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A Review on Artificial Neural Network and Alternative Fuels for Internal Combustion Engines

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Abstract Artificial Neural Network has a role in the fields of engineering because it helps in reducing the time and costs of practical experiments. IC drive is one of them. ANN was used to predict and analyze various characteristics such as performance, combustion, and emissions of an IC engine to save time and energy. The complex nature of an ANN may lead to the computation of time, energy, and space. Recent studies focus on changing network topology, deep learning, and ANN design to get the highest performance. Internal combustion engines can be classified into spark ignition engines and compression ignition engines. There are various alternative fuels used instead of these conventional fuels to reduce emissions and toxicity such as hydrogen, natural gas, biodiesel, and biogas, some of these fuels are suitable for spark ignition engines while others are suitable for compression ignition engines. Various fuels with their combustion process are going to be studied by indicating different emissions resulting from this combustion. Finally, the effect of artificial intelligence on combustion control in internal combustion engines is going to be studied as it is a future promising technology for this branch.

Keywords:. IC engines; Alternative fuels; Artificial neural network (ANN).

1 Introduction

Internal combustion engines are extensively used in energy generation and all transportation methods for people and goods. So, the demand of fuels used in IC engines has largely increased. The need of liquid fuels reaches to 3000 million tons oil equivalent per year and they are the cause of 10% of the world's greenhouse emissions [1]. Our need for transport energy (IC engines) increases rapidly for both SI (passenger cars) and CI (commercial road transport and marine sectors) engines. This increase is predicted to reach about 40% in 2040 depending on 90% petroleum based liquid fuels, 5% natural gas. Now, the main development in petrol engines is to reach maximum performance while in diesel engines is to reduce soot and NO_x emissions without affecting efficiency [2]. Internal combustion engines can be classified to spark ignition engines that use gasoline fuel where fuel-air are mixed before ignition and then combustion occurs, and compression ignition engines that uses diesel as a fuel that is compressed and injected so it reaches to self-ignition temperature. But at these days, there are many alternative fuels used instead of gasoline and diesel fuels such as ethanol, natural gas, liquefied petroleum gas, coal-derived liquid fuels, hydrogen, biodiesel, fuels other than alcohol, derived from biological materials, and non-petroleum fuels. Global transportation need of fuels is as in **Figure 1.** This indicates that biofuels reach 3% of the total fuel consumed in transportation sector [3]. These alternative sources reduce emissions and Sulphur contents [4]. Fuels of internal combustion engines in the general can be classified as shown in **Figure 2.** that indicates all types of conventional and alternative fuels [5]. In the last years, internal combustion engines have been controlled by artificial neural network as this method has various advantages, they can save time and money. This method is used to give us an indication about performance, combustion, and emissions. The purpose of the study is to look into the network topologies used to design the model, followed by a statistical analysis of the created ANN models. Also provided is a comparison of the ANN model and other prediction models [6].

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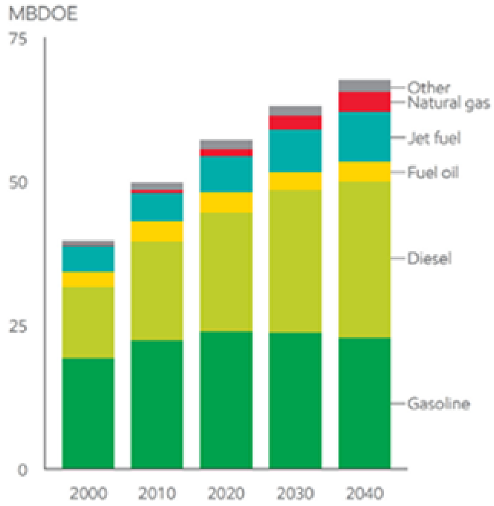


Fig .1 Global transportation fuel consumption [3]

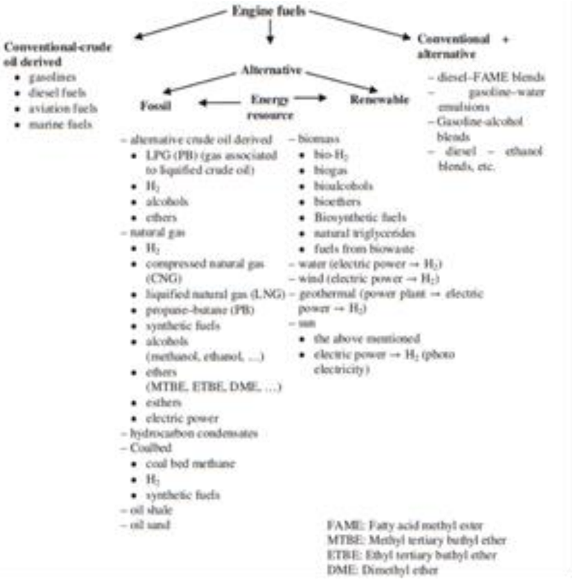


Fig. 2 Fuel types of IC engines [5].

Nomclature			
SI	Spark ignition	BMEP	Brake Mean Effective Pressure
CI	Compression ignition	RAFR	Relative air–fuel ratio
NO_x	Nitrogen oxides	MTBE	Methyl tert-Butyl Ether
ANN	Artificial neural network	UHC	Unburned Hydrocarbons
CO	Carbon monoxide	EM	Ethanol-methanol-gasoline blends
A/F	air/fuel	E	ethanol-gasoline blends
CO2	Carbon dioxide	G	straight gasoline
HC	hydrocarbons	M	Methanol-gasoline blends
O—H—C	Aldehydes	EM3	3 vol.% ethanol and methanol in gasoline
HCHO	Formaldehyde	LPG	Liquefied petroleum gas
SO2	Sulfur dioxide	F-T	Fischer-Tropsch
THC	Unburned hydrocarbon emissions	DME	Dimethyl ether
EGR	Exhaust gas recirculation	HCCI	Homogeneous charge compression ignition
AL	Artificial intelligence	BTE	Brake thermal efficiency

2 Gasoline Engines

Spark ignition engines may be port fuel injected (where fuel injection takes place besides the intake valve producing a well-mixed charge) or direct-injected (fuel is injected in the cylinder during intake stroke to form homogeneous mixture at high loads, while injection timing can be retarded at lower loads). At both types, gasoline fuel is used. The most important property in gasoline is knock resistance that is measured by octane number. Knocking occurs when unburnt charge ignites as it reaches to its self-ignition temperature before ignition time [7]. Knocking is used to measure the durability, fuel consumption, noise, emission performance and power density of the engine. This property limits the compression ratio of the engine so the thermal efficiency of the engine stills low. Modern gasoline engines are unable to achieve the necessary boost for detonation to increase their power density because of super-knock. **Figure 3.** Shows different types of combustion according to cylinder pressure, the first curve gives the normal combustion at low pressure without any knock, the second curve describes the low knocking with differential pressure (vibration) of 0.5 MPa, and it reaches to 5 MPa in the super-knock curve [8]. There are various emissions produced from combustion of gasoline such as emissions of CO are affected with air/fuel ratio as shown in **Figure 4.** The CO concentrations for a given air/fuel ratio depend on the fuel's composition; the higher the H/C ratio, the lower the concentrations. For fuel-rich mixes with a particular fuel composition, CO concentrations rise gradually as the air/fuel ratio falls. CO concentrations barely change with the air/fuel ratio for fuel-lean combinations. At full load, SI engines frequently run on practically fuel-rich compositions, resulting in considerable CO emissions. Due to inadequate mixing, localized rich patches, incomplete combustion, insufficient time to attain equilibrium of CO oxidation to CO2, and even for fuel-lean mixes, some CO will be created. [9]. HC emissions are also another type of SI emissions. Hydrocarbon fuel's insufficient combustion is the main cause of HC emissions. Aromatics (benzene, toluene, ethyl benzene), olefins (propane, ethylene), acetylene, and paraffines are crucial constituents of unburned hydrocarbons (e.g. methane). Unburned hydrocarbons will only stay in gaps near cylinder head gaskets, piston top lands, piston rings, and spark plugs because these locations are where the flame cannot spread. Additionally, HC emissions are produced as a result of the quench effect, misfires, and the separation of lubricating film. It is seen that nitrogen oxides are most abundant when there is a modest air surplus. High local peak temperatures and a matching air surplus facilitate the generation of these components. The high temperatures promote the breakdown of N2 and O2 into their individual atomic components. A surplus of air guarantees that there is enough oxygen available. NOx emissions are influenced by all engine-related factors, such as load, air/fuel ratio, ignition angle, and compression ratio. About 90–98% of all NOx emissions during engine operation are made up of NO emissions. Aldehydes are hydrocarbons with extra oxygen atoms incorporated into them. These O—H—C compounds are mostly created when high oxygen content fuels, like alcohols, are burned. Formaldehyde (HCHO), a significant member of this pollution class, is already governed by laws in states like California. There are also lead emissions from spark-ignition engines from the lead additives included in gasoline. Lead is typically present in anti-knock additives made of compounds based on chlorine and bromine, which are used to lower the high boiling point of lead. As lead compounds contaminate the modern catalytic converters, their use is progressively declining. **Figure 5.** provides a qualitative representation of the HC, CO, and NO generation mechanisms in a spark-ignition engine [10].

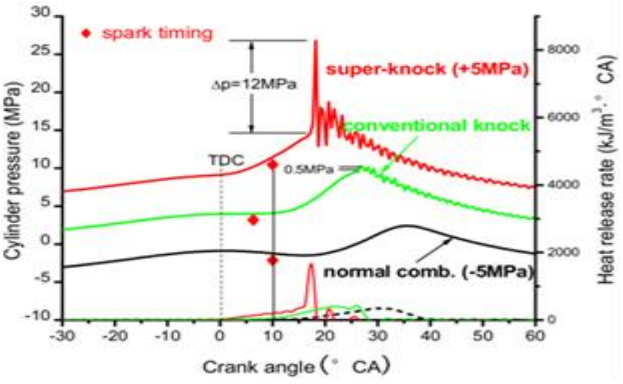


Fig. 3 Different combustion pressures of SI engines [8]

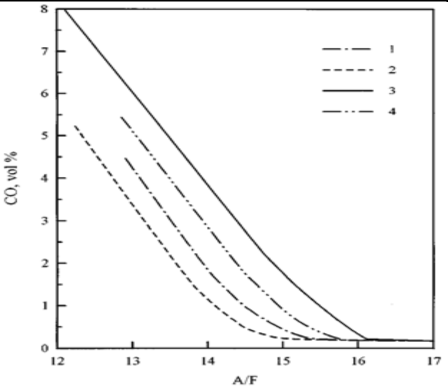


Fig. 4 CO emissions with various fuels' H/C to air/fuel ratios [10].

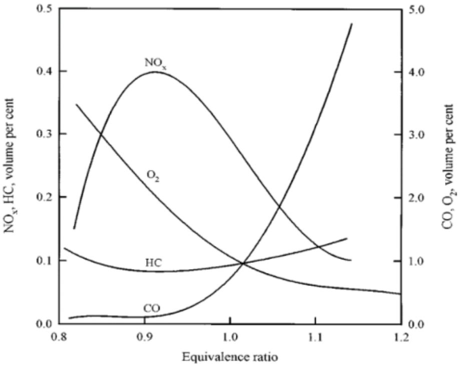
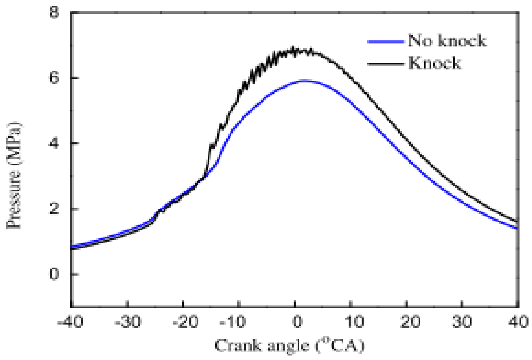


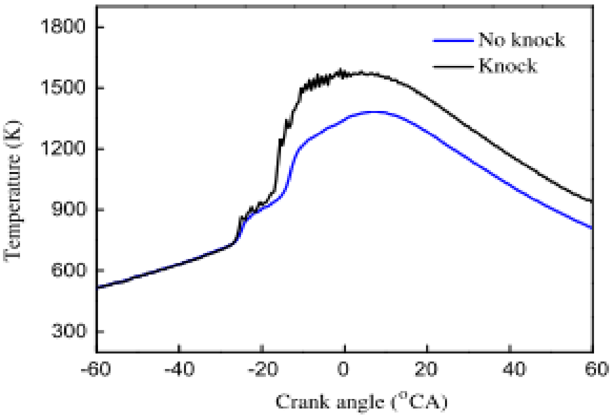
Fig. 5 Emissions from spark-ignited engines at various fuel/air ratios [10].

3 Diesel Engines

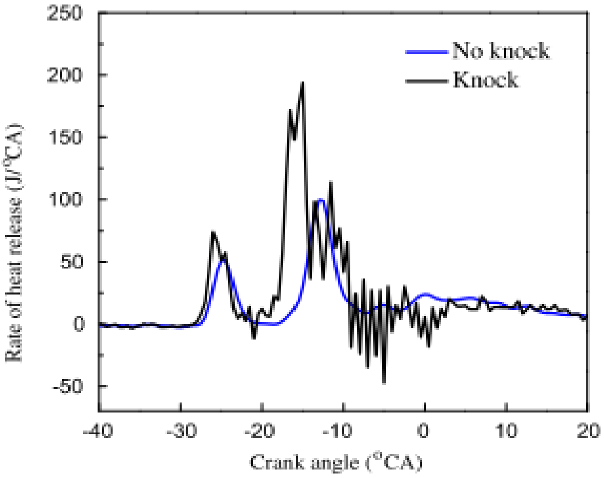
Diesel engine is an internal combustion engine that depends on compression of air, and then injecting diesel fuel onto high temperature air that has a temperature higher than self-ignition temperature of fuel so the ignition occurs. **Figure 6.** Shows knocking if diesel engine on cylinder pressure, temperature, and rate of heat released [11]. Diesel engine's mean air/fuel ratio in the combustion chamber is much higher per cycle compared to a SI engine. There are also incredibly "rich" local zones since the stratification-generated mixture is not homogeneous. High CO concentrations are produced as a result; which post-oxidation reduces to varying degrees. Dropping temperatures lead to a reduction in the post-oxidation rate (the reactions "freeze up") as the excess-air ratio rises. As a result, diesel engine CO concentrations are far lower than those of SI engines. However, the fundamental rules governing CO creation remain the same. Unburned HC is another type of emissions. During the diesel combustion process, excessively high excess-air ratios are present in some zones because the air—fuel combination is not uniformly distributed throughout. The local temperature decreases as the air/fuel ratio increases. This indicates that chemical processes move along somewhat slowly or could even "freeze-up," which would increase HC emissions. Diesel engines typically have lower HC concentrations than spark-ignition engines. Also, we have NOx emissions. Compared to spark-ignition engines, NOx concentrations are lower, with a somewhat larger NOx emission fraction. The production of nitrogen oxide is significantly influenced by the type of combustion process. When there is a severe lack of oxygen, combustion begins in the pre-combustion or swirl chamber of engines with a divided combustion chamber. This results in high temperatures and low NOx levels because there isn't enough air or oxygen present. Within the primary combustion chamber, this procedure is reversed. Low NOx generation is also a result of extreme surplus air ratios and, hence, low temperatures. The aforementioned characteristics that reduce NO emissions are absent from the direct-injection diesel engine. So, compared to an engine with a divided combustion chamber, NO generation is roughly twice as high. Sulfur compounds are another type of emission. The sole cause of Sulphur compounds is the Sulphur concentration of the fuel. Sulfur dioxide (SO2) turns into Sulphur acid when it is mixed with the water that is created during combustion. Acid rain and particle production are issues brought on by Sulphur-containing chemicals via Sulphur. Finally, Particulates is one of diesel emissions. Soot emissions are essentially a subset of particle emissions. Extreme air shortages lead to soot development. Localized air or oxygen deficit exists in diesel engines. As the air/fuel ratio falls, it rises. Long-chain molecules thermally break, releasing soot as a result. Acetylene and other polymerization procedures produce molecules with a high carbon content, which then result in soot particles Once soot has developed, only a little amount of oxidation is possible. As a result of soot creation, molecules become heavier and have a lower hydrogen content, eventually aggregating to form soot particles. Particulates are made up of liquid and solid phases that are both organically soluble. Amorphous carbon, ash, oil additives, corrosion products, and abrasion products make up the solid phase. In the majority of cases, soot is blended with the fuel and lubricant ingredients in the liquid phase. After cooling by turbulent mixing with air, the hydrocarbons present in the hot exhaust are still primarily gaseous and transformed into a liquid, organically soluble phase (particulates). Operating point and combustion process have a significant impact on particulate composition. **Figure 7**. Shows the composition of diesel engine emissions [10].



(a) In-cylinder pressure



(b) In-cylinder temperature



(c) Rate of heat release

Fig. 6 Effect of knocking on engine characteristics [11].

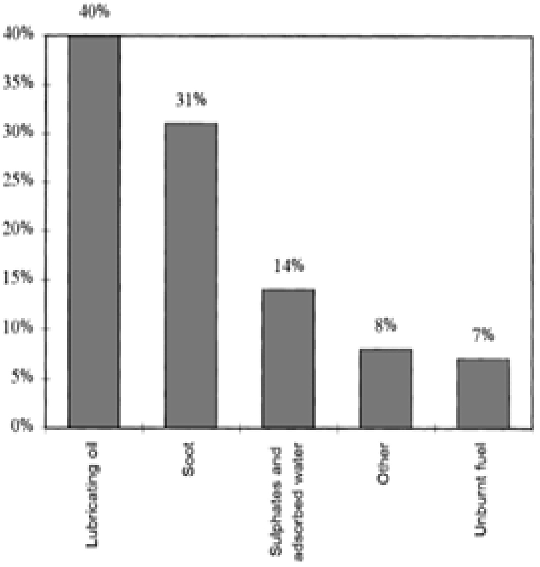


Fig. 7 Particulate composition of diesel engine exhaust [10]

4 Alternative Fuels of Internal Combustion Engines

Gaseous fuels like hydrogen, natural gas, and propane, alcohols like ethanol, methanol, and butanol, vegetable and waste-derived oils, and electricity are examples of alternative fuels. These fuels can be utilized in systems that are solely dedicated to burning them or in systems that combine them with other fuels, such as conventional gasoline or diesel, as in the case of hybrid-electric or flexible fuel vehicles. Some automobiles and engines have been manufactured with alternate fuels in mind. Others have their engines' fueling and control systems modified from their factory settings in order to run on an alternate fuel. There are many types of alternative fuels used in internal combustion engines, some of them are used for gasoline engines, while others are used in diesel engines.

4.1 Alternative Fuels used in gasoline engines

4.1.1 Hydrogen

Hydrogen is one of the most important types of fuel used in internal combustion engines, as it does not cause harmful emissions such carbon dioxide emissions so it is considered as an ideal alternative fuel for internal combustion engines [12], [13]. Despite requiring a considerable amount of energy, Hydrogen is the only fuel that can be made totally from the abundant renewable resource water. While it only ever creates water when combusted with oxygen, it does occasionally produce some nitrogen oxides when combined with air. Due to these characteristics, hydrogen is a great fuel that may help to meet the increasingly strict environmental regulations governing the exhaust emissions from combustion equipment, including the reduction of greenhouse gas emissions. Through the use of energy, hydrogen can be created as a sustainable fuel supply to gradually replace conventional fossil fuels whose sources are running out [14]. Knocking occurs when using hydrogen as a fuel in spark ignition engines. One of the most crucial factors in the operation of an H_2 spark ignition engine is the prevention of knock. The main factors that affect the knock-limited equivalence ratio are the compression ratio and intake temperature, but the effect of spark timing is typically less significant. With rising compression ratio and/or intake temperature, the knock-free operational mixture zone has a tendency to become much smaller. This serves as a realistic restriction on hydrogen engines' ability to become more powerful and efficient. While the addition of carbon monoxide generally tends to have a less significant impact, methane and hydrogen together boost knock limits [15]. Despite a loss in brake power, the use of hydrogen fuel increased brake thermal efficiency at various engine speeds. CO and THC emissions were almost nonexistent, while a sharp increase of up to 99.5% in NOx emissions was not stopped [16].

4.1.2 Natural Gas

In many nations, natural gas is a potential alternative fuel to meet stringent engine pollution laws. Different combustion and emission characteristics are possible for natural gas engines when operating at lean burn and stoichiometric conditions. Future strict emission regulations can be addressed by stoichiometric natural gas engines fitted with three-way catalysts, but this requires accurate air-fuel ratio management techniques and very effective catalyst to oxidize methane. The addition of EGR to a stoichiometric mixture is one way to improve fuel economy under pure stoichiometric SI operation conditions. Natural gas engines' brake mean effective pressures are constrained by thermal loading and knocking. By lowering combustion temperature, EGR can increase knock limit. Miller cycle and EGR work well together to boost the BMEP of natural gas engines [17]. Natural gas-powered SI engines have the ability to operate at higher compression ratios, which results in higher thermal efficiency but also higher nitrogen oxide (NOx) emissions. By contrast, lesser levels of carbon dioxide (CO2), unburned hydrocarbons (HC), and carbon monoxide are produced (CO). Due to the convergence of one or more of the following three factors, these engines also generate relatively less power than gasoline-fueled engines: a decrease in volumetric efficiency brought on by the injection of natural gas into the intake manifold; the lower stoichiometric fuel/air ratio of natural gas compared to gasoline; and the lower equivalence ratio at which these engines may be operated in order to reduce NOx emissions With exhaust gas recirculation, high NOx emissions, especially at high loads, are reduced (EGR) [18]. An artificial neural network approach to analyze the cylinder's nonlinear combustion process is used. The research indicate that the artificial neural network algorithm created in this study was suitable for accurately predicting pressure, phasing, and exhaust-related parameters with acceptable error levels [19]. When using natural gas with ammonia (by more than 50% of the volume fraction) in spark ignition engine, it is found that Particular carbon dioxide emissions decreased by about 28%. In terms of nitrogen oxide emissions, the fuel-bound emissions predominated the total emission level of nitrogen oxides as combustion phasing was delayed as the ammonia fraction grew due to the slow flame speed and high minimum ignition energy. The early flame propagation was significantly impacted by the ammonia's slow laminar flame speed [20].

4.1.3 Biogas

Because of its clean combustion characteristics and renewable energy status in contrast to non-renewable fuel resources, biogas is a widely used energy substitute, especially when produced from biomass.

Biogas is one of the alternative fuels that are used instead of fossil fuels. It consists of methane and carbon dioxide [21]. The biogas's ability to burn was improved by the presence of hydrogen. Through the use of numerical simulations, the combustion of biogas in a Controlled Auto Ignition (CAI) engine is examined. For the purpose of studying the utilisation of biogas in a Chemkin setting, a combustion system model was created [22]. Biogas is produced by combining various domestic natural gas and carbon dioxide combinations. To cover the range frequently seen in sources of biogas in practice, the percentage of carbon dioxide was varied from 0 to around 40% by volume in the simulated biogas. The reduction of NOx emissions and higher compression ratio were the main effects of carbon dioxide in the biogas fuel on engine performance. However, as the carbon dioxide fraction reached 40%, the cylinder pressure decreased and the thermal efficiency of the power and brakes decreased by 3%. The addition of CO2 to the fuel also resulted in an increase in overall hydrocarbon emissions. The CO emissions were minimal and did not vary with the CO2 fraction in the biogas while running with lean fuel mixes. As the mixtures were rich, incomplete combustion caused the CO emissions to grow quickly when the CO2 component rose above 30%. The compression ratio and engine speed had essentially no impact on the CO emissions, which were connected with the relative air-to-fuel ratio. The brake mean effective pressure and thermal efficiency increase with increasing compression ratio. Power and thermal efficiency rose only little above the key ratio of 13:1 for compression ratios. The detonation above 15:1 caused a rapid increase in cylinder pressure. When the compression ratio was between 13:1 and 15:1 and the RAFR was between 1.05 and 0.95, power and thermal efficiency were at their maximum levels. While NOx levels were rather high in these circumstances, HC and CO emissions were relatively modest. (This was less when the fuel's CO2 level was high.) [23].

4.1.4 Ethanol and Methanol Blends

Utilizing oxygenated biofuels is known to lower exhaust emissions and minimize reliance on depleted fossil fuels [24]. The latent heat of evaporation, higher flame speed for enhancing engine power, low combustion temperature, and high hydrogen to carbon ratio that lowers dangerous exhaust emissions are just a few of the benefits of using methanol as a fuel for internal combustion (IC) engines [25]. When mixing ethanol with gasoline emissions produced are improved due to reducing CO and HC emissions [19]. The elimination of lead from all gasoline grades and the negative consequences of MTBE on both human health and the environment have prompted interest in the generation of higher alcohols from synthesis gas, particularly ethanol. As octane enhancers in vehicle fuels, low molecular weight alcohols like ethanol have taken the place of other chemicals. Petroleum products can burn more thoroughly when alcohols are added since they contain oxygen. This improves combustion efficiency and lowers air pollution [26]. Experimental research has been done on engine performance and pollutant emissions from various blended fuels in terms of kinds (ethanol, methanol, and gasoline) and rates (3 - 10 vol.% methanol and/or ethanol in gasoline). According to the test results, ethanol-methanol-gasoline blends (EM) burn cleaner than both ethanol-gasoline blends (E) and straight gasoline (G); nonetheless, methanol-gasoline blends (M) confirm the lowest emissions of CO and UHC among all test fuels. In terms of numbers, the M fuels produce CO and UHC emissions that are about 5.5% and 6% lower than those of the EM, while the EM produces CO and UHC emissions that are about 5% and 2% lower than those of the E, and the E produces a relative reduction in CO and UHC emissions that is about 31% and 14% lower than that of the G fuel. The engine produces fewer emissions when more ethanol and/or methanol are added to gasoline. Specifically, the CO and UHC emissions are reduced by about 17% and 10% when using EM3 (3 vol.% ethanol and methanol in gasoline), but they are reduced by about 35% and 15% when using EM7, and they are reduced by about 46% and 23%, respectively, when using EM10. This is in comparison to when using neat gasoline [27].

4.1.5 Liquefied Petroleum Gas (LPG)

LPG is used for spark ignition engines such as gasoline fuel. This fuel is used as a fuel for vehicles with internal combustion engines, LPG, or liquefied petroleum gas, is frequently referred to as auto gas. Additionally, it can be applied to stationary ICE equipment like generators. Propane or a mixture of propane and butane makes up auto gas. Fuel gas is LPG. Liquefied petroleum gas, commonly known as liquid petroleum gas (LPG), propane, or butane, is a flammable hydrocarbon gas mixture used as auto gas, home heating fuel, and cooking fuel.

LPG has received a lot of attention recently, especially because it is affordable and typically emits fewer pollutants than fossil fuels [28]. When establishing the ideal LPG mixture for a spark-ignition (SI) engine that runs on gasoline-LPG blends in order to maximize performance and minimize emissions, it is found that ideal LPG content was discovered to be 35% and Adding LPG lowers all emissions, but has a negative impact on BTE and BSFC [29]. When LPG is used in SI engines, the fuel burns more quickly, reducing the time needed for combustion. As a result, cylinder pressures and temperatures for LPG are projected to be higher than those seen for gasoline. LPG is expected to operate at greater temperatures and cylinder pressures. This can harm some of the structural components of the engine. LPG lowers the volumetric efficiency and, consequently, the effective power of the engine. Additionally, as volumetric efficiency declines, engine effectiveness declines as well, increasing specific fuel usage. The mole fractions of CO and NO in the exhaust gases are reduced by LPG. 5. When utilized at the same fuel-air equivalency ratios as gasoline, LPG has detrimental impacts on engine performance, fuel efficiency, and structural elements. However, it has beneficial benefits on offensive exhaust pollutants like CO and NO [30].

4.2 Alternative Fuels used in gasoline engines

Vegetable oil, biodiesel, Fischer-Tropsch (F-T) diesel, and dimethyl ether are just a few of the alternative fuels that can be used in conventional compression ignition engines with moderate ease. You can use vegetable oils as an alternative fuel for diesel engines, including palm, soybean, sunflower, peanut, and olive oils. Natural gas may be used to make F-T and DME, therefore the availability of feedstock is not a constraint. The cobalt catalyst's higher parafin content and the iron catalyst's higher olefin and oxygenate content are both clear examples of how the Fischer-Tropsch product composition is greatly influenced by the catalyst composition. Biodiesel is technically comparable to conventional petroleum diesel fuel and has technological advantages over it. The viscosities of the vegetable oils used as alternative engine fuels range from 10 to 20 times higher than that of petroleum diesel fuel [31]. In order to provide a source of ignition for the charge, high-cetane fuel is injected with natural gas in CI engines' dual-fuel mode, which uses natural gas to power them. Dual-fuel operation often maintains thermal efficiency levels relative to standard diesel-fueled CI-engine operation while dramatically reducing smoke levels. When compared to standard CI-engine operating at low and intermediate loads, lower NOx and CO2 emissions, as well as higher HC and CO emissions, are reported. Low combustion temperatures are the outcome of the low charge temperature and prolonged ignition delay, which are the causes of these trends. A lack of ignition centers is caused, among other things, by the pilot fuel's poor penetration and dispersion throughout the charge [18]. Additionally, efforts are being made to employ biogas as a substitute fuel in diesel engines, with dual fueling being suggested as the optimal method for biogas CI functioning. Thermal efficiency is increased when CO2 levels in biogas for dual fueling are reduced. The high heat release rate in the biogas HCCI mode is controlled by the presence of CO2, therefore the engine parts' longevity is unaffected. So it is advised to use biogas as a substitute fuel for diesel engines [32]. Diesel fuels with biogases are combusted in CI engines and ANN technology is used that indicated that the outcomes of the experiments were comparable and fell within the same intervals. Additionally, it assisted in extrapolating and interpolating experimental data that was previously challenging to conduct experimentally [33].

5 Artificial Neural Network in Internal Combustion Engines

The artificial neural network (ANN) is the mainstream of artificial intelligence. Artificial intelligence is the development of intelligence and its analysis in the machine. In automotive applications, artificial neural network is now considered as a favorable prediction tool. Since it does not need an understanding of the system or its underlying physics, an ANN model can be beneficial especially when the system is too complicated, and it is too costly to model it using a simulation program. Therefore, using ANN to model an internal combustion engine has been a growing research area in the last decade. The use of artificial intelligence (AI) systems as a technology offering an alternate approach to solving challenging and ill-defined issues is now widely acknowledged. They are fault tolerant in the sense that they can handle noisy and incomplete data, they can learn from examples, they can handle non-linear problems, and once trained, they can predict and generalize quickly. They've been put to use in a variety of fields, including control, robotics, pattern recognition, forecasting, medical, power systems, manufacturing, optimization, signal processing, and social and psychological sciences. They are especially helpful in system modelling for implementing intricate mappings and identifying systems [34]. Artificial neural network is considered a branch of machine learning and the heart of deep learning algorithms. ANN consists of node layers, input layer, hidden layer, and output layer a shown in Figure 8. ANN can be classified as shown in Figure 9. [35]. Artificial neural networks (ANN) are based on natural neural networks, or more specifically, on the principles of biological neurons. The biological nervous system is made up of a large number of interconnected processing units called neurons that work concurrently. As a result, the human brain could be compared to a supercomputer that is extraordinarily complex, highly non-linear, and massively parallel. The neurons of one layer are linked to those of another layer by weights, and an ANN is an architecture with a large number of neurons described in different layers. It may be trained or prepared to perform a particular task by accurately altering its design, bias, and linking weights [36]. ANN is used in different branches in internal combustion engines. For example, on the performance of both supervised and unsupervised artificial neural networks (ANN), the impact of choosing the right de-noising wavelet is examined [37]. Internal combustion engines are controlled by this technology as it is noticed that both ANN and response surface can give similar relations between input variables and output results for both gasoline and diesel engines [38]. In order to use biodiesel in the constructed artificial neural network, diesel fuel, biodiesel, B20, and bioethanol-diesel fuel with varying percentages (5%, 10%, and 15%) were mixed together. Motor studies were run to gather the reference values, and mixtures' fuel characteristics were also controlled. Using an artificial neural network created using reference values, power, moment, hourly fuel consumption, and specific fuel consumption were evaluated. **Figure 10.** provides a comparison of experimental data with ANN training estimations. The correlation coefficient for the ANN estimation test data set is 0.9994. R's values are suitable. The estimation results and experimental results are in good agreement, as shown in the figures. For any power, torque, fuel consumption, and specific fuel consumption, the differences between experimental and calculated findings are extremely minor and inconsequential [39]. An artificial neural network (ANN) was used to model the findings of experimental work for reliable outputs. In this context, measurements, calculations, and robust estimation using ANN were made for cylinder pressure, mass fraction burned, average gas temperature, rate of heat release, cumulative heat release, and velocity of heat transfer variations for diesel and safflower biodiesel fuels under various loads. The engine setup is shown in **Figure 11**. Studies in science made use of the Febris programme. The feed forward multilayer ANN model was trained using the MATLAB/artificial neural network module based on the input parameters. This study's use of ANN modelling is presented in **Figure 12.** And **Figure 13.** [40]**.** The values of the measured parameters' in-cylinder pressure are closely matched to the values predicted by the ANN, demonstrating the accuracy of the estimations. The heat release rate experiment and ANN findings revealed that the calculated results from the experimental works are obviously shown to be almost identical to the results estimated by the chosen ANN. The developed ANN software once more delivered reliable estimations of the starting values of cumulative heat release that were perfectly in line with the experimental findings. For all engine loads, the ANN results and predicted values from the experimental data are pretty close for the fraction of mass burning rates of D2 and Biodiesel [40]. For performance, emission, and vibration of a CI engine using Alumina Nano-Catalyst added to diesel-biodiesel blends, a conventional back-propagation learning algorithm-based ANN model was created as shown in **Figure 14.** The input and target parameters were mapped nonlinearly using a multi-layer perception network. The experimental data set had 324 values, of which 227 were utilized to train the network, 32 were randomly chosen to evaluate the trained network's performance, and 65 were randomly chosen to validate the network. The experimental data was analyzed using the ANN technique, and the results showed that there is a good correlation between the expected and measured data. For torque, power, CO, CO2, NO, and HC, respectively, performance and emission regression R-values using ANN were 0.97, 0.96, 0.98, 0.99, 0.98, and 0.98. Additionally, the regression R-values for the vibration parameters were 0.99, 0.99, 0.98, 25 0.94, 0.98, and 0.95, respectively. The results of the current study showed that the ANN is an effective tool for reasonably accurate performance, emission, and vibration prediction in CI and SI engines [41]. This technology is also used in vibration analysis to give an indication about misfire location in gasoline engines it is discovered that the three-dimensional vibration signal at x, y, and z enhances clustering with minimum quantitive error of 0.0025, 0.0011, and 0.00043, respectively [12].

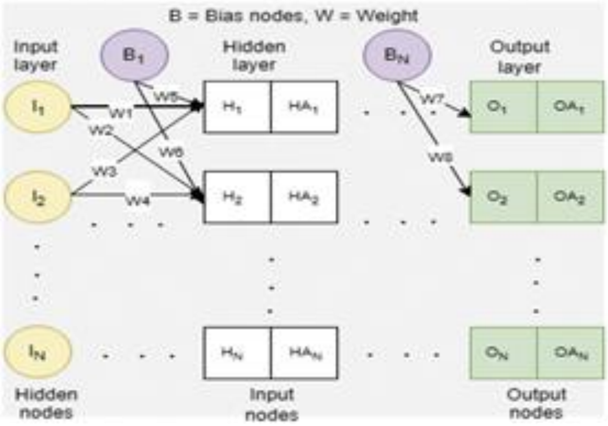


Fig. 8 Neural network architecture [35].

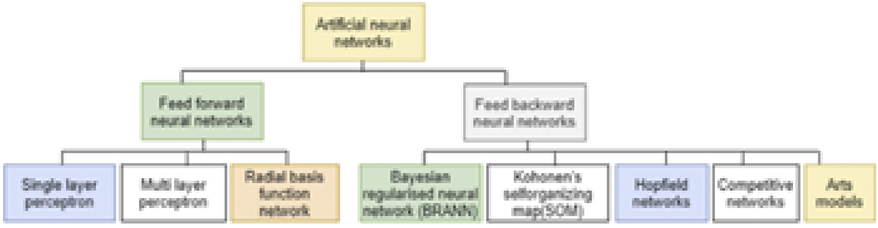
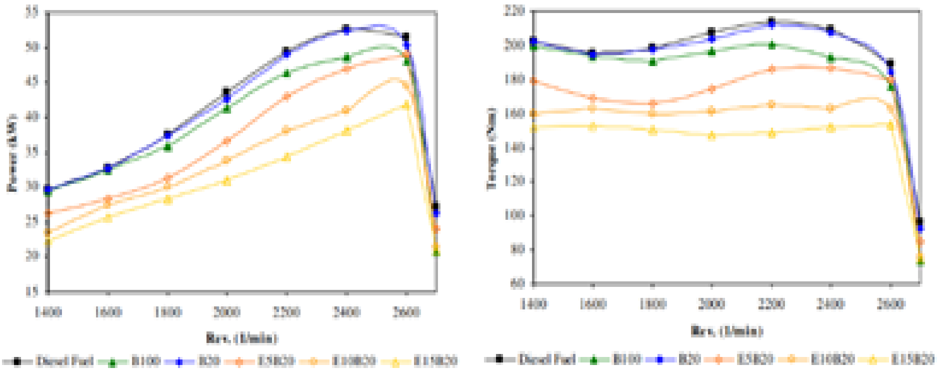
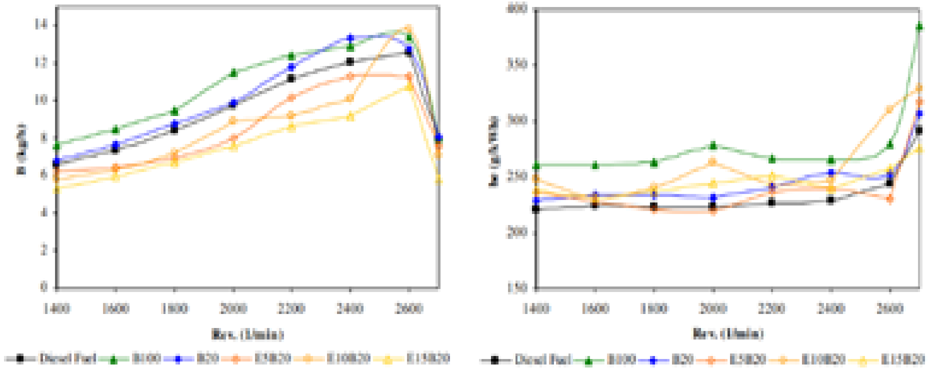


Fig.9 ANN classifications [35].



a. Power b. Torque



c. Fuel consumption (B) d. Specific fuel consumption (be)

Fig. 10 The time comparison between experimental data and estimated values from ANN training [39].

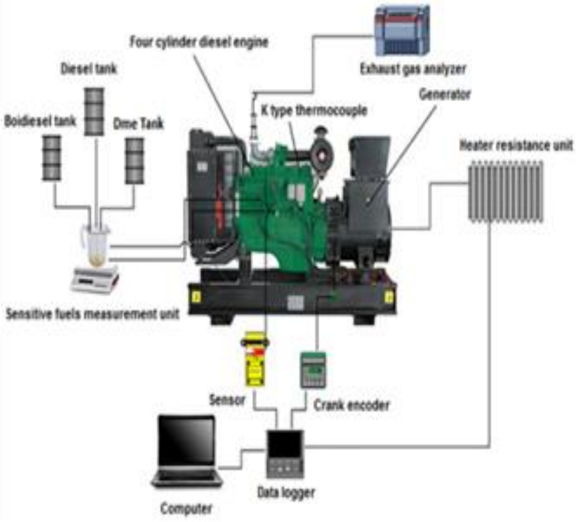


Fig. 11 Engine experimental setup [40].

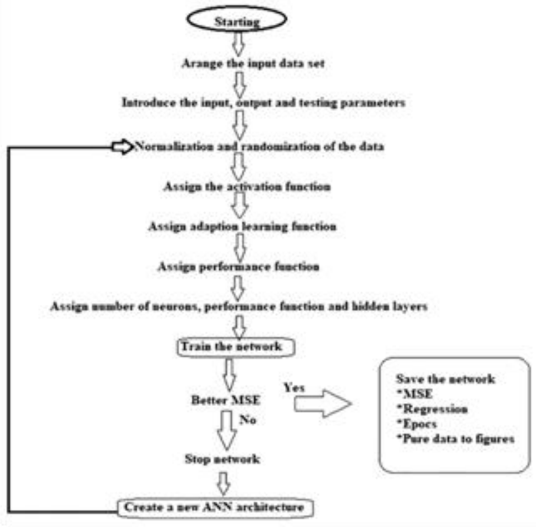
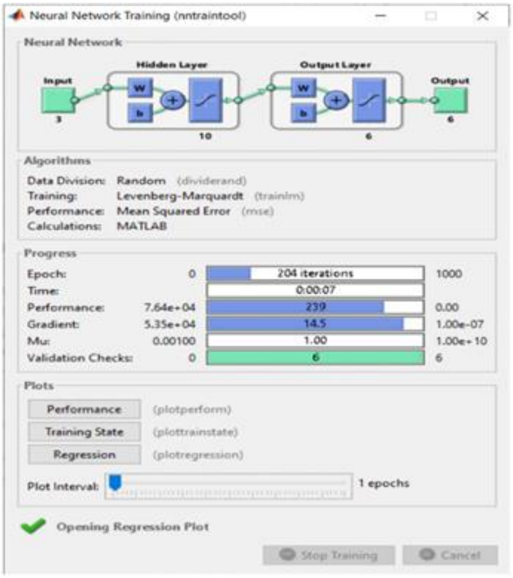


Fig. 12 Flowchart of the ANN Network [40]



Data Division: Random (dividerand)
Training: Levenberg-Marquardt (trainlm)
Performance: Mean Squared Error (mse)
Calculations: MATLAB

Epoch: 0 204 iterations 1000
Time: 0:00:07
Performance: 7.64e+04 239 0.00
Gradient: 5.35e+04 14.5 1.00e-07
Mu: 0.00100 1.00 1.00e+10
Validation Checks: 0 6 6

(plotperform)
(plottrainstate)
(plotregression)

Plot Interval: 1 epochs

✓ Opening Regression Plot

Fig. 13 Training processes of the Neural Network [40].

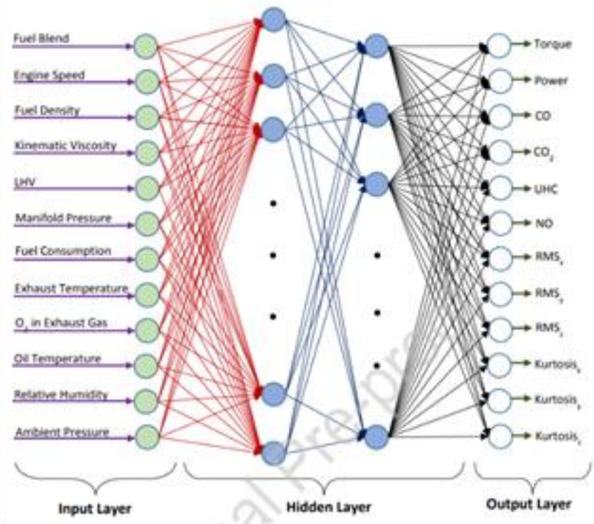


Fig. 14 Neural network architecture diagram [41].

6 Conclusion

Combustion, and different emissions of internal combustion engines have been studies according to previous experimental studies. This survey has studied conventional and alternative fuels for both spark ignition and compression ignition engines with different emissions. Conventional fuels are gasoline and diesel fuels, while alternative fuels such as hydrogen, natural gas, biogas, and biodiesel. Previous studies have shown that biofuels reach 3% of the total fuel consumed in transportation sector, that means that our need for alternative fuels increases annually. Our survey has shown artificial neural network technology as it is a branch of machine learning and artificial intelligence that is used in internal combustion engines for studying different parameters such as power, torque, and fuel consumption. The results of the studies showed that the ANN is an effective tool for reasonably accurate performance, emission, and vibration prediction in CI and SI engines.

References

[1] R. D. Reitz *et al.*, "IJER editorial: The future of the internal combustion engine," *International Journal of Engine Research*, vol. 21, no. 1, pp. 3–10, 2020, doi: 10.1177/1468087419877990.

[2] G. T. Kalghatgi, "The outlook for fuels for internal combustion engines," *International Journal of Engine Research*, vol. 15, no. 4, pp. 383–398, 2014, doi: 10.1177/1468087414526189.

[3] C. Bae and J. Kim, "Alternative fuels for internal combustion engines," *Proceedings of the Combustion Institute*, vol. 36, no. 3, pp. 3389–3413, 2017, doi: 10.1016/j.proci.2016.09.009.

[4] N. Ghazaly and M. Salah Hofny, "Injection and Combustion of biodiesel at different blends: A review," *SVU-International Journal of Engineering Sciences and Applications*, vol. 3, no. 2, pp. 37–46, 2022, doi: 10.21608/svusrc.2022.130956.1043.

[5] E. Requirement, "Fuels for internal combustion engines 1.," no. 2014, 2016, doi: 10.1002/0471238961.koe00016.

[6] A. Narayan and B. Nitin, "Application of Artificial Neural Network for Internal Combustion Engines : A State of the Art Review," *Archives of Computational Methods in Engineering*, vol. 29, no. 2, pp. 897–919, 2022, doi: 10.1007/s11831-021-09596-5.

[7] T. J. Wallington, E. W. Kaiser, and J. T. Farrell, "Automotive fuels and internal combustion engines : a chemical perspective," no. 1974, pp. 335–347, 2006, doi: 10.1039/b410469m.

[8] Z. Wang, H. Liu, and R. D. Reitz, "Knocking combustion in spark-ignition engines," *Progress in Energy and Combustion Science*, vol. 61, pp. 78–112, 2017, doi: 10.1016/j.pecs.2017.03.004.

[9] A. J. M. Novak and P. N. Blumberg, "Parametric Simulation of Significant Design and Operating Alternatives Affecting the Fuel Economy and Emissions of Spark-Ignited Engines Parametric Simulation of Significant Design and Operating Alternatives Affecting the Fuel Economy and Emissions of Spa," vol. 87, pp. 3485–3511, 1978.

[10] "ON THE EMISSIONS FROM INTERNAL-COMBUSTION ENGINES : A RE » IE ¼," vol. 513, no. February 1997, pp. 483–513, 1998.

[11] J. Hou, X. Qiao, Z. Wang, W. Liu, and Z. Huang, "Characterization of knocking combustion in HCCI DME engine using wavelet packet transform," *Applied Energy*, vol. 87, no. 4, pp. 1239–1246, 2010, doi: 10.1016/j.apenergy.2009.06.014.

[12] N. M. Ghazaly, A. O. Moaaz, M. M. Makrahy, M. A. Hashim, and M. H. Nasef, "Prediction of misfire location for SI engine by unsupervised vibration algorithm," *Applied Acoustics*, vol. 192, p. 108726, Apr. 2022, doi: 10.1016/J.APACOUST.2022.108726.

[13] Y. Li, W. Gao, P. Zhang, Z. Fu, and X. Cao, "Influence of the equivalence ratio on the knock and performance of a hydrogen direct injection internal combustion engine under different compression ratios," *International Journal of Hydrogen Energy*, vol. 46, no. 21, pp. 11982–11993, 2021, doi: 10.1016/j.ijhydene.2021.01.031.

[14] G. A. Karim, "Hydrogen as a spark ignition engine fuel," vol. 28, pp. 569–577, 2003.

[15] H. Li and G. A. Karim, "Knock in spark ignition hydrogen engines," *International Journal of Hydrogen Energy*, vol. 29, no. 8, pp. 859–865, 2004, doi: 10.1016/j.ijhydene.2003.09.013.

[16] Y. Karagöz, Ö. Balcı, and H. Köten, "Investigation of hydrogen usage on combustion characteristics and emissions of a spark ignition engine," *International Journal of Hydrogen Energy*, vol. 44, no. 27, pp. 14243–14256, 2019, doi: 10.1016/j.ijhydene.2019.01.147.

[17] H. M. Cho and B. Q. He, "Spark ignition natural gas engines-A review," *Energy Conversion and Management*, vol. 48, no. 2, pp. 608–618, 2007, doi: 10.1016/j.enconman.2006.05.023.

[18] T. Korakianitis, A. M. Namasivayam, and R. J. Crookes, "Natural-gas fueled spark-ignition (SI) and compression-ignition (CI) engine performance and emissions," *Progress in Energy and Combustion Science*, vol. 37, no. 1, pp. 89–112, 2011,

doi: 10.1016/j.pecs.2010.04.002.

[19] P. Iodice and M. Cardone, "Ethanol/gasoline blends as alternative fuel in last generation spark-ignition engines: A review on co and hc engine out emissions," *Energies*, vol. 14, no. 13, 2021, doi: 10.3390/en14134034.

[20] S. Oh, C. Park, S. Kim, Y. Kim, Y. Choi, and C. Kim, "Natural gas–ammonia dual-fuel combustion in spark-ignited engine with various air–fuel ratios and split ratios of ammonia under part load condition," *Fuel*, vol. 290, no. January, p. 120095, 2021, doi: 10.1016/j.fuel.2020.120095.

[21] D. Kriaučiūnas, S. Pukalskas, A. Rimkus, and D. Barta, "Analysis of the influence of CO2 concentration on a spark ignition engine fueled with biogas," *Applied Sciences (Switzerland)*, vol. 11, no. 14, 2021, doi: 10.3390/app11146379.

[22] A. Mariani, M. Minale, and A. Unich, "Use of biogas containing CH4, H2 and C02 in controlled auto-ignition engines to reduce NOx emissions," *Fuel*, vol. 301, no. February, p. 120925, 2021, doi: 10.1016/j.fuel.2021.120925.

[23] J. Huang and R. J. Crookes, "Assessment of simulated biogas as a fuel for the spark ignition engine," *Fuel*, vol. 77, no. 15, pp. 1793–1801, 1998, doi: 10.1016/S0016-2361(98)00114-8.

[24] M. Abu-Zaid, O. Badran, and J. Yamin, "Effect of methanol addition on the performance of spark ignition engines," *Energy and Fuels*, vol. 18, no. 2, pp. 312–315, 2004, doi: 10.1021/ef030103d.

[25] B. Waluyo, M. Setiyo, Saifudin, and I. N. G. Wardana, "Fuel performance for stable homogeneous gasoline-methanol-ethanol blends," *Fuel*, vol. 294, no. December 2020, p. 120565, 2021, doi: 10.1016/j.fuel.2021.120565.

[26] V. Rao, A. Kumar, and J. Kozinski, "Applied Catalysis A : General Alcohols as alternative fuels : An overview," *"Applied Catalysis A, General,"* vol. 404, no. 1–2, pp. 1–11, 2011, doi: 10.1016/j.apcata.2011.07.021.

[27] A. Elfasakhany, "Engineering Science and Technology , an International Journal Investigations on the effects of ethanol e methanol e gasoline blends in a spark-ignition engine : Performance and emissions analysis," *Engineering Science and Technology, an International Journal*, pp. 1–7, 2015, doi: 10.1016/j.jestch.2015.05.003.

[28] K. Yeom, J. Jang, and C. Bae, "Homogeneous charge compression ignition of LPG and gasoline using variable valve timing in an engine," *Fuel*, vol. 86, no. 4, pp. 494–503, 2007, doi: 10.1016/j.fuel.2006.07.027.

[29] S. Simsek, S. Uslu, H. Simsek, and G. Uslu, "Improving the combustion process by determining the optimum percentage of liquefied petroleum gas (LPG) via response surface methodology (RSM) in a spark ignition (SI) engine running on gasoline-LPG blends," *Fuel Processing Technology*, vol. 221, no. June, p. 106947, 2021, doi: 10.1016/j.fuproc.2021.106947.

[30] H. Bayraktar and O. Durgun, "Investigating the effects of LPG on spark ignition engine combustion and performance," vol. 46, pp. 2317–2333, 2005, doi: 10.1016/j.enconman.2004.09.012.

[31] P. Taylor and A. Demirbas, "Energy Sources , Part B : Economics , Planning , and Policy Alternatives to Petroleum Diesel Fuel," no. October 2014, pp. 37–41, 2007, doi: 10.1080/15567240600629518.

[32] N. H. S. Ray, "Biogas as Alternate Fuel in Diesel Engines: A Literature Review," *IOSR Journal of Mechanical and Civil Engineering*, vol. 9, no. 1, pp. 23–28, 2013, doi: 10.9790/1684-0912328.

[33] A. Mandal, H. Cho, and B. S. Chauhan, "Ann prediction of performance and emissions of ci engine using biogas flow variation," *Energies*, vol. 14, no. 10, 2021, doi: 10.3390/en14102910.

[34] S. A. Kalogirou, *Artificial intelligence for the modeling and control of combustion processes : a review*, vol. 29. 2003. doi: 10.1016/S0360-1285(03)00058-3.

[35] O. Isaac, A. Jantan, and A. Esther, "State-of-the-art in arti fi cial neural network applications : A survey," *Heliyon*, no. October, p. e00938, 2018, doi: 10.1016/j.heliyon.2018.e00938.

[36] A. B. Garg, P. Diwan, and M. Saxena, "Artificial Neural Networks based Methodologies for Optimization of Engine Operations," vol. 3, no. 5, pp. 1–5, 2012.

[37] M. A. Hashim, M. H. Nasef, A. E. Kabeel, and N. M. Ghazaly, "Combustion fault detection technique of spark ignition engine based on wavelet packet transform and artificial neural network," *Alexandria Engineering Journal*, vol. 59, no. 5, pp. 3687–3697, 2020, doi: 10.1016/j.aej.2020.06.023.

[38] I. M. Yusri, A. P. P. Abdul Majeed, R. Mamat, M. F. Ghazali, O. I. Awad, and W. H. Azmi, "A review on the application of response surface method and artificial neural network in engine performance and exhaust emissions characteristics in alternative fuel," *Renewable and Sustainable Energy Reviews*, vol. 90, no. June 2017, pp. 665–686, 2018, doi: 10.1016/j.rser.2018.03.095.

[39] I. Sarıtas, H. Emre, and H. Og, "Expert Systems with Applications Prediction of diesel engine performance using biofuels with artificial neural network," vol. 37, pp. 6579–6586, 2010, doi: 10.1016/j.eswa.2010.02.128.

[40] I. Bahattin, "ANN modeling for justi fi cation of thermodynamic analysis of experimental applications on combustion parameters of a diesel engine using diesel and sa ffl ower biodiesel fuels," vol. 279, no. May, 2020, doi:

10.1016/j.fuel.2020.118391.

[41] S. H. Hosseini, A. Taghizadeh-alisaraei, B. Ghobadian, and A. Abbaszadeh-, “Artificial Neural Network Modeling of Performance , Emission , and Vibration of a CI Engine Using Alumina Nano-Catalyst Added to Diesel-Biodiesel Blends,” *Renewable Energy*, 2019, doi: 10.1016/j.renene.2019.10.080.