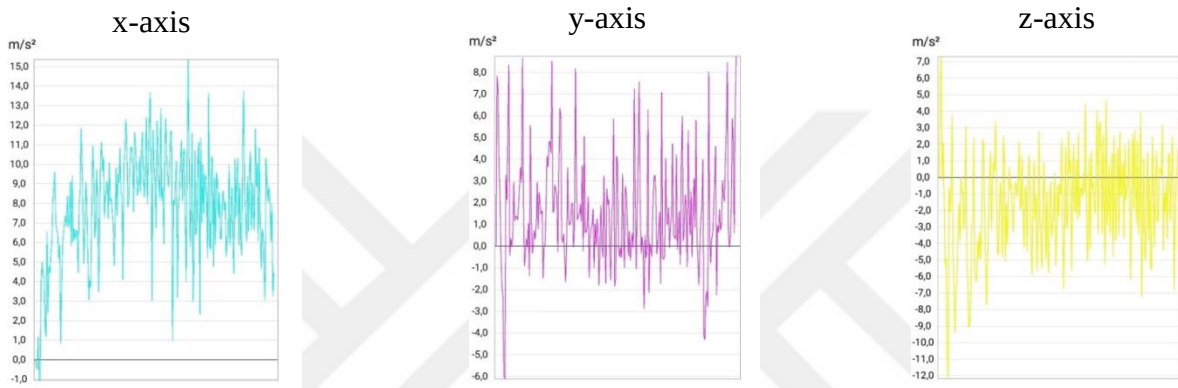


Figure 51. $a(\text{m/s}^2)$ - time at x, y, and z axis

4.3.2. Vibration and ANNs results of hazelnut-NH₃ mixtures

The hazelnut biodiesel was blended with 5%, 10%, and 15% NH₃ additive and ANNs models were generated to predict the experimental engine vibration for all fuel mixtures. The comparison of the experimental and simulation vibration data was given in Figure 51, Figure 52, Figure 53, and Figure 54 for all NH₃ additive ratios.

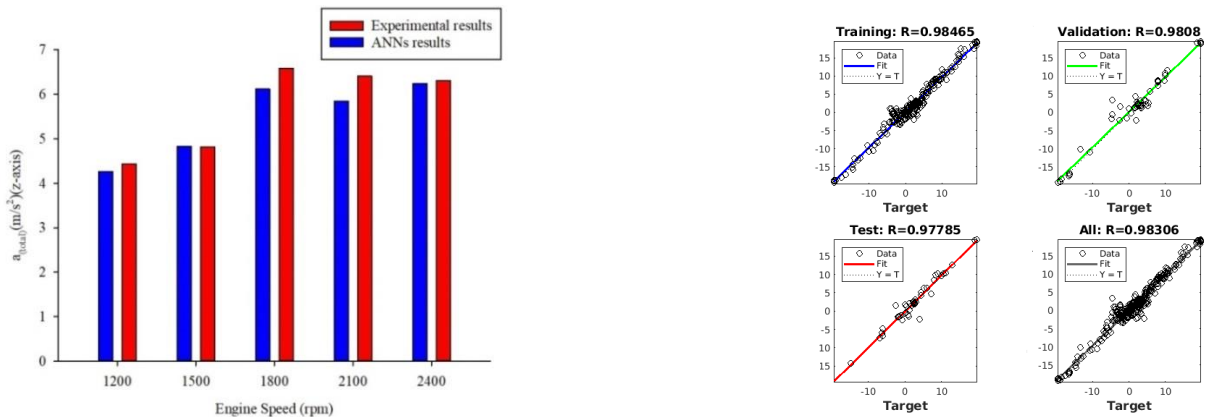


Figure 52. $a_{\text{total}}(\text{m/s}^2)$ - Engine Speed (rpm) and ANNs model R error values for N100

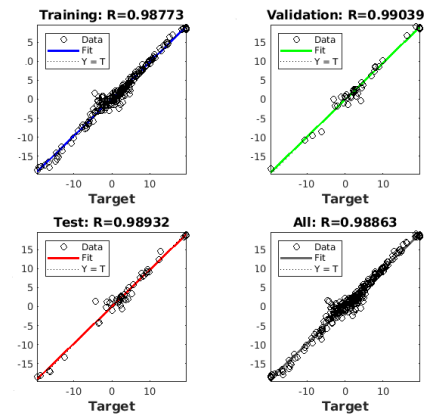
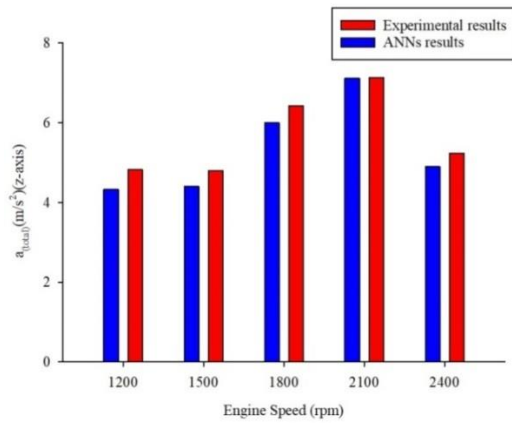


Figure 53. $a_{total}(m/s^2)$ - Engine Speed (rpm) and ANNs model R error values for N95A5

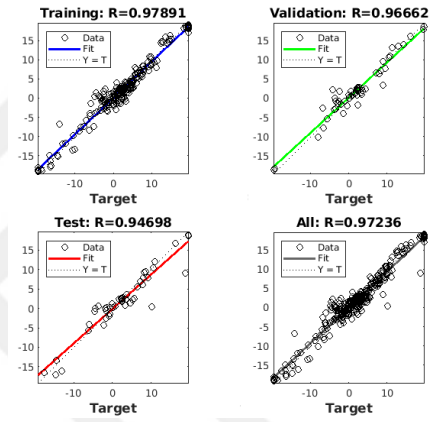
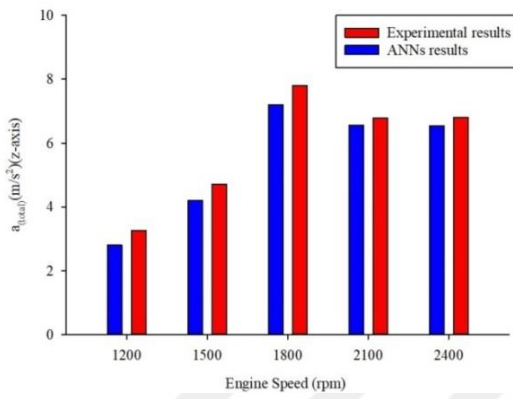


Figure 54. $a_{total}(m/s^2)$ - Engine Speed (rpm) and ANNs model R error values for N90A10

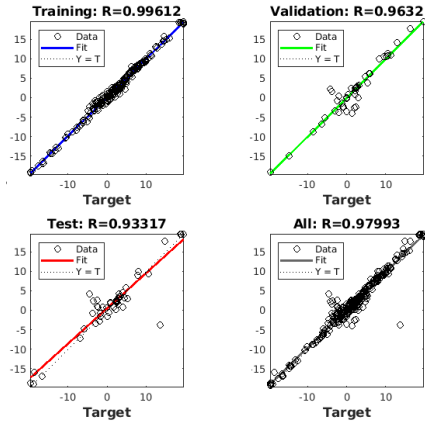
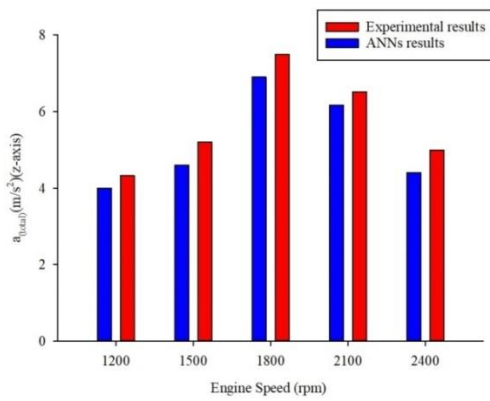


Figure 55. $a_{total}(m/s^2)$ - Engine Speed (rpm) and ANNs model R error values for N85A15

All regression formulations that are used to predict the vibration data are given in Table 15. As a result of the comparison of the vibration data, the highest z-axis vibration data that are recorded for all mixtures according to the engine speed and the accuracy values of the ANNs models were given in Table 16.

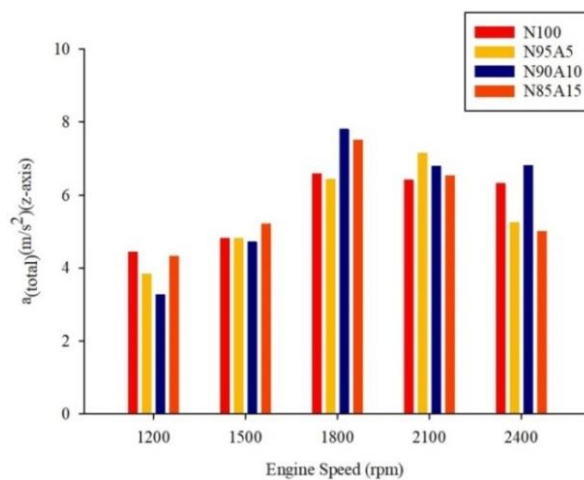
Table 15. Regression formulations for hazelnut-NH₃ mixtures

NH ₃ additive	Regression formulations in ANNs models
No NH ₃	$z(\text{m/s}^2) = 26,75 - 0,0130 \text{ Time (second)} + 2,7249 x(\text{m/s}^2) - 0,738 y(\text{m/s}^2) + 0,1107 \text{ RMS}(\text{m/s}^2) + 0,00006 \text{ Engine Speed (m/s)}$
5% NH ₃	$z(\text{m/s}^2) = 23,27 - 0,0095 \text{ Time (second)} + 2,210 x(\text{m/s}^2) - 0,036 y(\text{m/s}^2) + 0,2343 \text{ RMS}(\text{m/s}^2) - 0,00151 \text{ Engine Speed (rpm)}$
10% NH ₃	$z(\text{m/s}^2) = 28,25 - 0,0041 \text{ Time (second)} + 2,5816 x(\text{m/s}^2) + 0,1077 y(\text{m/s}^2) + 0,2081 \text{ RMS}(\text{m/s}^2) - 0,00209 \text{ Engine Speed (rpm)}$
15% NH ₃	$z(\text{m/s}^2) = 14,29 - 0,0431 \text{ Time (second)} + 1,9861 x(\text{m/s}^2) - 0,792 y(\text{m/s}^2) + 0,0813 \text{ RMS}(\text{m/s}^2) + 0,00545 \text{ Engine Speed (rpm)}$

Table 16. The z-axis vibration data and its accuracy values for hazelnut-NH₃ mixtures

Engine speed (rpm)	Fuel type	Accuracy values	Highest z-axis vibration data
1800 rpm	N100	98.306%	6.57 m/s ²
2100 rpm	N95A5	98.863%	7.13 m/s ²
1800 rpm	N90A10	97.236%	7.79 m/s ²
1800 rpm	N85A15	97.993%	7.48 m/s ²

All vibration data in the z-axis and RMS of vibration data for varying engine speed were respectively given in Figure 55 and Figure 56.

**Figure 56.** All vibration data in z-axis for varying engine speed

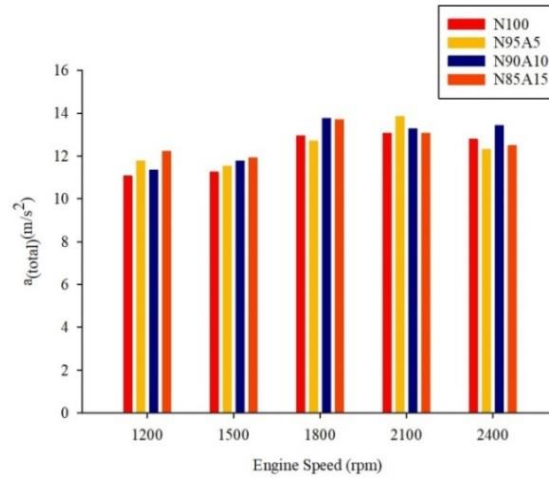


Figure 57. RMS of vibration data for varying engine speed

As seen in Figure 55, NH_3 additive showed an increment for all additive ratios when the engine speed was gradually increased with a 300 rpm increment. 5% NH_3 additive positively affected the engine vibration. Therefore, the z-axis vibration data partially decreased for the N95A5 fuel mixture. On the contrary of this decrement, it was observed that 10% and 15% NH_3 additives worsen the z-axis vibration data depending on the engine speed. Therefore, the highest vibration data was recorded as 7.79 m/s^2 at 1800 rpm for N90A10 fuel mixture. Besides, the important vibration increments were generally recorded at 1800 rpm for the hazelnut- NH_3 fuel mixtures. The captured vibration images during experiments were given in Figure 57 for the x, y, and z-axis.

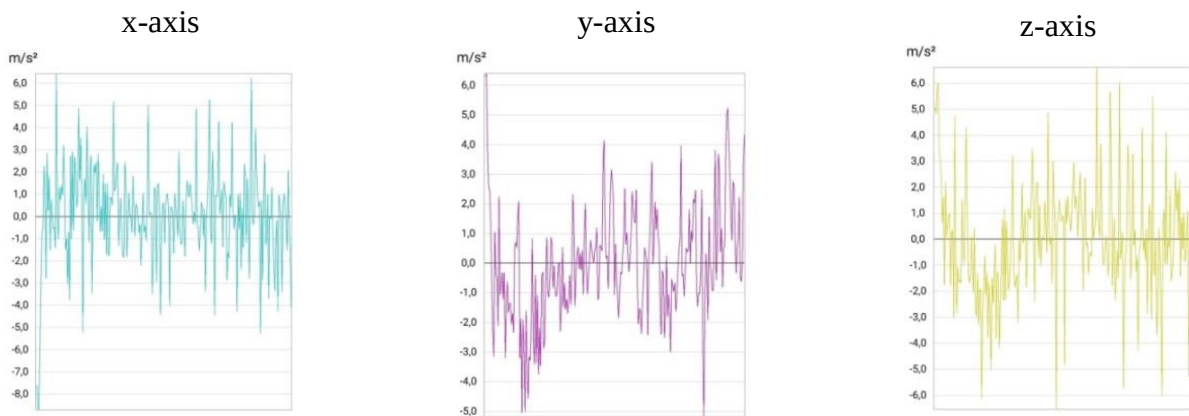


Figure 58. $a(\text{m/s}^2)$ - time at x, y, and z axis

4.3.3. Vibration and ANNs results of peanut-NH₃ mixtures

The peanut biodiesel was blended with 5%, 10%, and 15% NH₃ additive and ANNs models were generated to predict the experimental engine vibration for all fuel mixtures. The comparison of the experimental and simulation vibration data was given in Figure 58, Figure 59, Figure 60, and Figure 61 for all NH₃ additive ratios.

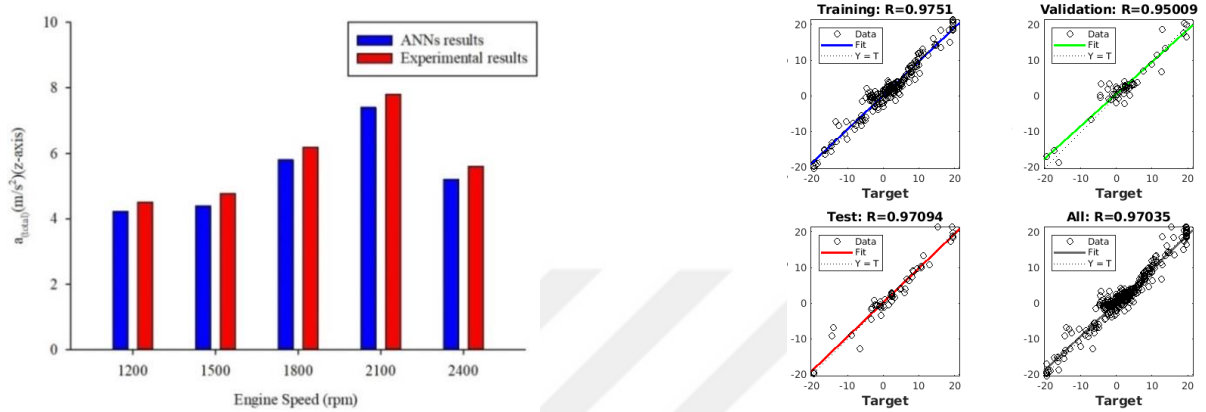


Figure 59. a_{total} (m/s²) - Engine Speed (rpm) and ANNs model R error values for P100

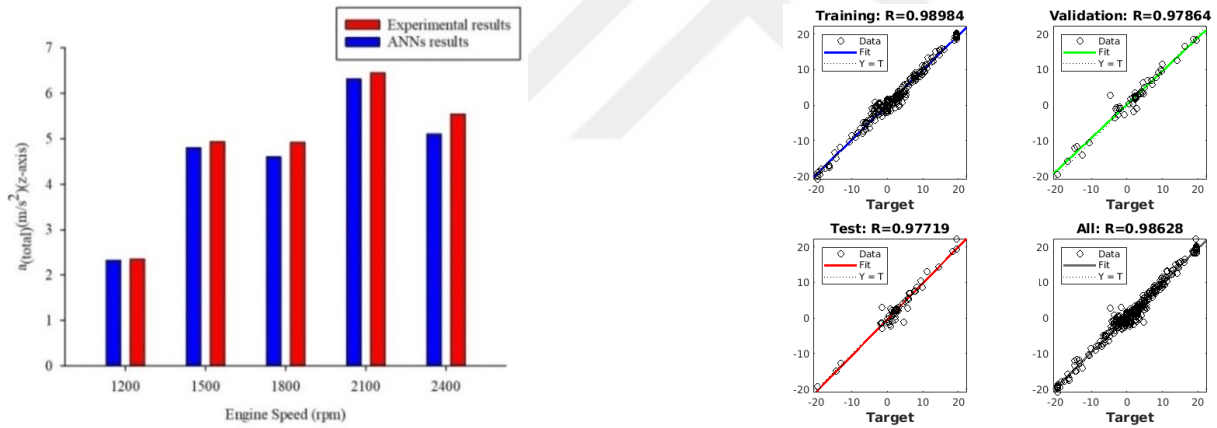


Figure 60. a_{total} (m/s²) - Engine Speed (rpm) and ANNs model R error values for P95A5

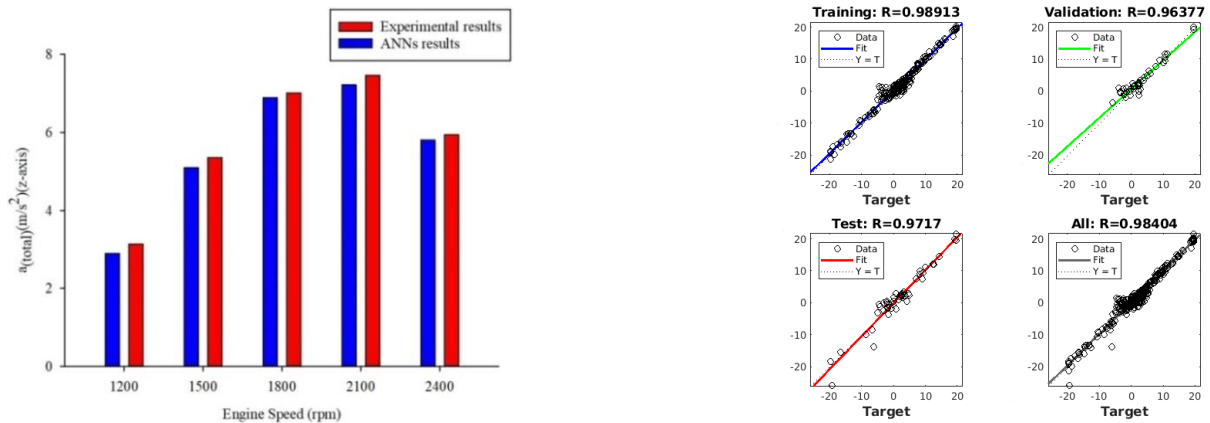


Figure 61. a_{total} (m/s²) - Engine Speed (rpm) and ANNs model R error values for P90A10

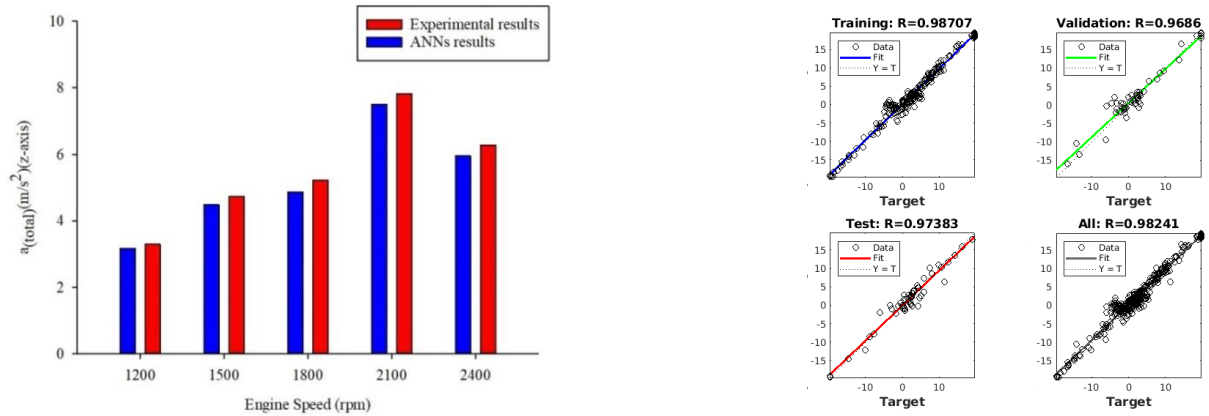


Figure 62. $a_{(total)}(m/s^2)$ - Engine Speed (rpm) and ANNs model R error values for P85A15

All regression formulations in the ANNs models were given in Table 17 according to different NH_3 additive ratios. As a result of the comparison of the experimental vibration data, the highest z-axis vibration data were tabulated in Table 18 for all NH_3 additive ratios.

Table 17. Regression formulations for peanut- NH_3 mixtures

NH_3 additive	Regression formulations in ANNs models
No NH_3	$z(m/s^2) = 15,15 - 0,0190 \text{ Time (second)} + 1,784 x(m/s^2) - 0,270 y(m/s^2) + 0,361 \text{ RMS}(m/s^2) + 0,00046 \text{ Engine Speed (m/s)}$
5% NH_3	$z(m/s^2) = 19,31 - 0,0025 \text{ Time (second)} + 1,9558 x(m/s^2) - 0,598 y(m/s^2) + 0,1822 \text{ RMS}(m/s^2) - 0,00055 \text{ Engine Speed (m/s)}$
10% NH_3	$z(m/s^2) = 20,74 - 0,0000 \text{ Time (second)} + 2,0192 x(m/s^2) - 1,025 y(m/s^2) + 0,0772 \text{ RMS}(m/s^2) - 0,00087 \text{ Engine Speed (m/s)}$
15% NH_3	$z(m/s^2) = 25,12 + 0,0058 \text{ Time (second)} + 2,2253 x(m/s^2) - 0,470 y(m/s^2) + 0,0383 \text{ RMS}(m/s^2) - 0,00206 \text{ Engine Speed (m/s)}$

Table 18. The z-axis vibration data and its accuracy values for peanut- NH_3 mixtures

Engine speed (rpm)	Fuel type	Accuracy values	Highest z-axis vibration data
2100 rpm	P100	97.035%	7.81 m/s^2
2100 rpm	P95A5	98.628%	6.45 m/s^2
2100 rpm	P90A10	98.404%	7.45 m/s^2
2100 rpm	P85A15	98.241%	7.84 m/s^2

All vibration data in the z-axis and RMS of vibration data for varying engine speed were respectively given in Figure 62 and Figure 63 according to all NH_3 additive ratios.

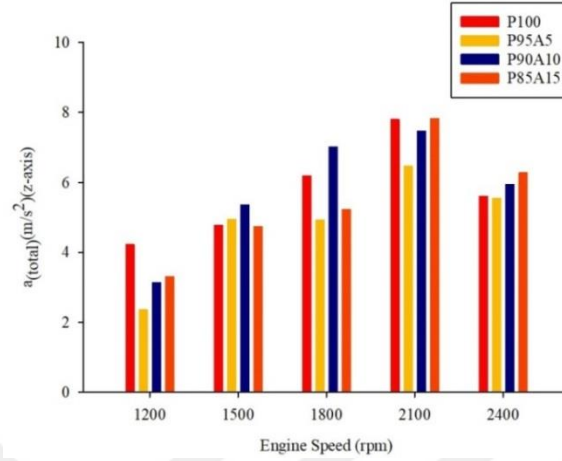


Figure 63. All vibration data in z-axis for varying engine speed

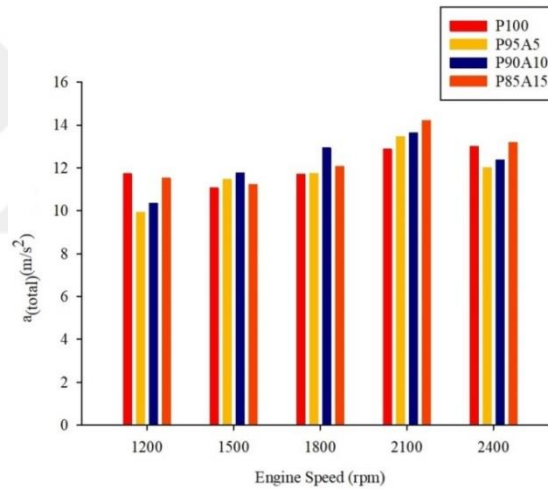


Figure 64. RMS of vibration data for varying engine speed

As seen in Figure 62, high z-axis vibration data was recorded for the P100. In this sense, 5% NH_3 additive positively affected z-axis vibration data and a noticeable decrement were observed for the engine vibration data. On the other hand, 10% and 15% NH_3 additive ratios caused an increase in the z-axis vibration data contrary to the 5% NH_3 additive ratio. Therefore, the highest vibration data was recorded as 7.84 m/s^2 at 2100 rpm for the P85A15 fuel mixture. Moreover, the highest z-axis vibration data was observed at 2100 rpm for all fuel mixtures. The images that are captured from the accelerometer sensor during the experiment were given in Figure 64 for the x, y, and z-axis.

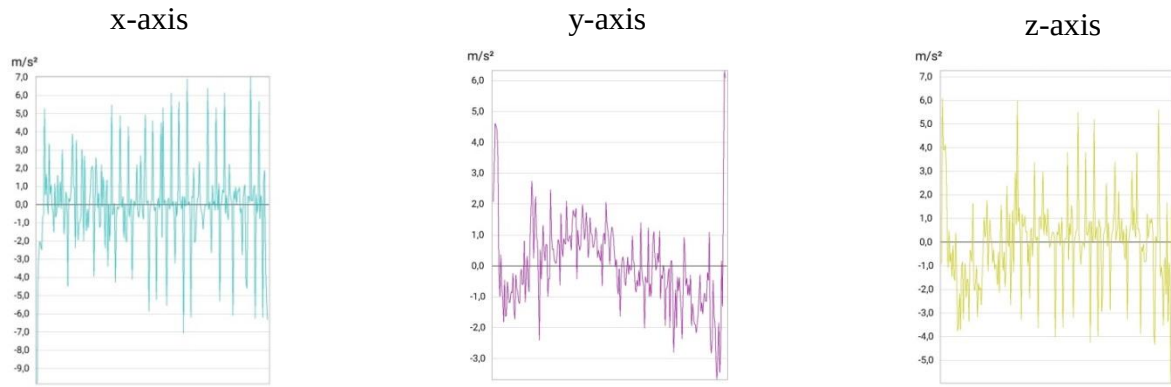


Figure 65. $a(m/s^2)$ - time at x, y, and z axis

4.3.4. Vibration and ANNs results of waste oil -NH₃ mixtures

The waste oil biodiesel was blended with 5%, 10%, and 15% NH₃ additive and the ANNs models were generated to predict the experimental engine vibration for all fuel mixtures. The comparison of the experimental and simulation vibration data was respectively given in Figure 65, Figure 66, Figure 67, and Figure 68 for all NH₃ additive ratios.

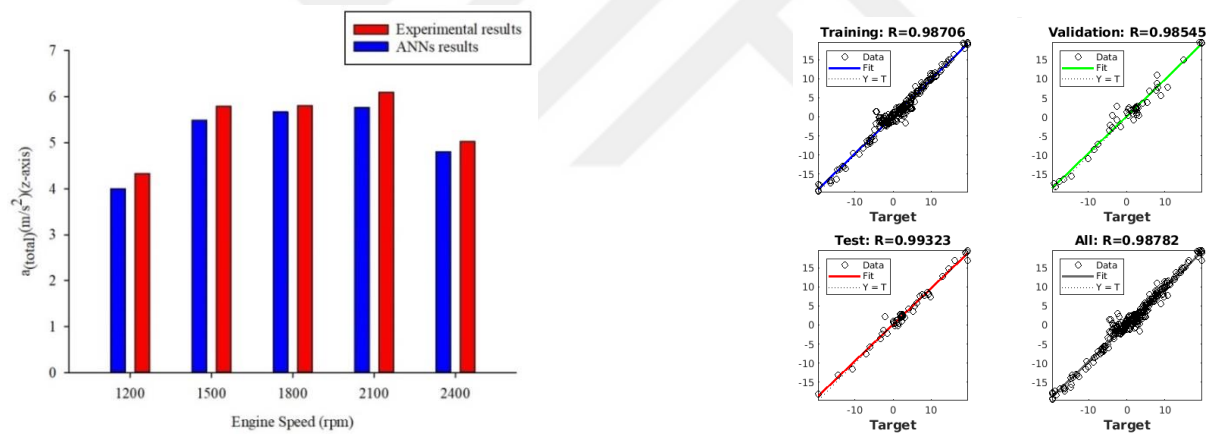


Figure 66. $a_{total}(m/s^2)$ - Engine Speed (rpm) and ANNs model R error values for W100

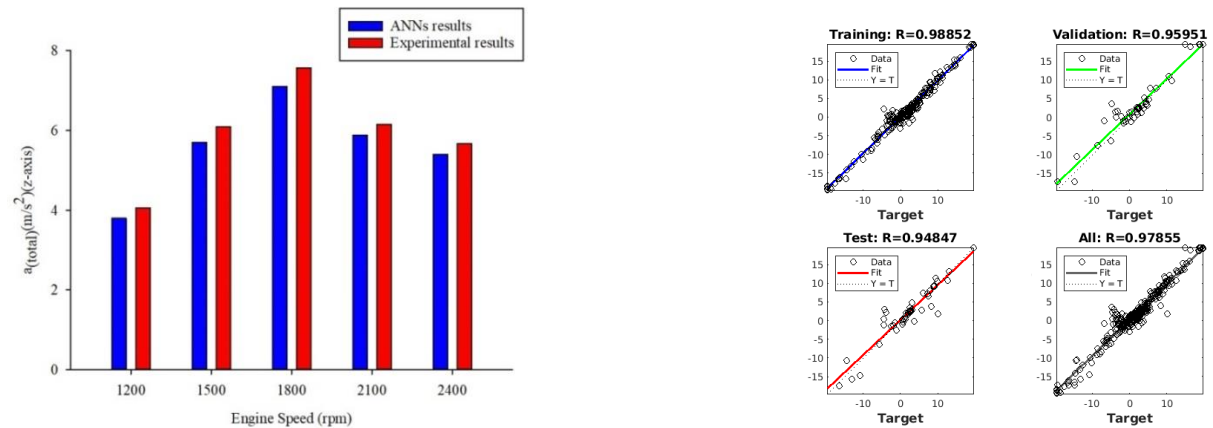


Figure 67. $a_{total}(m/s^2)$ - Engine Speed (rpm) and ANNs model R error values for W95A5

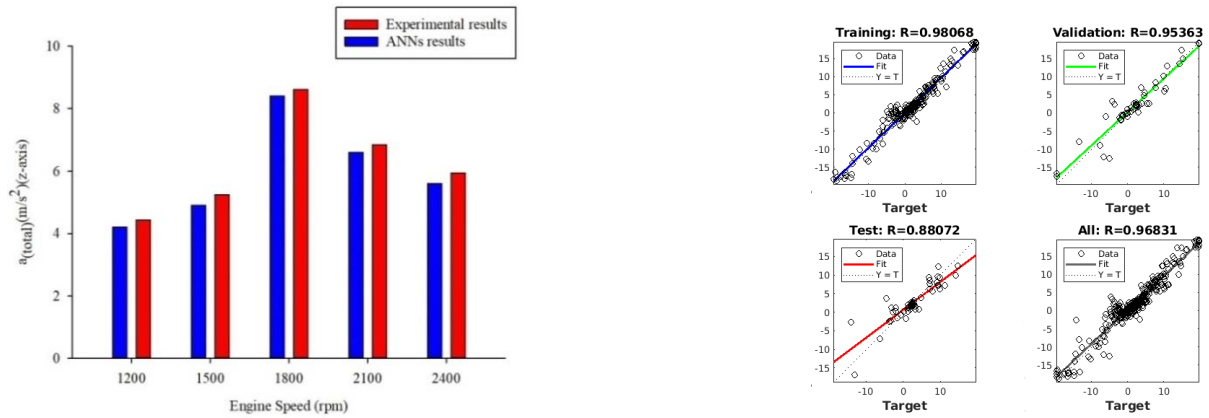


Figure 68. a_{total} (m/s²) - Engine Speed (rpm) and ANNs model R error values for W90A10

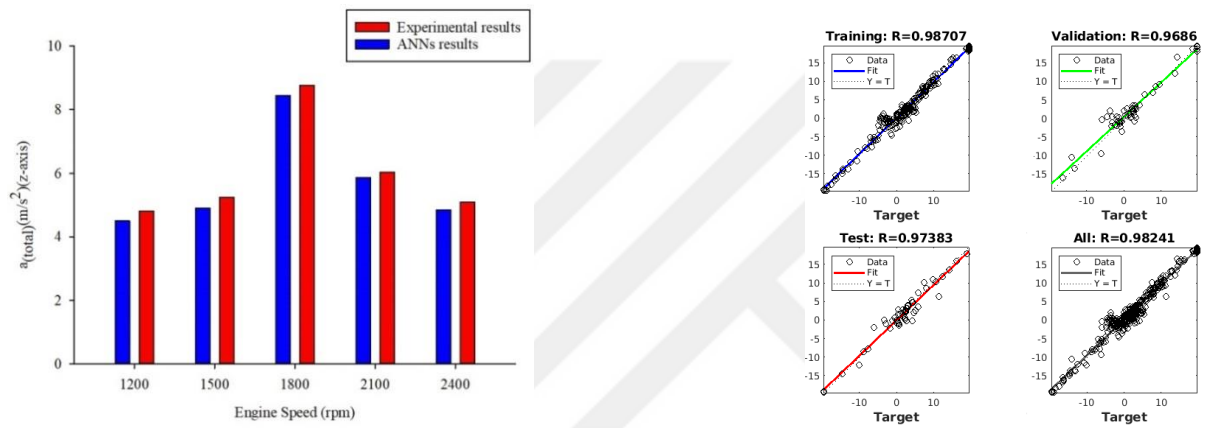


Figure 69. a_{total} (m/s²) - Engine Speed (rpm) and ANNs model R error values for W85A15

All regression formulations that are used to predict the vibration data are given in Table 19. Besides, the highest z-axis vibration data was tabulated in Table 20.

Table 19. Regression formulations for waste oil-NH₃ mixtures

NH ₃ additive	Regression formulations in ANNs models
No NH ₃	$z(\text{m/s}^2) = 20,05 - 0,0332 \text{ Time (second)} + 2,186 x(\text{m/s}^2) - 0,962 y(\text{m/s}^2) + 0,0781 \text{ RMS}(\text{m/s}^2) + 0,00230 \text{ Engine Speed (m/s)}$
5% NH ₃	$z(\text{m/s}^2) = 21,69 - 0,0141 \text{ Time (second)} + 2,3511 x(\text{m/s}^2) - 0,794 y(\text{m/s}^2) + 0,2246 \text{ RMS}(\text{m/s}^2) + 0,00045 \text{ Engine Speed (m/s)}$
10% NH ₃	$z(\text{m/s}^2) = 23,30 - 0,0438 \text{ Time (second)} + 2,5402 x(\text{m/s}^2) - 0,1301 y(\text{m/s}^2) + 0,0706 \text{ RMS}(\text{m/s}^2) + 0,00341 \text{ Engine Speed (m/s)}$
15% NH ₃	$z(\text{m/s}^2) = 25,10 - 0,0598 \text{ Time (second)} + 2,5480 x(\text{m/s}^2) - 0,480 y(\text{m/s}^2) + 0,1946 \text{ RMS}(\text{m/s}^2) + 0,00162 \text{ Engine Speed (m/s)}$

Table 20. The z-axis vibration data and its accuracy values for waste oil -NH₃ mixtures

Engine speed (rpm)	Fuel type	Accuracy values	Highest z-axis vibration data
2100 rpm	W100	98.782%	6.09 m/s ²
1800 rpm	W95A5	97.855%	7.56 m/s ²
1800 rpm	W90A10	96.831%	8.61 m/s ²
1800 rpm	W85A15	98.241%	8.71 m/s ²

All vibration data in the z-axis and RMS of vibration data for varying engine speed were respectively given in Figure 69 and Figure 70 according to all NH₃ additive ratios.

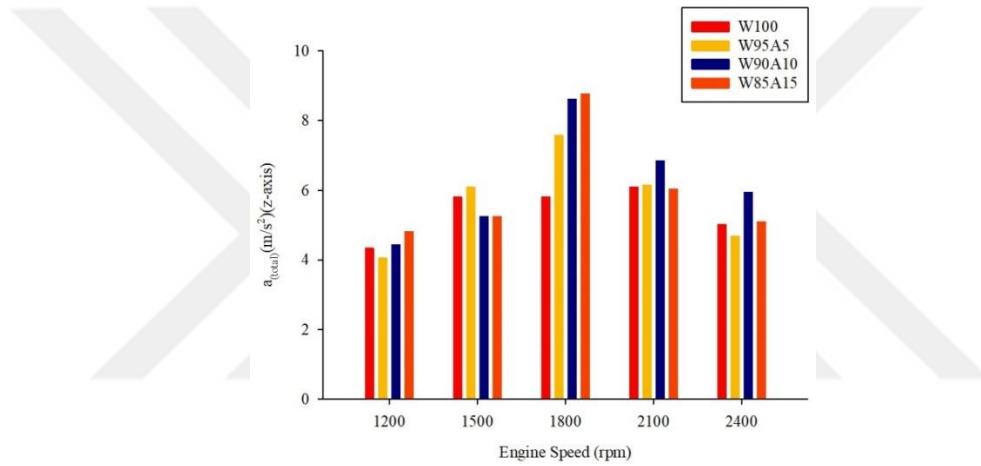


Figure 70. All vibration data in z-axis for varying engine speed

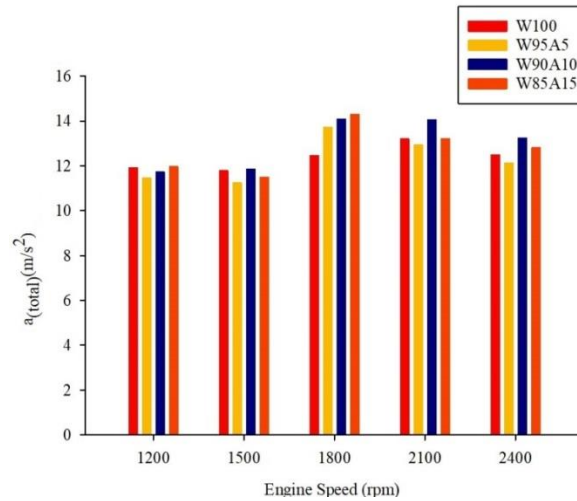


Figure 71. RMS of vibration data for varying engine speed

As seen in Figure 69, no noticeable vibration difference was observed between W100 and W95A5 fuel mixtures depending on the engine speed except at 1800 rpm. In addition to that, 10% and 15% NH_3 additive particularly caused to increase the z-axis vibration data. Therefore, the highest vibration data was recorded as 8.71 m/s^2 at 1800 rpm for the W85A15 fuel mixture. Moreover, the highest z-axis vibration data was observed at 1800 rpm for all fuel mixtures. The images that are captured from the accelerometer sensor during the experiment were given in Figure 71 for the x, y, and z-axis.

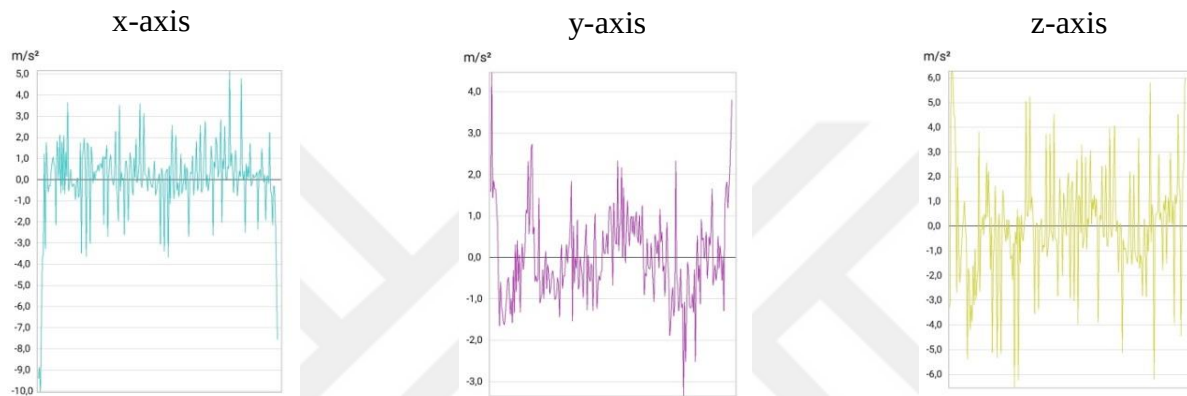


Figure 72. $a(\text{m/s}^2)$ - time at x, y, and z axis

5. CONCLUSION

The effects of NH_3 as a fuel additive on the engine vibration, emission, and performance parameters were numerically and experimentally investigated in this study. The sunflower, peanut, hazelnut, and waste oil biodiesel were produced from vegetable oils in the laboratory of Adana Alparslan Türkeş Science and Technology University. In the first part of the study, the Diesel-RK was used as a combustion simulation programme to observe numerically the effects of NH_3 additive on the engine emission and performance parameters. The combustion simulations were generated according to the chemical and physical properties of biodiesel. NH_3 as a fuel additive was gradually blended with the different types of biodiesel in 5%, 10%, and 15%. As a result, the following conclusions can be drawn from these combustion simulations;

In this study, the emission parameters were numerically investigated in a wide range. These parameters are NO_x , PM, and smoke opacity. As a result of the combustion simulations, the NH_3 additive dramatically decreased the NO_x emission depending on biodiesel variety. The highest NO_x concentration was observed as 444.16 ppm at 1500 rpm for the P100 fuel mixture. The highest NO_x emission reductions for all fuel mixtures were tabulated in Table 21.

Table 21. NO_x reduction ratios for all fuel mixture types

S85A15	36.39 % ↓
P85A15	54,90% ↓
N85A15	33,77% ↓
W85A15	34,84% ↓

As seen in Table 21, 15% NH_3 additive caused the highest reductions for all fuel mixtures. In this sense, it was concluded that the NH_3 additive significantly reduces NO_x emission for all fuel mixtures depending on the varying engine speed.

The NH_3 additive negatively affected the PM parameter on the contrary to the NO_x parameter. In this sense, as the NH_3 additive ratios were gradually increased, the PM concentration showed an increment depending on the varying engine speed. Therefore, the highest PM

concentration was observed as 0.9584 g/kWh at 1200 rpm for S85A15 fuel mixture. The highest PM increments for all fuel mixtures were tabulated in Table 22.

Table 22. PM increment ratios for all fuel mixture types

S85A15	7.44% ↑
P85A15	13.17% ↑
N90A10	7.66% ↑
W85A15	8.68% ↑

As seen in Table 22, 15% and 10% NH₃ additive ratios caused the increment of the PM concentration for all fuel mixtures. Therefore, it was concluded that the NH₃ additive dramatically increased the PM parameter.

NH₃ as a fuel additive partially increased the smoke opacity parameter. In this sense, it has been revealed that there is a direct relationship between the PM parameter and the smoke opacity parameter. The highest smoke opacity value was observed as 2.41 at 1200 rpm for S85A15 fuel mixture. The highest smoke opacity increments for all fuel mixtures were tabulated in Table 23.

Table 23. Smoke opacity increment ratios for all fuel mixture types

S90A10	2.84% ↑
P85A15	4.69% ↑
N90A10	3.07% ↑
W85A15	3.52% ↑

As seen in Table 23, the highest smoke opacity increments were observed for 10% and 15% NH₃ additive ratios when all fuel mixtures were compared between each other. As a result of the combustion simulations, it was concluded that NH₃ additive negatively affected the smoke opacity parameter.

In the scope of this study, the effects of NH₃ additive on engine performance have been extensively studied. These performance parameters that are examined can be described as the engine torque, power, and IMEP parameters.

As mentioned in the previous sections, the NH_3 additive can worsen the combustion and thermal efficiency of the engine due to having a low oxygen content of the fuel mixtures. In this sense, the NH_3 additive generally has a negative effect on all engine performance parameters. Therefore, the NH_3 additive partially causes to decrease in the engine torque. The highest torque value was calculated as 147.47 N*m at 1800 rpm for the N90A10 fuel mixture. The highest torque reductions for all fuel mixtures were tabulated in Table 24.

Table 24. Torque reduction ratios for all fuel mixture types

S85A15	3.1% ↓
P85A15	5.88% ↓
N90A10	3.09% ↓
W90A10	3.1% ↓

As seen in Table 24, 10% and 15% NH_3 additive ratios caused the highest decrement for all fuel mixtures as in the emission parameters. Therefore, it was concluded that the NH_3 additive slightly decreased the engine torque depending on the varying engine speed.

The engine power parameter was investigated to more clearly evaluate the effect of the NH_3 additive on the torque of the engine. There is a direct proportional relationship between engine power and torque parameters. Therefore, the NH_3 additive slightly decreased the engine power for all fuel mixtures as well as engine torque. The highest engine torque was calculated as 36,238 kW at 2400 rpm for P100 fuel mixture. The highest power reductions for all fuel mixtures were tabulated in Table 25.

Table 25. Power reduction ratios for all fuel mixture types

S95A5	2.97% ↓
P85A15	5.92% ↓
N85A15	3.29% ↓
W85A15	3.33% ↓

As seen in Table 25, 15% NH_3 additive caused to decrease the highest reduction P85A15, N85A15, and W85A15. Besides, the highest decrement was observed for 5% NH_3 additive in sunflower biodiesel. Therefore, it was concluded that slightly decrement was observed in the

engine power parameter for all fuel mixtures and the engine power has a parallel relationship with the engine torque.

The IMEP parameter has a critical importance for the investigation of the engine power and torque parameters to become more meaningful. The usage of NH_3 as a fuel additive directly affects the IMEP parameter due to the reduction of the engine torque and power parameters. Therefore, NH_3 additive partially caused to decrease the IMEP parameter for all fuel mixtures. The highest IMEP value was calculated as 6.94 bar at 2400 rpm for N100 fuel mixture. The highest IMEP reductions for all fuel mixtures were tabulated in Table 26.

Table 26. IMEP reduction ratios for all fuel mixture types

S90A10	2.43% ↓
P85A15	4.89% ↓
N90A10	2.59% ↓
W90A10	2.58% ↓

As seen in Table 26, the highest reductions were generally observed in the sunflower, hazelnut, and waste oil biodiesel for a 10% NH_3 additive ratio. In addition to that, 15% NH_3 additive specifically caused to decrease in the IMEP parameter for peanut biodiesel. Therefore, it was concluded that the NH_3 additive negatively affected the IMEP parameter for all fuel mixtures as in other performance parameters.

In the second part of the study, the engine vibration parameter was experimentally investigated. Therefore, Mitsubishi Canter 4D31 was worked under no-load conditions and was gradually increased from 1200 rpm until 2400 rpm with 300 rpm increments. Besides, the ANNs models were generated to predict the experimental vibration data. The predicted vibration data were compared with the experimental vibration data. The sunflower, peanut, hazelnut, and waste oil biodiesel were produced and blended with 5%, 10%, and 15% NH_3 additive to observe the effects of the fuel additive on the engine vibration parameter.

As a result of the all experimental studies, a slight z-axis vibration increment was observed depending on the engine speed when the sunflower biodiesel blended with 5%, 10%, and 15% NH_3 additive ratios was used as fuel mixtures. The decrement in the z-axis vibration was observed in the hazelnut biodiesel blended with 5% NH_3 additive ratio. On the contrary to %5

NH_3 additive, the increment was observed in the z-axis vibration for 10% and 15% NH_3 additive ratios. The peanut biodiesel blended with 5% NH_3 additive ratio positively affected and decreased the z-axis vibration but 10% NH_3 additive ratio caused a significant increment in the z-axis vibration as in hazelnut biodiesel. As 5%, 10%, and 15% NH_3 additive ratios were gradually increased in the fuel mixtures, an increment trend was observed in the z-axis vibration and the z-axis vibration data was negatively affected as in sunflower biodiesel.

As a result of the comparison of the fuel mixtures, it was concluded that NH_3 additive slightly caused the decrement for the hazelnut and peanut biodiesel blended with 5% NH_3 additive ratios. On the other hand, the NH_3 additive caused an increment in the sunflower and waste oil biodiesel for all NH_3 additive ratios. There are several reasons for the increment and decrement in the vibration data. As the NH_3 additive ratio in the biodiesel was increased, a change can be observed in the chemical properties of the fuel mixtures. The combustion quality decreased due to the decrement in oxygen content of the fuel mixtures. Besides, a noticeable change was observed in the physical properties of the fuel mixtures depending on the decrement in the density and viscosity of the biodiesel. Therefore, the NH_3 additive decreases the pressure inside the cylinder and can negatively worsen the combustion.

6. RECOMMENDATIONS

In the scope of this study, it has been revealed that the NH_3 as a fuel additive has a high usage potential for many energy sectors. In this sense, the effects of the NH_3 as a fuel additive on the engine emission, performance, and vibration parameters were experimentally and theoretically investigated and evaluated according to the different variable parameters. As a result of the study, it has been concluded that the usage of the NH_3 as a fuel additive is a determinant study in the fuel research field. Moreover, the negative results were partially determined for engine performance and vibration parameters. Therefore, it is necessary to carry out detailed studies for future studies in this research area.

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