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Engine Performance and Emissions Improvement Study on Direct Injection of Diesel/Ammonia Dual Fuel by Adding CNG as Partially Premixed Charge

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Abstract: ***Researchers have recently moved on in their studies to find a solution to prevent or reduce this problem. There have been directions taken by researchers to solve the problem, including, replacing fossil fuels with environmentally friendly types or by combining two or more types of fuel. This is by modifying fuel injection systems as appears in the PCCI, RCCI, or HCCI systems, or working to integrate the two trends by using new injection systems and burning alternative fuels with fossil fuels. Therefore, the trend has good results on the specific consumption of fuel, raising thermal efficiency, and working to reduce environmentally polluting emissions. This study employed ammonia hydroxide and diesel as a green fuel, with volume ratios of 7.5% to 92.5%, respectively. By adding a variable percentage of compressed natural gas (CNG) (1.5 litres/min - 2.5liters/min) using the PCCI system in a four-stroke single-cylinder diesel engine the experimental studies will performed on the engine thermal efficiency (BTE) and emissions polluting the environment. The change in specific fuel consumption (BSFC) will be discussed and the results will be compared with their counterparts in the case of using diesel only and using diesel with ammonia hydroxide of the mentioned percentage only. The vibration analysis system has been employed to evaluate the actual performance of the engine by measuring the vibration using the Fast Fourier Transform (FFT) approach. Moreover, after practical experiments, we concluded that using ammonia hydroxide with diesel in volume proportions of 7.5% - 92.5%, when compared to diesel only worked to improve thermal efficiency by 20.98%, and 23.95%, respectively. When natural gas is added by 1.5 litres per minute, the thermal efficiency increases to 26.83%, but when it is added at a rate of 2.5 litres per minute, the thermal efficiency increases to 27.45%. The exhaust temperature, specific fuel consumption, emissions species, and soot opacity will record in the study.***

Keywords: Diesel engine; Ammonia Hydroxide; PCCI system; compressed natural gas (CNG); NOx emissions; vibration analysis.

I. INTRODUCTION

Lately, scientists have been working to discover answers to three major global issues that have caught the attention of the whole world: industry waste that harms the environment, toxic exhaust emissions, and global warming[1-5]. Researchers have discovered solutions to combat global warming, one of which is attempting to lessen internal combustion engine emissions [6-10]. Internal combustion engines have undergone several advancements over the previous few decades and are still undergoing ongoing research to lower the resultant emissions, improve thermal efficiency, and lower fuel-specific consumption[11-14]. Scientists have used a few strategies to implement these techniques as the use of green fuel [7, 15-18]. In our present study, we will address adding carbon-free fuel or using one of the more contemporary fuel injection systems, such as premixed charge compression ignition(PCCI), Homogeneous charge compression ignition(HCCI), or attempt to blend the two trends[19-23]. Using a single-cylinder, four-stroke, intercooler compression engine, we will investigate the effects of adding compressed natural gas (CNG) fuel in varying volumes (1.5L/min-2.5L/min) using an advanced PCCI injection system to a mixture of ammonia hydroxide and diesel fuel with a volume ratio of 7.5% - 92.5%, respectively, using a direct injection system using the atmosphere[13]. Thermal efficiency, specific fuel consumption, and emissions that pollute the environment are all measured for the "DEUTZ FL 511/W" model[12, 24-26].

The use of the previously described blend was selected due to studies conducted by Elkelawy and associates, which demonstrated a roughly 23.5% rise in thermal efficiency[6]. However, in the case of using diesel only, the thermal efficiency reached 20.47%. Specific fuel consumption, exhaust temperature, and polluting emissions Such as nitrogen oxides and soot are decreased. In the cases of developments, it was chosen to equip the engine with a new injection system (PCCI)[27], which is a modern technology of low-temperature combustion (LTC). its primary purpose is to reduce exhaust emissions in the event of increased or constant efficiency by keeping the temperature inside the cylinder low[28]. This will cause a reduction in the percentage of nitrogen oxide emissions and soot production[28-33]. PCCI technology is considered an intermediate technology between HCCI and the traditional system, as part of the fuel is used to provide a homogeneous mixture of air and fuel, but it is not as homogeneous as the mixture used in HCCI[34, 35]. Compared to HCCI technology, PCCI technology has produced higher nitrogen oxide, HC, and CO emissions [36-39]. In addition, we can control the internal conditions of the cylinder by controlling the proportion of pre-mixed fuel in addition to controlling the main injection fuel[40]. PCCI technology is considered a mixture of the traditional pressure system and the spark ignition system (SI)[41-43]. This is the reason we chose it to

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be the path of discussion in the research. It reduces emissions such as NOX, CO, HC, and soot while maintaining the thermal efficiency value compared to the traditional mode (CI)[44, 45]. Natural gas was added in different proportions due to its good combustion properties and high-octane number, making it available on the market, which makes the economic feasibility of its use great, in addition to its burning, which reduces the emission of greenhouse gases, nitrogen oxides, and soot[46, 47]. It was chosen to mix with the air in the PCCI system because of its chemical composition, as methane is the main component of natural gas, and the ease of mixing it with air makes the mixture homogeneous of air and fuel, and this is what we mentioned in the benefits of the PCCI system[48-50].

As a result of the above, the experiment was carried out at a fixed speed of 1500 rpm for a diesel engine, as previously mentioned, under standard weather conditions. It was found that in the case of 1.5L/min, the thermal efficiency increased to 26.83%.In addition, the specific fuel consumption was 341.87g/kw.h, as in the case of 2.5L/min The thermal efficiency increased to 27.45% and the specific fuel consumption was 333.64g/kw.h, compared to the case of diesel only, so the thermal efficiency was 20.98% and the specific fuel consumption was 440.79g/kw.h. Based on the previous results, the combustion engines can operate stably and efficiently in the case of the previous system leads us to future studies in this field.

II. EXPERIMENTAL METHODOLOGY AND PROCEDURE:

A. *TEST RIG SETUP*:

An internal combustion engine was modified to operate with a PCCI injection system, and a homogeneous mixture of air and natural gas was injected to improve the combustion characteristics of polluted emissions, thermal efficiency, and qualitative fuel consumption. The engine previously operated with diesel fuel and liquid ammonia hydroxide with a traditional injection system. An operational internal combustion engine was used for this experiment. The single-cylinder quadruple engine "Deutz F 511/W" is cooled with air as illustrated in figures 2 and 3, which represent an illustration of the engine and its contents, respectively. This engine works at a constant speed of about 1500 rpm, with a temperature of 90 ° C, direct pressure of 220 bar at 32 degrees below the dead upper centre of the cylinder, and a compression ratio of about 17. The technical properties of the engine are displayed in Table 1. To keep the engine at a constant speed of 1500 rpm with the change in the amount of fuel injected, an electronic console was added to control speed. The engine contains a fuel consumption system, which includes a tank in which diesel is placed in the event of operation and a gradual test in which the mixture or any other fuel used is placed, which will be injected into the engine according to the volumetric ratio -used engine. Using a dynamic scale of a vortex, the engine is loaded. The Dynamometer scale contains a simultaneous generator of 5 kW connected to the elbow column and the generator is connected to 6 lamps (for each cap power block 1 kW) and a variable voltage device to control the output energy as shown in Figure 1

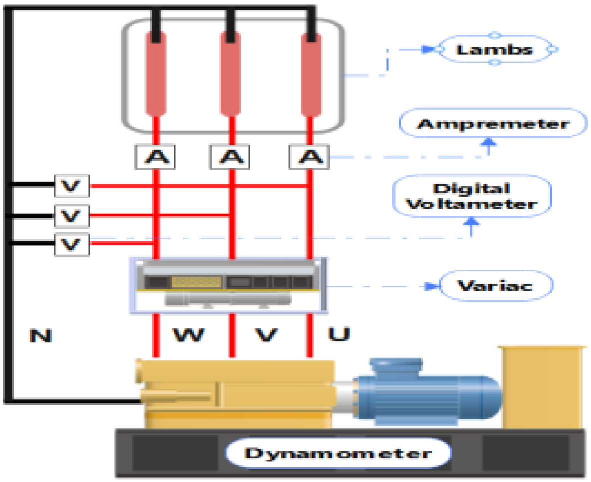

Figure 1: Load and dynamometer circuit schematic diagram

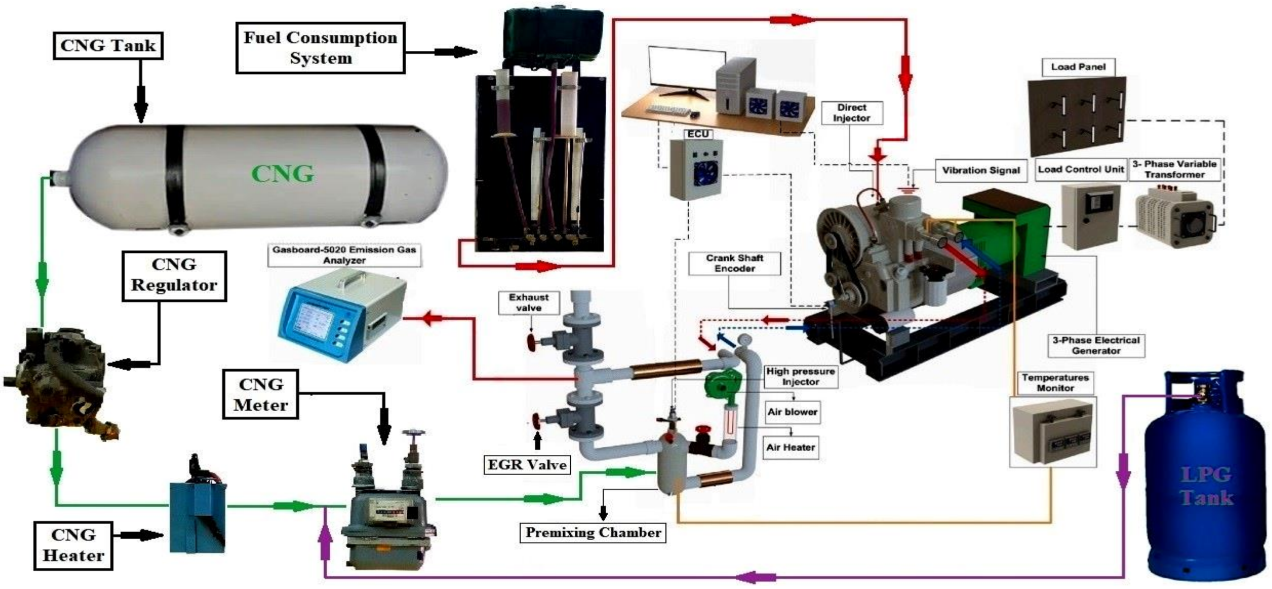

Figure 2: Schematic diagram of the PCCI engine setup with fuel vaporizer

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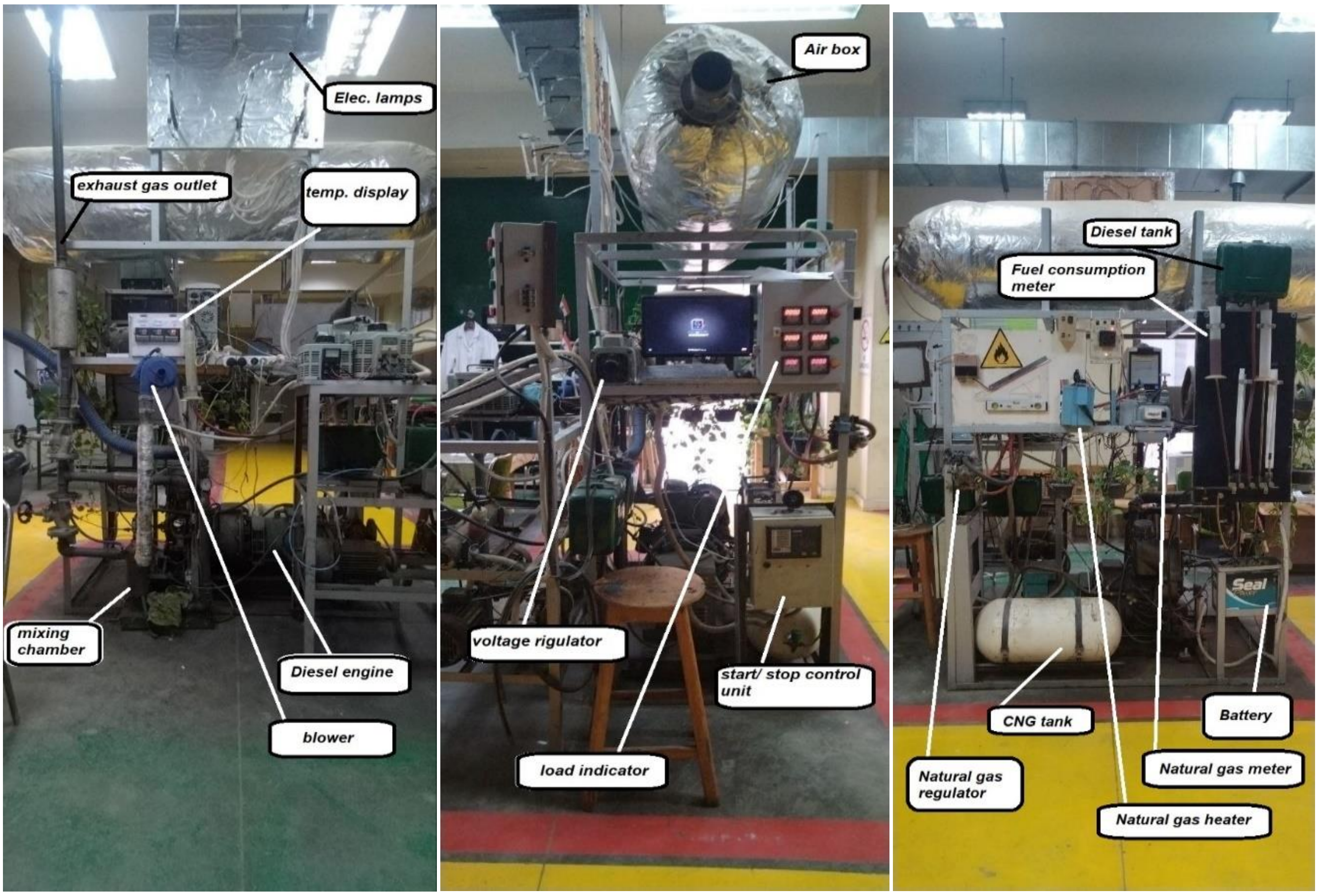

Figure 3: Actual image of the experimental setup of the engine with fuel vaporizer

Table 1: technical characteristics of the engine [51, 52]

Parameters	Dimensions	Parameters	Dimensions
No. of cylinder	Single	**Injection system**	Direct in injection
Engine version	DEUTZ FL500/W	Rated power	5KW at 1500rpm
Displacement	825 cm^3	**Compression ratio**	17
Bore	10cm	Inlet valve opening	32 CA BTDC
Cooling system	Air-cooled	**Inlet valve closing**	59 CA ABDC
Stroke	10.5cm	Exhaust valve opening	71 CA BBDC
Power cycle	Four strokes	**Exhaust valve closing**	32 CA BTDC

B. FUEL PREPARATION:

Two tests of fuel (diesel - ammonia hydroxide) with volume ratios of 7.5% - 92.5%, respectively, will be carried out in this study. Natural gas will be added to the fuel and injected using the PCCI system in amounts ranging from 1.5L/min to 2.5L/min. Diesel is combined with ammonia hydroxide at a volume ratio of 92.5% and a concentration of 33% (NH3 - HOH) to create the combination. To make sure there is no fuel separation, the mixture is put in a bowl beneath the mixer and mixed for an hour at a speed of around 550 rpm.

C. MEASUREMENT AND UNCERTAINTY (ERROR ANALYSIS):

The Following Table shows the Emission Analyzer and Sensors Used inthetestTable2. In Figure5 we find actual pictures of the measuring devices used to measure polluting emissions and soot resulting from the engine[53, 54]

Table 2: devices and sensors utilization

Device/sensor	Utilization
1st thermocouple	To measure air temperature
2nd thermocouple	To measure exhaust temperature
Speed sensor	To measure engine speed, attach to the engine's crankshaft.
DASHBOARD-5020 emission gas analyzer	Measure the values of [CO, O_2, and CO_2] in (% vol) and [HC, NOx] in (ppm).
Orifice system	Measure the volume of air flowing into the engine
GASBOARD-6010 opacity meter	Used to measure soot opacity

Figure 4: emission gas and opacity analyzers

Because of the use of many devices, equipment, and optical measurement methods, each of them has an error rate that makes the results of the studied research need to be reviewed. Therefore, the total error rate resulting from the research must be studied by using Equation 1[55-57] .

$$\frac{\Delta w}{w} = \sqrt{\sum_{x=1}^{\infty}\left(\frac{\Delta x_n}{x_n}\right)^2} --------eq.1$$

Where; $\frac{\Delta w}{w}$ is a total uncertainty rate of the experimental results, Δx_n is an error of the equipment, $\frac{\Delta x_n}{x_n}$ is an uncertainty of each device used.

Measuring fuel consumption is one of the methods used to measure specific fuel consumption (SFC) [58-60], in which the measurement is done using a stopwatch and looking to determine the scale on the burette for its range. Where 10 cubic millilitres are measured during the time measured on the stopwatch, and we find the percentage of error in the measured volume $\Delta x = \pm 0.1cm$, $x = 10cm$ the uncertainty value (accuracy) will be $\frac{\Delta x}{x} = \pm 0.01 = \pm 1\%$

Table 3 shows the devices used, their range, and the measurement accuracy of each device.

Table 3: Device characteristics and accuracy

Instrument	Parameters	Range	Accuracy
GASBOARD-6010 opacity meter	Soot opacity	0-100%	+2%, -2%
Shaft encoder	Speed	0-720^{0}CA	+0.2%, -0.2%
K-thermocouple	Exhaust gas temp.	0-800 ^{0}C	+1%, -1%
GASBOARD-5020 emission gas analyzer	CO	0-20%	+0.06%, -0.06%
	HC	0-9999ppm	+0.12%, -0.12%
	CO2	0-20%	+0.4%, -0.4%
	NO	0-5000ppm	+0.5%, -0.5%
	O2	0-25%	+0.1%, -0.1%
Graduated cylinder/stop watch	Fuel flow meter	1-30 cm^3	+1%, -1%

From the above, the total uncertainty includes many factors in the experiment, as appeared in the accuracy of the devices used and the accuracy of the methods used[61, 62]. Thus, by applying Equation 1 to the coefficients, it becomes clear that the accuracy of the results in the experiment is as follows.

$$\frac{\Delta w}{w} = \sqrt{(1)^2+(2)^2+(0.2)^2+(1)^2+(0.06)^2+(0.12)^2+(0.4)^2+(0.5)^2+(0.1)^2+(1)^2} *\%$$

$\frac{\Delta w}{w} = 2.735\%$, the total error value will be $\Delta w = \pm 0.02735$

D. EXPERIMENTAL METHODOLOGY:

In this study, the experiment was conducted on a single-cylinder, four-stroke diesel engine operating at a constant speed of 1500 rpm under different load conditions [63, 64]. The experiments begin at no load and partial load and reach full load[64-66]. The experiments were carried out using a mixture of traditional direct injection technology, and dual fuel was used, including diesel, ammonia hydroxide, and PCCI technology, in which natural gas fuel was used. The effect of the combustion of the mixture on the combustion characteristics, engine performance, and the value of the resulting emissions was studied[67]. This mixture includes a volume percentage of ammonia hydroxide and diesel 7.5% - 92.5%, respectively, and compares it with its values for pure diesel in direct injection mode and the effect of adding natural gas with values (1.5L/min-2.5L/min) to study the effect of adding natural gas to the diesel mixture[68-70].

And ammonia hydroxide and choose the best ratio between them.

III. RESULTS AND DISCUSSION:

The use of a mixture (ammonia hydroxide - diesel) with the addition of compressed natural gas will improve the combustion characteristics, and thermal efficiency of the engine and will reduce emissions resulting from combustion.

A. BRAKE THERMAL EFFICIENCY-BTE:

The thermal efficiency of brakes is defined as the percentage of chemical energy produced by the fuel that is converted into usable work. we can evaluate its value from Equation 2,3.

$$BTE = \frac{power}{m^{\bullet} * Cv} * 100\% ------(eq.2)$$ [71].

$$m^{\bullet} = \rho * V^{\bullet}_{ol} ----(eq.3)$$

where; $m^{\bullet}$ is defined as mass flow rate, Cv is defined as the calorific value of each fuel, ρ is defined as the density of each fuel, $V^{\bullet}_{ol}$ is defined as volume flow rate.

Figure 5 shows the difference in BTE for pure diesel and a mixture (diesel - ammonia hydroxide) with a volumetric ratio (7.5% - 92.5%) and another with the addition of compressed natural gas in volumetric quantities $(1.5L/min \equiv 2*10^{-3}g/\sec - 2.5L/min \equiv 3.33*10^{-3}g/\sec)$, respectively. It is clear from the figure that thermal efficiency increases with increasing load under all operating conditions due to decreased heat loss. The resulting energy increases because of the quality of combustion, and with the increase in the percentage of ammonia in the mixture, the thermal efficiency of the brakes increases. Adding natural gas and injecting it into the PCCI system works to increase thermal efficiency.

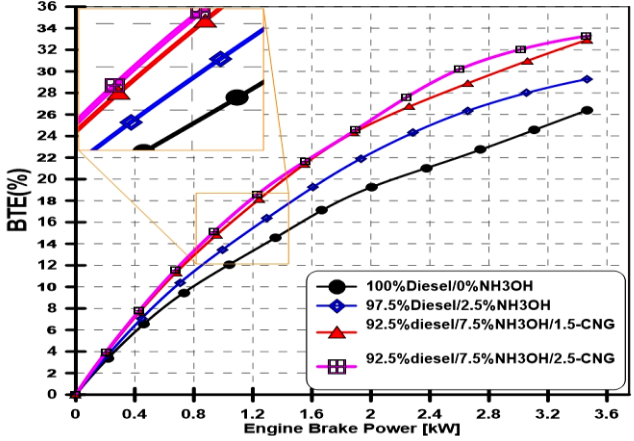

Figure 5: Brake Thermal Efficiency- BTE under Various Loads Conditions.

B. BRAKE SPECIFIC FUEL CONSUMPTION- BSFC:

Brake-specific fuel consumption, or BSFC, is the amount of fuel required to produce one unit of braking power and is determined by the calorific value of the fuel. Diesel and ammonia hydroxide mixtures have variable calorific values; hence they are not a reliable indicator of engine performance. Brake-specific energy consumption (BSEC) should be utilized as the benchmark when using a variety of fuels with different calorific values. By dividing the overall energy used by the braking force produced, the BSEC is determined. To get the BSEC value in MJ/kWh, use equation 4[6, 72-74].

$$BSEC = \frac{[(m^{\circ} * LHV)_{diesel} + (m^{\circ} * LHV)_{NH4OH} + (m^{\circ} * LHV)_{CNG}] * 3600}{power} --- eq.4$$

Where, BSEC in (MJ/kW.hr), m˚ in (kg/sec), LHV in (MJ/kg), and Power in (kW).

Figure 6 shows that in the case of pure diesel, the average fuel consumption was 440.79 [g/kWh]. By adding ammonia hydroxide to diesel at a rate of 7.5% by volume, the average fuel consumption value decreased to 384.78 [g/kWh]. By adding compressed natural gas at a rate of 1.5L/min, the average fuel consumption value decreased to 341.87 [g/kWh], and the average fuel consumption value in the case of compressed natural gas by 2.5 L/min is reduced to its lowest value, which is 333.64 [g/kWh]. It is clear from the figure that at the same loads, the consumption rates in the presence of ammonia hydroxide are lower than in pure diesel, and in the case of adding natural gas, the consumption rate decreases further.

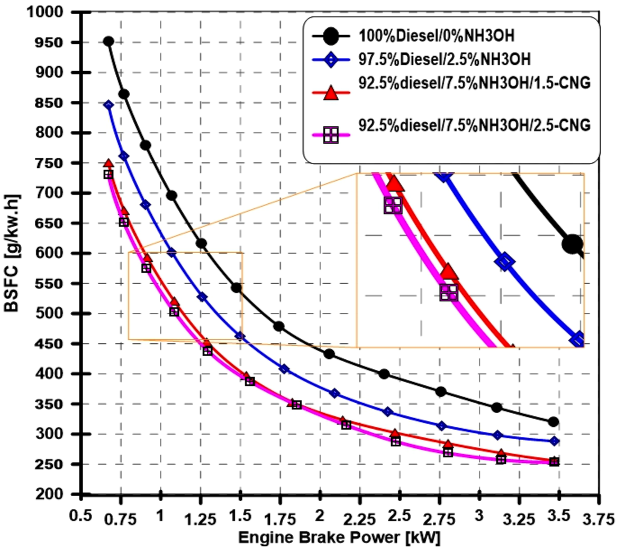

Figure 6: Brake-Specific Fuel Consumption Under Variation of Load Conditions

C. EXHAUST GAS TEMPERATURE-EGT:

The measurement of exhaust gas temperature is crucial because it serves as a gauge for the combustion temperature and heat loss from the exhaust gases, which are related to the thermal efficiency of the engine. Figure 7 provides an example of the fluctuation in exhaust temperatures under different loads. The presence of a percentage of water in the mixture may be the reason for the apparent difference in results when adding ammonia hydroxide to diesel. The thermal properties of natural gas and their effect on combustion make it burn more slowly, which leads to higher exhaust temperatures. In contrast to what we see when using pure diesel, adding natural gas to ammonia and diesel increases the exhaust temperature or reduces the effect of additional ammonia on the exhaust temperature. However, since the PCCI injection system is in use and natural gas helps increase the overall thermal efficiency, it does not affect the exhaust temperature. The data clearly show that although the average temperature rises to 204 degrees Celsius in the case of pure diesel. it decreases to 7.5% with the addition of ammonia hydroxide to 196 degrees Celsius. In the case of compressed natural gas at a rate of 1.5 litres/minute, the average exhaust temperature reaches 196 degrees Celsius, while in the case of compressed natural gas at a rate of 2.5 litres/minute it reaches 203 degrees Celsius.

From the previous results, it is clear that there is no clear change in exhaust temperatures despite the clear change in specific fuel consumption and thermal efficiency.

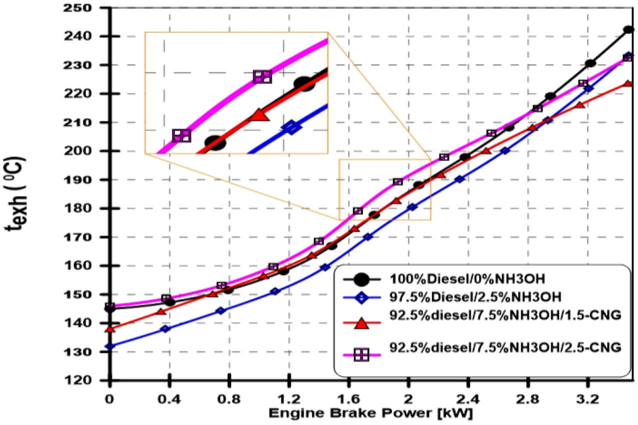

Figure 7: exhaust gas temperature under variation of load conditions

D. OXIDES OF NITROGEN – NO:

The availability of oxygen, the increasing combustion period and the temperature of the combustion chamber are the main factors on which the emission of NOx depends. The figure shows the variation of nitrogen oxide emission values with the braking power of pure diesel and a mixture of ammonia hydroxide and diesel, and the effect of adding natural gas in the PCCI system at its different values. It is clear from the figure that as the load increases, the NOx emission increases. This is due to an increase in the temperature of the combustion chamber, but in the case of the mixture, and as a result of the presence of water and nitrogen in the mixture, which works to reduce the temperature of the combustion chamber, the emission percentage of nitrogen oxides in the mixture is lower than the diesel, while by adding natural gas to the air in the PCCI system is at the previously mentioned values, and as a result of the higher temperatures and the increased duration of combustion inside the cylinder, the values of nitrogen oxides decrease in the case of natural gas compared to their counterparts in the case of diesel and conventionally injected mixtures.

E. UNBURNED HYDROCARBONS-UHC:

Unburned hydrocarbons are produced because of wetting the liquid wall, abnormally lean or rich mixtures, and incomplete combustion of fuel trapped in crack volumes. The difference in engine HC emission values is shown in Figure 9. In the case of pure diesel, it is evident that greater temperatures and the consequence of full combustion inside the engine cause hydrocarbon emissions levels to rise with increasing loads. A drop in engine temperatures and a rise in hydrocarbons result from the addition of ammonia hydroxide and the impact of evaporated water. Because of the combustion behaviour of compressed natural gas and the long combustion period that natural gas takes to complete combustion and be injected with air with the PCCI system, this has led to an increase in the percentage of hydrocarbons resulting from combustion. For example, we find that the hydrocarbons in the case of diesel reach 14 ppm, and in the case of the mixture they reach 18 ppm. However, by adding natural gas at a value of 1.5 litres/minute to the mixture, the value of the hydrocarbons reaches 54 ppm.

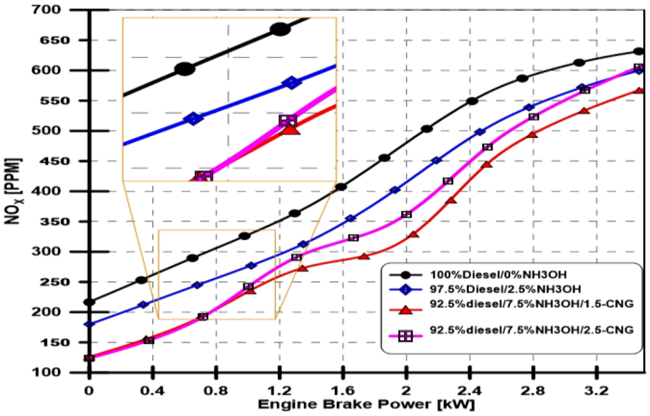

Figure 8: Oxides of Nitrogen under Variation of Loads Conditions

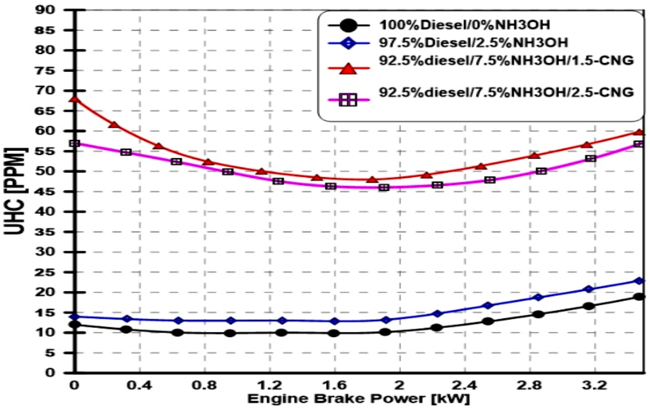

Figure 9: The variation of the unburned Hydrocarbon under various load conditions

F. CARBON MONOXIDE-CO:

Carbon monoxide is one of the most dangerous engine emissions because it is a toxic gas and has the potential to be flammable. It is a product of incomplete combustion of carbon dioxide, and due to the low combustion temperature and low oxygen content, partial oxidation of carbon is generated, forming carbon monoxide. In Figure 10 The variation in carbon monoxide results is shown for pure diesel fuel, a mixture of diesel, ammonia hydroxide, and the mixture added to natural gas with a PCCI injection system. It has been shown that as loads increase in the experiment and because of increasing combustion temperature, carbon monoxide emission decreases. In the case of adding ammonia hydroxide, as we explained previously, and as is clear in the graph, as the exhaust temperature decreases and partial oxidation of carbon dioxide occurs, carbon monoxide is generated. We will find that by adding ammonia hydroxide, the emission will increase compared to diesel, and in the case of using PCCI, because of the longer duration. When combustion occurs and incomplete combustion occurs, the emission of carbon monoxide increases.

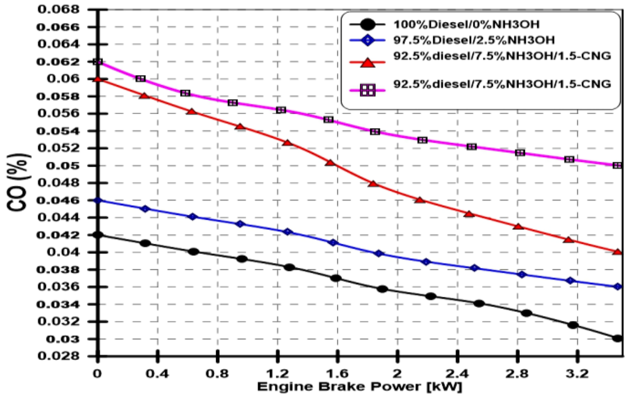

Figure 10: The variation of the Carbon monoxide under various load conditions

G. SMOKE OPACITY – SOOT:

Figure 11 shows the variation in the results of soot appearance in the engine with increasing engine load under all operating conditions and based on the richness of the fuel-air ratio. When comparing pure diesel, a mixture of diesel, ammonia hydroxide, and the mixture with natural gas, you will find that in the case of diesel, the opacity of the smoke increases due to the richness of the air and fuel mixture. The results shown in the case of the mixture show that the soot value decreases at the same load, and in the case of adding natural gas with the PCCI system, the SOOT values decrease depending on the values of the injected natural gas. This is evident from the values. We find that in the case of diesel, the percentage of soot reaches 51.2%, and in the case of the mixture reduces to 46.2%, and then by adding natural gas with the PCCI injection system to the mixture, the soot value reaches 39.6%.

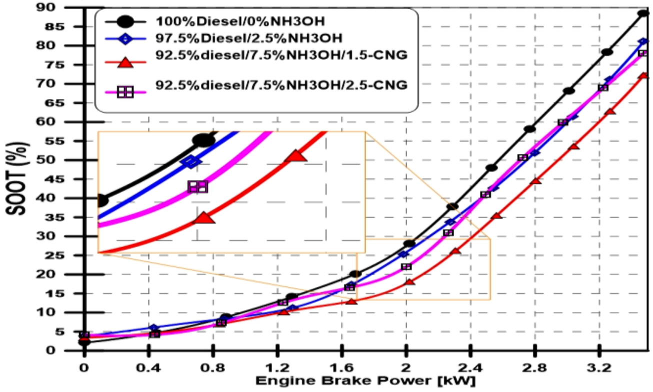

Figure 11: The variation of smoke opacity (SOOT) under various load conditions

H. AVERAGE WEIGHTED:

To determine the ideal mixture ratio that we may use going forward and incorporate in future research, the average findings will be explained below, along with comparisons between the outcomes of diesel combustion and those from combinations of ammonia hydroxide and diesel. The following demonstrations will calculate average values for the outcomes of our experiment using Equation 4.[75]

$$W = \frac{\sum_{i=1}^{n} \omega_i * X_i}{\sum_{i=1}^{n} \omega_i} --------- eq.4$$

Where; W Is the Weighted Average, n is no. of terms to be averaged, ω_i weights are applied to x values, and X_i data values are to be averaged.

1. WEIGHTED AVERAGE -BTE:

Figure 12 shows the average thermal efficiency values of the engine in the case of using pure diesel and a mixture of ammonia hydroxide, diesel, and the mixture with the addition of natural gas with the PCCI injection system. It is clear from the curves that the case of natural gas at a rate of 2.5 L/min gives the highest efficiency compared to the case of mixture or diesel. Natural gas added to the mixture achieves an average thermal efficiency of 27.45%, while diesel achieves 20.98%.

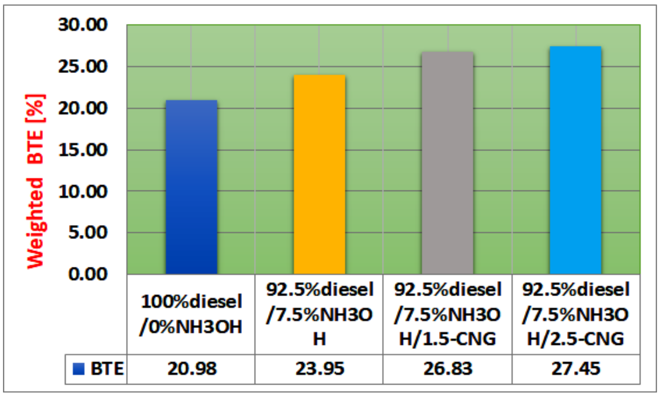

Figure 12: Weighted Average of BTE of the hydroxide ammonia variation

2. WEIGHTED AVERAGE – BSFC:

Figure 13 shows the average values of the fuel consumption rate injected into the engine in the case of using pure diesel, a mixture of ammonia hydroxide, diesel, and the mixture with the addition of natural gas injected with the PCCI injection system. In the case of the mixture using natural gas with a ratio of 2.5 L/min, the lowest fuel consumption is recorded, with a value compared to diesel, at 333.34 g/kw.h while in the case of diesel only, a value of 441 g/kw.h was recorded.

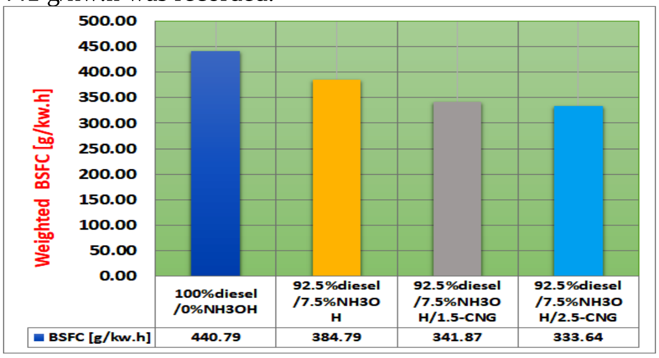

Figure 13: Weighted Average of BSFC of the Hydroxide Ammonia Variation

I. VIBRATION ANALYSIS:

Vibration analysis is known as the practice of monitoring vibration levels and patterns within a piece of equipment, machinery, or a building to identify unusual vibration occurrences and assess the general state of the test object[76]. In addition to directly examining the vibration signal's time waveforms, it is frequently performed on the frequency spectrum, which is produced by applying the Fourier Transform to the time waveform[77]. By extracting and analyzing parameters such as root-mean-square (RMS), standard deviation, peak amplitude, kurtosis, crest factor, skewness, and many more, the time domain analysis on chronologically recorded vibration waveforms reveals when and how severe the abnormal vibration events occur. The general state of the objectives under observation may be accessed via time domain analysis[78]. It is extremely desired to include frequency spectrum analysis in addition to time domain analysis in real-world applications, particularly in rotating equipment[79]. A complicated machine made up of several parts will produce a mixture of vibrations, which are the result of the rotation of each component separately. As such, it is challenging to assess the state of the crucial parts of a big rotating apparatus, such as gears, bearings, and shafts, simply using time waveforms[80]. To analyze the frequency components that correlate to each component, frequency analysis breaks down time waveforms and characterizes how repetitive vibration patterns are. Furthermore, designing different digital noise filters and conducting quick and effective frequency analyses are made easier by the widely used Fast Fourier Transform (FFT) approach[81]. Numerous kinds of sensors may be used to monitor vibration. Sensors such as piezoelectric (PZT) sensors, microelectromechanical sensors (MEMS), proximity probes, laser Doppler micrometres, and many more are used to detect displacement, velocity, and acceleration based on various vibration types[82].

The most widely used type of sensor, PZT sensors, produce voltages when they are distorted. The vibrations can be represented by digitally digitizing and translating the voltage signals[83]. The vibration levels/dynamic range, maximum frequency range/bandwidth, and other working environment factors like temperature, humidity, and pH level should all be taken into account when choosing appropriate vibration sensors[84]. Installing sensors is essential to guarantee that high-quality data is captured. The best way to install sensors on a machine is to stud mount them on a smooth, clean surface[85]. This guarantees the capturing of a wide and coherent frequency range. If stud mounting is not an option, vibration levels and frequencies can be taken into consideration when using magnet holders, wax, or glue as replacements[86].

1- VIBRATION CHARACTERISTICS:

Vibration can be described in terms of intensity by amplitude or periodicity by frequency. Figure 15 shows the vibration time waveform captured for a single-cylinder diesel engine at different mechanical loads for the diesel fuel type. The changing movement due to the four strokes of the internal combustion engine complicates the waveform. It is clear from the figure that in the no-load condition and at a load of 1 kW, the maximum amplitude is about 0.017 mv, and it appears in Figure 14 that it is at the frequency of 35 Hz after 0.06 seconds from the start. Operating, in the case of load at 2 kW, the maximum capacity is about 0.015 mV, and it is clear in Figure 14 that it is at a frequency of 45 Hz after 0.17 seconds of operation, while in the case of maximum load, the frequency is about 60 Hz after 0.3 seconds of operation startup.

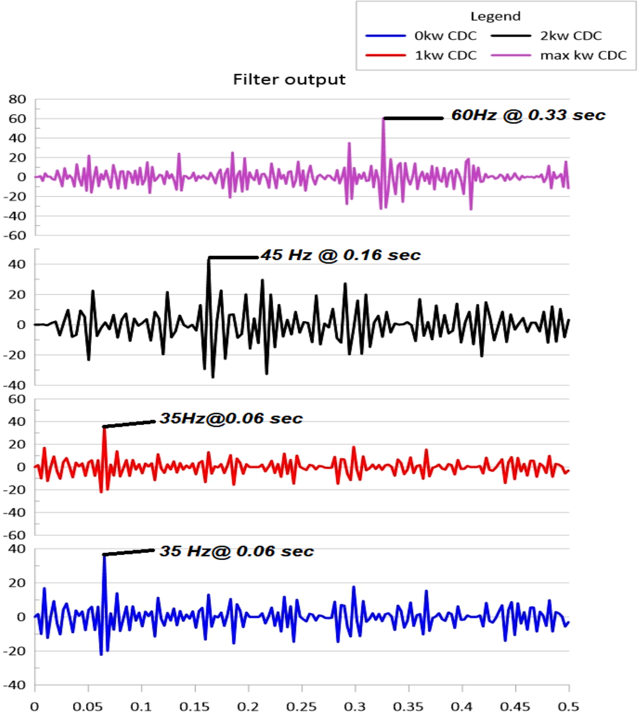

Figure 14: filter output for vibration analysis of diesel fuel only

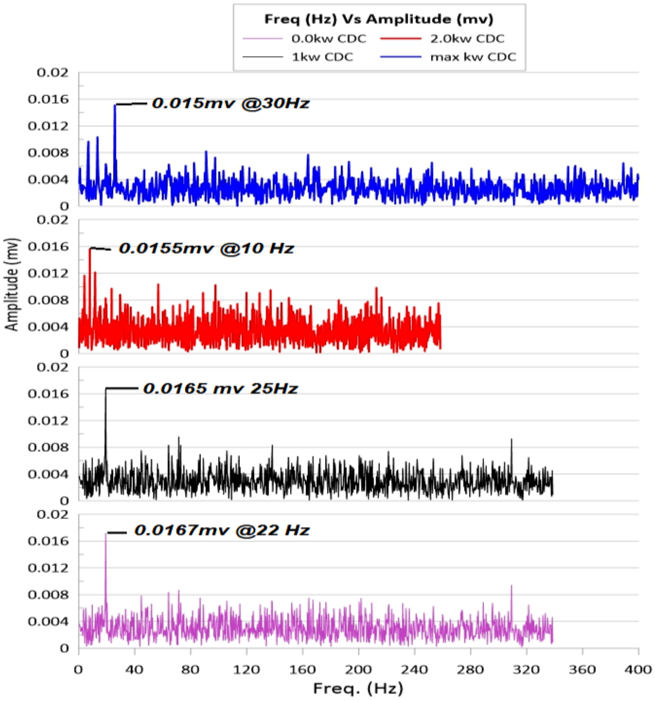

Figure 15: Amplitude vs Frequency for diesel in CDC

As before, we find that using different types of fuel, as we mentioned previously, but in the case of vibration analysis, it becomes clear to us that in the case of using ammonia hydroxide with a volume ratio of 7.5% at no load, we find that the frequency reached 35 Hz after 0.04 seconds, and at 1 kW load it reaches 72 Hz. After 0.17 seconds, reaching the maximum load, the frequency is at 62 Hz after 0.05 seconds. This is evident in Figure 16, while it is evident in Figure 17 that the loads vary in the case of using a fuel mixture of diesel and ammonia hydroxide. We find that in the case of no load, the maximum capacity is 42 Hz, and in the case of a 1-kW load, the maximum capacity is 30 Hz, reaching the maximum load, the maximum capacity is at 35 Hz.

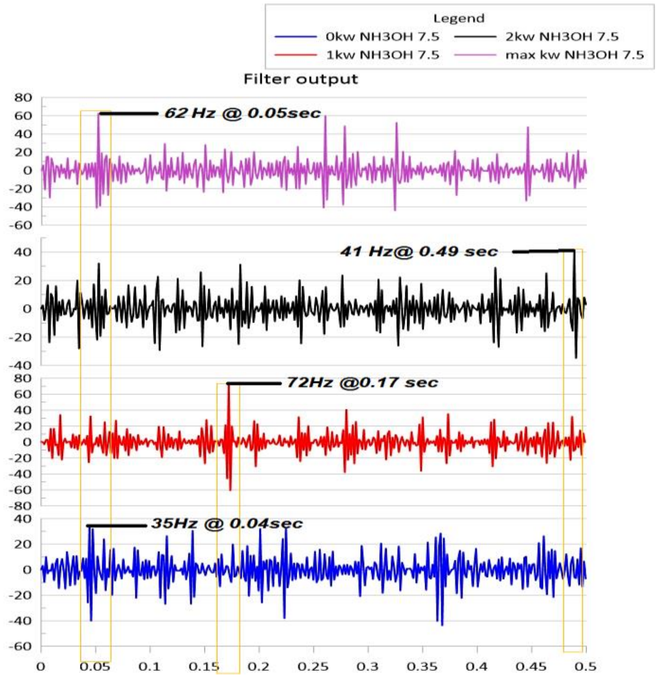

Figure 16: filter output for vibration analysis of blend only

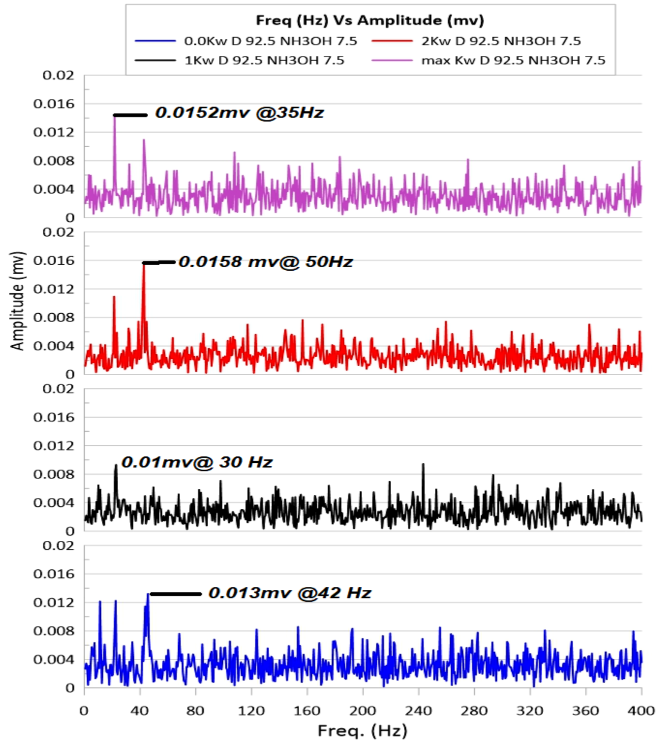

Figure 17: Amplitude vs Frequency for Blend in CDC

In the case of using a fuel mixture of diesel and ammonia hydroxide with the addition of CNG fuel with a PCCI injection system at a volume ratio of 1.5 litres/second, we find in Figure 18 that at no load the frequency is 75 Hz after 0.065 seconds. Moreover, when 1 kW load the frequency reaches 63Hz after 0.067 seconds, reaching the maximum load. The frequency reaches 73 Hz after 0.26 seconds. In Figure 19, with different loads, the maximum capacity at no load appears to be 25 Hertz, and with a 1 KW load, the maximum capacity is at 10 Hertz, reaching the maximum load. Maximum amplitude of 25 Hz

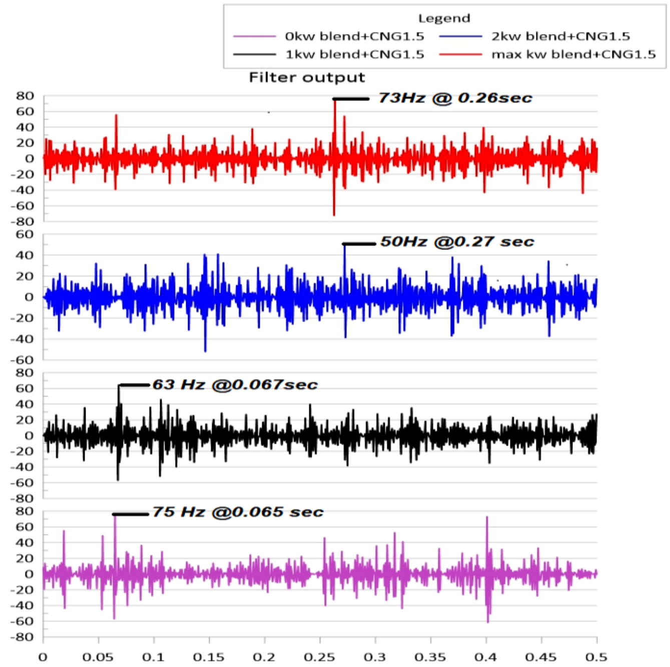

Figure 18: filter output for vibration analysis of blend + 1.5 CNG

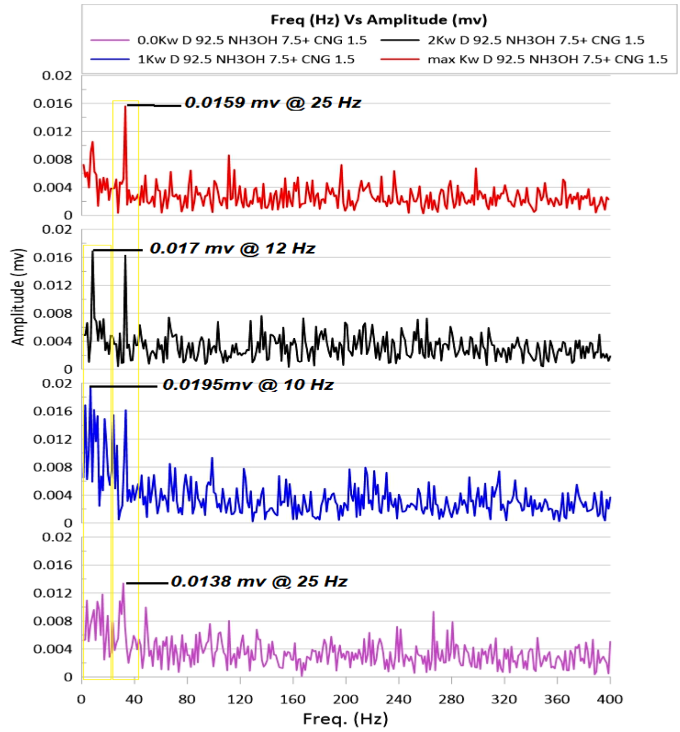

Figure 19: Amplitude vs Frequency for blend+ 1.5 CNG in PCCI

In the case of using a fuel mixture of diesel and ammonia hydroxide with the addition of CNG fuel with a PCCI injection system with a volume ratio of 2.5 litres/second, we find in Figure 20 that at no load the frequency is 50 Hz after 0.15 seconds and at 1 kW load the frequency reaches 49 Hz. After 0.015 seconds, reaching the maximum load, the frequency reaches 82 Hz after 0.09 seconds. In Figure 21, with different loads, the maximum capacity at no load appears to be 36 Hz, and with a 1 KW load, the maximum capacity is at 10 Hz, reaching the maximum load. The maximum recorded amplitude is 19 Hz.

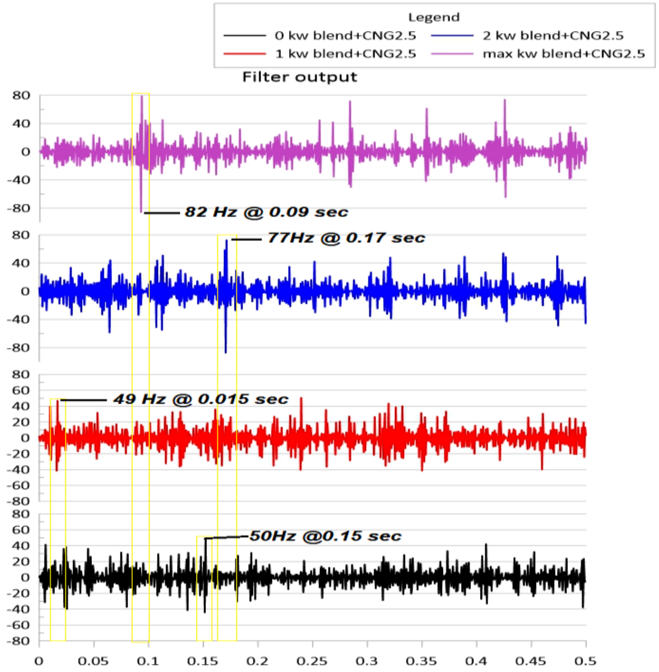

Figure 20: filter output for vibration analysis of blend + 2.5 CNG

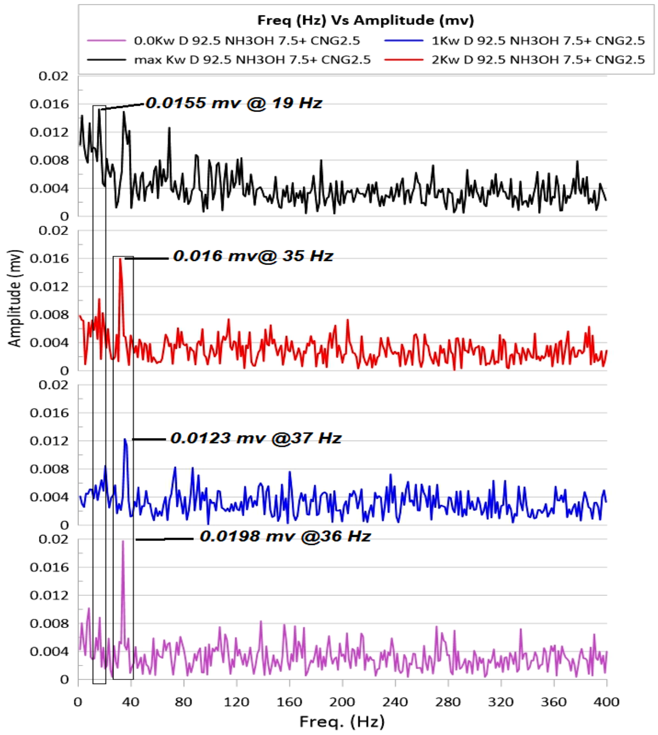

Figure 21: Amplitude vs Frequency for blend+ 2.5 CNG in PCCI

In Figures 22 and 23, the analysis of vibrations will be illustrated in the case of maximum load depending on the types of fuel used in the current study. We find in Figure 22 that in the case of using only diesel fuel, the maximum frequency value is 60 after 0.33 seconds, and in the case of using a mixture of diesel and ammonia hydroxide, the maximum frequency value reaches. 62 Hz after 0.05 seconds, and when adding CNG at a value of 1.5 litres/second, the maximum frequency value reaches 73 Hz after 0.26 seconds, while if the value of CNG is increased to 2.5 litres/second, the maximum frequency value reaches 82 Hz after 0.05 seconds. 09 seconds, while in Figure 23 in the case of using diesel only, the value of the maximum frequency at the maximum capacity reaches a value of 30 Hz. In the case of adding ammonia hydroxide, the maximum frequency reaches 25 Hz. In the case of adding CNG at a value of 1.5 litres/second, the maximum frequency reaches 35 Hz. However, when adding CNG at a value of 2.5 litres/second, the maximum frequency reaches 19 Hz.

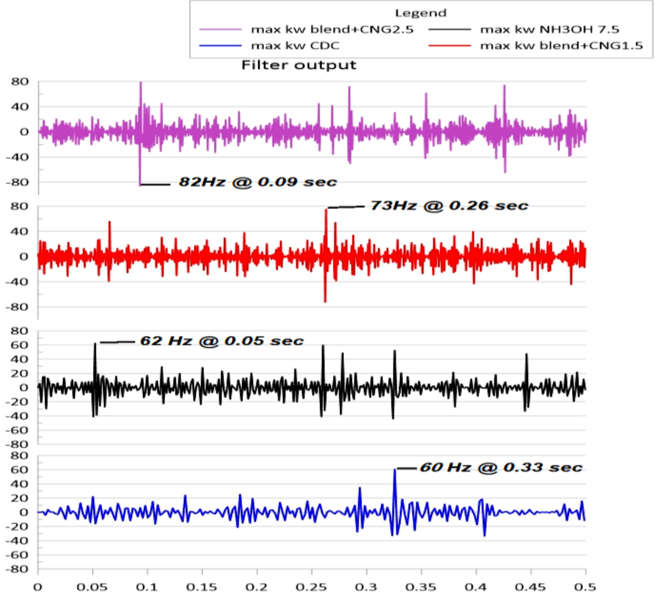

Figure 22: filter output for vibration analysis for a maximum load of different fuels

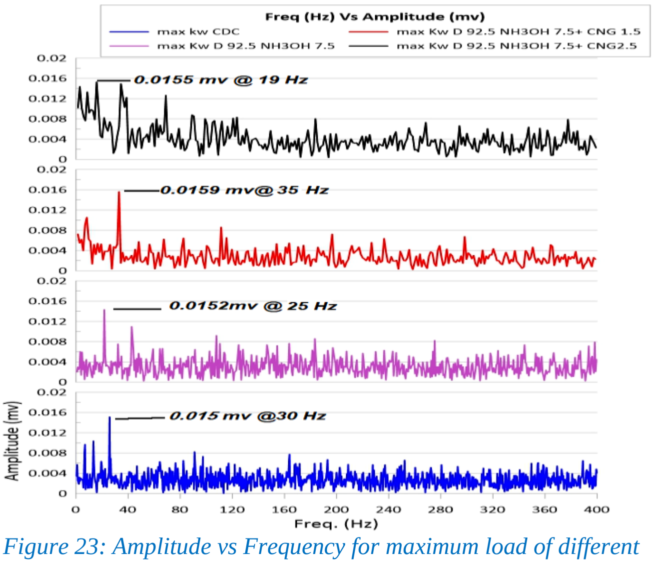

Figure 23: Amplitude vs Frequency for maximum load of different fuels.

Vibration analysis helps characterize the machine’s performance and evaluate its efficiency. The vibration analysis is based on the intensity of the vibration according to the peak amplitude and the periodicity according to the frequency. From the previously mentioned results, we find that as the loads increase for the same type of fuel, the amplitude increases and the frequency value increases, and with the addition of several types of fuel, the results appear as previously mentioned.

IV. CONCLUSIONS:

Thermal efficiency, specific fuel consumption rate, and environmental pollutant emissions were studied in the case of using pure diesel fuel, in the case of using a mixture of diesel and ammonia hydroxide, and in the case of adding compressed natural gas injected with a PCCI injection system to the mixture in varying volume ratios between (1.5L/min - 2.5L/min). The results showed that using natural gas in the mixture improves fire properties, emissions, and thermal efficiency. The following results from the experiments will be summarized:

- In the case of a 2.5L/min CNG mixture, the average BTE value increases by about 23.5%, and the average fuel consumption (BSFC) decreases by about 24.3% compared to diesel.
- NOx emissions values decrease due to the lower exhaust temperature when using compressed natural gas with a PCCI injection system added to the diesel and ammonia hydroxide mixture.
- The smoke opacity value decreases if a mixture of (ammonia hydroxide and diesel) is used, and it also decreases when compressed natural gas is added. The average smoke opacity values were calculated at the studied values, and it was found that in the case of pure diesel, the value was 51.2%, and in the case of compressed natural gas at a rate of 1.5 litres/min it was 39.6%.
- HC values increase if the mixture is used because of lower exhaust temperatures and incomplete combustion and increase at an average rate of about 54 ppm in the case of compressed natural gas at a rate of 1.5 litres/minute, while in the case of pure diesel, it is 14 ppm.
- The drop in combustion temperature causes a rise in CO emission levels, which leads to the partial oxidation of carbon dioxide and the formation of carbon monoxide.

The study was confirmed by conducting vibration analysis, and it became clear that by increasing the load at the same type of fuel or stabilizing the load while changing the type of fuel injected and changing the injection system used, the value of the peak amplitude increases and the value of the frequency increases, as the intensity of the vibration is measured by the amplitude and the periodicity is measured by the frequency, and the two values are determined. An evaluation of vibration shows the actual performance of the machine, and this was previously explained in the study.

In the end, it is recommended to use compressed natural gas injected with the PCCI injection system, and a mixture of diesel and ammonia hydroxide, injected with the traditional system in compression internal combustion engines, which works to improve the combustion properties and raise the thermal efficiency of the engine.

V. FUTURE RESEARCH DIRECTION

Because of discussing the impact of adding a mixture of ammonia and diesel hydroxide and adding compressed natural gas injected with the PCCI system on the engine emissions characteristics, performance, and combustion characteristics, which were previously mentioned, it is advised to conduct future research on some interesting topics. Among the most important recommended topics are:

- The application of innovative technology for injection systems, including RCCI. Numerous studies and research have endorsed the usage of the technology due to its advantages in terms of combustion, emissions, and engine performance.
- Looking for other fuel sources that can be blended with diesel and ammonia hydroxide to create a homogenous mixture and assessing the impact of these additions on engine output, combustion characteristics, and fuel emissions.
- To achieve good control, dependability, and the potential to work in combustion, using an electric injector is preferable to its mechanical counterpart with fuel injection pressure because it allows it to control the amount of fuel that is sent directly to the injection in the cylinder to prevent knocking accidents in the engine.

VI. REFERENCES:

[1] M. Elkelawy, H. Alm ElDin Mohamad, M. Samadony, and A. S. Abdalhadi, "Utilization of Ammonia Hydroxide/Diesel Fuel Blends in Partially Premixed Charge Compression Ignition (PPCCI) Engine: A Technical Review," *Journal of Engineering Research,* 2023.

[2] S. C. Sekhar, K. Karuppasamy, R. Sathyamurthy, M. Elkelawy, H. A. E. D. Bastawissi, P. Paramasivan, *et al.*, "Emission analysis on compression ignition engine fueled with lower concentrations of Pithecellobium dulce biodiesel-diesel blends," *Heat Transfer—Asian Research,* vol. 48, pp. 254-269, 2019.

[3] M. Elkelawy, S. E.-d. H. Etaiw, H. Alm-Eldin Bastawissi, M. I. Ayad, A. M. Radwan, and M. M. Dawood, "Diesel/ biodiesel /silver thiocyanate nanoparticles/hydrogen peroxide blends as new fuel for enhancement of performance, combustion, and Emission characteristics of a diesel engine," *Energy,* vol. 216, p. 119284, 2021/02/01/ 2021.

[4] M. Elkelawy, S. E.-d. H. Etaiw, M. I. Ayad, H. Marie, M. Dawood, H. Panchal, *et al.*, "An enhancement in the diesel engine performance, combustion, and emission attributes fueled by diesel-biodiesel and 3D silver thiocyanate nanoparticles additive fuel blends," *Journal of the Taiwan Institute of Chemical Engineers,* vol. 124, pp. 369-380, 2021/07/01/ 2021.

[5] M. Elkelawy, S. E.-d. H. Etaiw, H. A.-E. Bastawissi, H. Marie, A. Elbanna, H. Panchal, *et al.*, "Study of diesel-biodiesel blends combustion and emission characteristics in a CI engine by adding nanoparticles of Mn (II) supramolecular complex," *Atmospheric Pollution Research,* vol. 11, pp. 117-128, 2020/01/01/ 2020.

[6] M. Elkelawy, H. Alm ElDin Mohamad, M. Samadony, and A. S. Abdalhadi, "Impact of Utilizing a Diesel/Ammonia Hydroxide Dual Fuel on Diesel Engines Performance and Emissions Characteristics," *Journal of Engineering Research,* vol. 7, pp. 262-271, 2023.

[7] M. Elkelawy, H. A.-E. Bastawissi, E. A. El Shenawy, M. M. Shams, H. Panchal, K. K. Sadasivuni, *et al.*, "Influence of lean premixed ratio of PCCI-DI engine fueled by diesel/biodiesel blends on combustion, performance, and emission attributes; a comparison study," *Energy Conversion and Management: X,* vol. 10, p. 100066, 2021.

[8] M. Elkelawy, A. E. Kabeel, E. A. El Shenawy, H. Panchal, A. Elbanna, H. A.-E. Bastawissi, *et al.*, "Experimental investigation on the influences of acetone organic compound additives into the diesel/biodiesel mixture in CI engine," *Sustainable Energy Technologies and Assessments,* vol. 37, p. 100614, 2020/02/01/ 2020.

[9] M. Elkelawy, E. A. El Shenawy, H. Alm-Eldin Bastawissi, M. M. Shams, and H. Panchal, "A comprehensive review on the effects of diesel/biofuel blends with nanofluid additives on compression ignition engine by response surface methodology," *Energy Conversion and Management: X,* vol. 14, p. 100177, 2022/05/01/ 2022.

[10] H. A. E. Bastawissi, M. Elkelawy, H. Panchal, and K. Kumar Sadasivuni, "Optimization of the multi-carburant dose as an energy source for the application of the HCCI engine," *Fuel,* vol. 253, pp. 15-24, 2019/10/01/ 2019.

[11] H. Chehrmonavari, A. Kakaee, S. E. Hosseini, U. Desideri, G. Tsatsaronis, G. Floerchinger, *et al.*, "Hybridizing solid oxide fuel cells with internal combustion engines for power and propulsion systems: A review," *Renewable and Sustainable Energy Reviews,* vol. 171, p. 112982, 2023.

[12] E. A. El Shenawy, M. Elkelawy, H. A.-E. Bastawissi, M. M. Shams, H. Panchal, K. Sadasivuni, *et al.*, "Investigation and performance analysis of water-diesel emulsion for improvement of performance and emission characteristics of partially premixed charge compression ignition (PPCCI) diesel engines," *Sustainable Energy Technologies and Assessments,* vol. 36, p. 100546, 2019.

[13] E. A. El Shenawy, M. Elkelawy, H. A.-E. Bastawissi, H. Panchal, and M. M. Shams, "Comparative study of the combustion, performance, and emission characteristics of a direct injection diesel engine with a partially premixed lean charge compression ignition diesel engines," *Fuel,* vol. 249, pp. 277-285, 2019/08/01/ 2019.

[14] M. Elkelawy, H. Alm-Eldin Bastawissi, E. A. El Shenawy, M. Taha, H. Panchal, and K. K. Sadasivuni, "Study of performance, combustion, and emissions parameters of DI-diesel engine fueled with algae biodiesel/diesel/n-pentane blends," *Energy Conversion and Management: X,* vol. 10, p. 100058, 2021/06/01/ 2021.

[15] M. Elkelawy, H. Alm-Eldin Bastawissi, K. K. Esmaeil, A. M. Radwan, H. Panchal, K. K. Sadasivuni, *et al.*, "Experimental studies on the biodiesel production parameters optimization of sunflower and soybean oil mixture and DI engine combustion, performance, and emission analysis fueled with diesel/biodiesel blends," *Fuel,* vol. 255, p. 115791, 2019/11/01/ 2019.

[16] M. Elkelawy, H. A.-E. Bastawissi, K. K. Esmaeil, A. M. Radwan, H. Panchal, K. K. Sadasivuni, *et al.*, "Maximization of biodiesel production from sunflower and soybean oils and prediction of diesel engine performance and emission characteristics through response surface methodology," *Fuel,* vol. 266, p. 117072, 2020/04/15/ 2020.

[17] S. Chandra Sekhar, K. Karuppasamy, N. Vedaraman, A. E. Kabeel, R. Sathyamurthy, M. Elkelawy, *et al.*, "Biodiesel production process optimization from Pithecellobium dulce seed oil: Performance, combustion, and emission analysis on compression ignition engine fuelled with diesel/biodiesel blends," *Energy Conversion and Management,* vol. 161, pp. 141-154, 2018/04/01/ 2018.

[18] A. Singh, S. Sinha, A. K. Choudhary, H. Panchal, M. Elkelawy, and K. K. Sadasivuni, "Optimization of performance and emission characteristics of CI engine fueled with Jatropha biodiesel produced using a heterogeneous catalyst (CaO)," *Fuel,* vol. 280, p. 118611, 2020/11/15/ 2020.

[19] M. Elkelawy, E. A. El Shenawy, H. A.-E. Bastawissi, M. M. Shams, and H. Panchal, "A comprehensive review on the effects of diesel/biofuel blends with nanofluid additives on compression ignition engine by response surface methodology," *Energy Conversion and Management: X,* vol. 14, p. 100177, 2022.

[20] M. Elkelawy, E. A. El Shenawy, S. A. Mohamed, M. M. Elarabi, and H. A.-E. Bastawissi, "Impacts of using EGR and different DI-fuels on RCCI engine emissions, performance, and combustion characteristics," *Energy Conversion and Management: X,* vol. 15, p. 100236, 2022/08/01/ 2022.

[21] M. Elkelawy, Z. Yu-Sheng, A. E.-D. Hagar, and J.-z. Yu, "Challenging and Future of Homogeneous Charge Compression Ignition Engines; an Advanced and Novel Concepts Review," *Journal of Power and Energy Systems,* vol. 2, pp. 1108-1119, 2008.

[22] M. M. El-Sheekh, M. Y. Bedaiwy, A. A. El-Nagar, M. ElKelawy, and H. Alm-Eldin Bastawissi, "Ethanol biofuel production and characteristics optimization from wheat straw hydrolysate: Performance and emission study of DI-diesel engine fueled with diesel/biodiesel/ethanol blends," *Renewable Energy,* vol. 191, pp. 591-607, 2022/05/01/ 2022.

[23] M. Elkelawy, E. A. El Shenawy, S. A. Mohamed, M. M. Elarabi, and H. Alm-Eldin Bastawissi, "Impacts of EGR on RCCI engines management: A comprehensive review," *Energy Conversion and Management: X,* vol. 14, p. 100216, 2022/05/01/ 2022.

[24] M. Elkelawy, E. A. El Shenawy, S. k. A. Almonem, M. H. Nasef, H. Panchal, H. A.-E. Bastawissi, *et al.*, "Experimental study on combustion, performance, and emission behaviours of diesel /WCO biodiesel/Cyclohexane blends in DI-CI engine," *Process Safety and Environmental Protection,* vol. 149, pp. 684-697, 2021/05/01/ 2021.

[25] E. A. El Shenawy, M. Elkelawy, H. A.-E. Bastawissi, M. Taha, H. Panchal, K. k. Sadasivuni, *et al.*, "Effect of cultivation parameters and heat management on the algae species growth conditions and biomass production in a continuous feedstock photobioreactor," *Renewable Energy,* vol. 148, pp. 807-815, 2020/04/01/ 2020.

[26] M. Elkelawy, S. E.-d. H. Etaiw, H. A.-E. Bastawissi, H. Marie, A. M. Radwan, M. M. Dawood, *et al.*, "WCO biodiesel production by heterogeneous catalyst and using cadmium (II)-based supramolecular coordination polymer additives to improve diesel/biodiesel fueled engine performance and emissions," *Journal of Thermal Analysis and Calorimetry,* vol. 147, pp. 6375-6391, 2022/06/01 2022.

[27] H. A. E. Bastawissi, M. Elkelawy, H. Panchal, and K. K. Sadasivuni, "Optimization of the multi-carburant dose as an energy source for the application of the HCCI engine," *Fuel,* vol. 253, pp. 15-24, 2019.

[28] M. Elkelawy, Z. Yu-Sheng, H. A. El-Din, and Y. Jing-zhou, "A comprehensive modeling study of natural gas (HCCI) engine combustion enhancement by using hydrogen addition," SAE Technical Paper 0148-7191, 2008.

[29] A. M. Elbanna, C. Xiaobei, Y. Can, M. Elkelawy, H. A.-E. Bastawissi, and H. Panchal, "Fuel reactivity controlled compression ignition engine and potential strategies to extend

Journal of Engineering Research (ERJ
ISSN: 2356-9441 Vol. 7 – No. 6, 2023 ©Tanta University, Faculty of Engineering e ISSN: 2735-4873

the engine operating range: A comprehensive review," *Energy Conversion and Management: X*, vol. 13, p. 100133, 2022.

[30] M. Elkelawy, "Experimental Investigation of Intake Diesel Aerosol Fuel Homogeneous Charge Compression Ignition (HCCI) Engine Combustion and Emissions," *Energy and Power Engineering*, vol. Vol.06No.14, p. 14, 2014.

[31] H. A. El-Din, M. Elkelawy, and Z. Yu-Sheng, "HCCI engines combustion of CNG fuel with DME and H 2 additives," SAE Technical Paper 0148-7191, 2010.

[32] M. Elkelawy, H. Bastawissi, S. C. Sekar, K. Karuppasamy, N. Vedaraman, K. Sathiyamoorthy, *et al.*, "Numerical and experimental investigation of ethyl alcohol as oxygenator on the combustion, performance, and emission characteristics of diesel/cotton seed oil blends in homogenous charge compression ignition engine," SAE Technical Paper 0148-7191, 2018.

[33] J.-z. Yu, Z. Yu-Sheng, M. Elkelawy, and Q. Kui, "Spray and combustion characteristics of HCCI engine using DME/diesel blended fuel by port-injection," SAE Technical Paper 0148-7191, 2010.

[34] A. M. Elbanna, C. Xiaobei, Y. Can, M. Elkelawy, and H. A.-E. Bastawissi, "A comparative study for the effect of different premixed charge ratios with conventional diesel engines on the performance, emissions, and vibrations of the engine block," *Environmental Science and Pollution Research*, pp. 1-16, 2022.

[35] S. F. Abd El Fattah, M. F. Ezzat, M. A. Mourad, M. Elkelawy, and I. M. Youssef, "Experimental Investigation of the Performance and Exhaust Emissions of a Spark-Ignition Engine Operating with Different Proportional Blends of Gasoline and Water Ammonia Solution," *Journal of Engineering Research*, vol. 5, pp. 38-45, 2022.

[36] M. Elkelawy, H. Alm ElDin Mohamad, E. Abd Elhamid, and M. A. M. El-Gamal, "A Critical Review of the Performance, Combustion, and Emissions Characteristics of PCCI Engine Controlled by Injection Strategy and Fuel Properties," *Journal of Engineering Research*, vol. 6, pp. 96-110, 2022.

[37] A. M. Elbanna, X. Cheng, C. Yang, M. Elkelawy, and H. Alm-Eldin Bastawissi, "Investigative research of diesel/ethanol advanced combustion strategies: A comparison of Premixed Charge Compression Ignition (PCCI) and Direct Dual Fuel Stratification (DDFS)," *Fuel*, vol. 345, p. 128143, 2023/08/01/ 2023.

[38] H. A. El-Din, Y.-S. Zhang, and M. Elkelawy, "A computational study of cavitation model validity using a new quantitative criterion," *Chinese Physics Letters*, vol. 29, p. 064703, 2012.

[39] H. A.-E. Bastawissi and M. Elkelawy, "Investigation of the Flow Pattern inside a Diesel Engine Injection Nozzle to Determine the Relationship between Various Flow Parameters and the Occurrence of Cavitation," *Engineering*, vol. Vol.06No.13, p. 13, 2014.

[40] A. M. Elbanna, X. Cheng, C. Yang, M. Elkelawy, and H. A.-E. Bastawissi, "Investigative research of diesel/ethanol advanced combustion strategies: A comparison of Premixed Charge Compression Ignition (PCCI) and Direct Dual Fuel Stratification (DDFS)," *Fuel*, vol. 345, p. 128143, 2023.

[41] H. Bastawissi, Z. Yu-Sheng, M. Elkelawy, and A. Bastawissi, "Detailed 3D-CFD/chemistry of CNG-hydrogen blend in HCCI engine," SAE Technical Paper 0148-7191, 2010.

[42] M. Elkelawy, H. A.-E. Bastawissi, A. M. Radwan, M. T. Ismail, and M. El-Sheekh, "Chapter 15 - Biojet fuels production from algae: conversion technologies, characteristics, performance, and process simulation," in *Handbook of Algal Biofuels*, M. El-Sheekh and A. E.-F. Abomohra, Eds., ed: Elsevier, 2022, pp. 331-361.

[43] S. El-din H. Etaiw, M. Elkelawy, I. Elziny, M. Taha, I. Veza, and H. Alm-Eldin Bastawissi, "Effect of nanocomposite SCP1 additive to waste cooking oil biodiesel as fuel enhancer on diesel engine performance and emission characteristics," *Sustainable Energy Technologies and Assessments*, vol. 52, p. 102291, 2022/08/01/ 2022.

[44] A. E. Kabeel, E. A. ElShenawy, M. Elkelawy, H. Alm ElDin Mohamad, and M. M. Elshanshoury, "Numerical Investigation of Combustion in HCCI Diesel Engine Fuelled with Biodiesel Blends," *Journal of Engineering Research*, vol. 3, pp. 1-10, 2019.

[45] A. M. Elbanna, C. Xiaobei, Y. Can, M. Elkelawy, and H. A.-E. Bastawissi, "A comparative study for the effect of different premixed charge ratios with conventional diesel engines on the performance, emissions, and vibrations of the engine block," *Environmental Science and Pollution Research*, vol. 30, pp. 106774-106789, 2023/10/01 2023.

[46] M. Elkelawy, H. Alm ElDin Mohamad, S. Abo-Samra, and I. Abd-Elhay Elshennawy, "Nanoparticles Additives for Diesel/Biodiesel Fuel Blends as a Performance and Emissions Enhancer in the Applications of Direct Injection Diesel Engines: A comparative Review," *Journal of Engineering Research*, 2023.

[47] A. E. Kabeel, M. Elkelawy, H. A. E. Bastawissi, and A. M. Elbanna, "An experimental and theoretical study on particles-in-air behavior characterization at different particles loading and turbulence modulation," *Alexandria Engineering Journal*, vol. 58, pp. 451-465, 2019/06/01/ 2019.

[48] M. Elkelawy, H. Alm ElDin Mohamad, and M. A. M. El-Gamal, "Experimental Investigation of the Biodiesel Direct Injection and Diesel Fuel as Premixed Charge on CI-Engine Emissions, Performance, and Combustion Characteristics," *Journal of Engineering Research*, vol. 7, pp. 177-187, 2023.

[49] H. Alm El-Din, M. Elkelawy, and A. E. Kabeel, "Study of combustion behaviors for dimethyl ether asan alternative fuel using CFD with detailed chemical kinetics," *Alexandria Engineering Journal*, vol. 56, pp. 709-719, 2017/12/01/ 2017.

[50] M. Elkelawy, E. A. El Shenawy, H. A. E. Bastawissi, and I. A. El Shennawy, "The effect of using the WCO biodiesel as an alternative fuel in compression ignition diesel engine on performance and emissions characteristics," *Journal of Physics: Conference Series*, vol. 2299, p. 012023, 2022/07/01 2022.

[51] H. A. E.-D. Bastawissi and M. Elkelawy, "Computational Evaluation of Nozzle Flow and Cavitation Characteristics in a Diesel Injector," *SAE International Journal of Engines*, vol. 5, pp. 1605-1616, 2012.

[52] M. ElKelawy, H. A.-E. Bastawissi, E.-S. A. El-Shenawy, H. Panchal, K. Sadashivuni, D. Ponnamma, *et al.*, "Experimental investigations on spray flames and emissions analysis of diesel and diesel/biodiesel blends for combustion in oxy-fuel burner," *Asia-Pacific Journal of Chemical Engineering*, vol. 14, p. e2375, 2019.

[53] R. L. Ott and M. T. Longnecker, *An introduction to statistical methods and data analysis*: Cengage Learning, 2015.

[54] M. M. El-Sheekh, A. A. El-Nagar, M. ElKelawy, and H. A.-E. Bastawissi, "Solubility and stability enhancement of ethanol in diesel fuel by using tri-n-butyl phosphate as a new surfactant for CI engine," *Scientific Reports*, vol. 13, p. 17954, 2023.

[55] M. T. ÇOban, "Error analysis of non-iterative friction factor formulas relative to Colebrook-White equation for the calculation of pressure drop in pipes," *Journal of Naval Sciences and Engineering*, vol. 8, pp. 1-13, 2012.

[56] J. Yu, Y. Zhang, M. Elkelawy, and H. Zhang, "Investigation and numerical simulation of DME flash boiling spray characteristics," *Chinese Internal Combustion Engine Engineering*, vol. 30, pp. 45-50, 2009.

[57] H. Wen, C. Wang, M. Elkelawy, and G. Jiang, "Influence of ambient pressure on gas ingestion in diesel nozzle after end of

injection," *Trans. Chin. Soc. Agri. Mach,* vol. 48, pp. 364-369, 2017.

[58] E. A. El-Shenawy, M. Elkelawy, H. A. Bastawissi, and M. Taha, "GROWTH CONDITIONS OF THE ALGAE SPECIES BIOMASS IN A CONTINUOUS FEEDSTOCK PHOTO BIOREACTOR BY CONTROLLING THE SOLAR THERMAL RADIATION AND CLIMATE TEMPERATURE," *The International Conference on Applied Mechanics and Mechanical Engineering,* vol. 18, pp. 1-19, 2018.

[59] M. Elkelawy, H. Alm ElDin Mohamad, A. K. Abdel-Rahman, A. Abou Elyazied, and S. Mostafa El malla, "Biodiesel as an Alternative Fuel in Terms of Production, Emission, Combustion Characteristics for Industrial Burners: a Review," *Journal of Engineering Research,* vol. 6, pp. 45-52, 2022.

[60] M. Elkelawy, H. Alm ElDin Mohamad, M. Samadony, A. M. Elbanna, and A. M. S. M. Safwat, "A Comparative Study on Developing the Hybrid-Electric Vehicle Systems and its Future Expectation over the Conventional Engines Cars," *Journal of Engineering Research,* vol. 6, pp. 21-34, 2022.

[61] H. W. Coleman and W. G. Steele, *Experimentation, validation, and uncertainty analysis for engineers*: John Wiley & Sons, 2018.

[62] B. Štrbac, B. Ačko, S. Havrlišan, I. Matin, B. Savković, and M. Hadžistević, "Investigation of the effect of temperature and other significant factors on systematic error and measurement uncertainty in CMM measurements by applying design of experiments," *Measurement,* vol. 158, p. 107692, 2020.

[63] M. M. El-Sheekh, A. A. El-Nagar, M. ElKelawy, and H. A.-E. Bastawissi, "Maximization of bioethanol productivity from wheat straw, performance and emission analysis of diesel engine running with a triple fuel blend through response surface methodology," *Renewable Energy,* vol. 211, pp. 706-722, 2023/07/01/ 2023.

[64] M. M. El-Sheekh, A. A. El-Nagar, M. ElKelawy, and H. A.-E. Bastawissi, "Bioethanol from wheat straw hydrolysate solubility and stability in waste cooking oil biodiesel/diesel and gasoline fuel at different blends ratio," *Biotechnology for Biofuels and Bioproducts,* vol. 16, p. 15, 2023/02/01 2023.

[65] M. Elkelawy, H. A.-E. Bastawissi, A. K. Abdel-Rahman, A. Abou El-Yazied, and S. Mostafa El malla, "Effect of multifunctional fuel additive in diesel/waste oil biodiesel blends on industrial burner flame performance and emission characteristics," *International Journal of Ambient Energy,* vol. 44, pp. 1382-1395, 2023/12/31 2023.

[66] M. Elkelawy, E. S. A. El Shenawy, H. A.-E. Bastawissi, and M. M. Shams, "Impact of Carbon Nanotubes and Graphene Oxide Nanomaterials on the Performance and Emissions of Diesel Engine Fueled with Diesel/Biodiesel Blend," *Processes,* vol. 11, p. 3204, 2023.

[67] M. Elkelawy, Z. Yu-Sheng, H. El-Din, Y. Jing-Zhou, A. El Zahaby, and E. El Shenawy, "Experimental Study on Flash Boiling and Micro-Explosion of Emulsified Diesel Fuel Spray Droplets by Shadowgraph Technology," *Transactions of CSICE,* vol. 27, pp. 306-308, 2009.

[68] M. Elkelawy, H. A. Bastawissi, E. A. El Shenawy, and M. A. M. El-Gamal, "Effects of using a novel fuel vaporizer on partially premixed charge compression ignition (PPCCI) engine emissions, performance, and combustion characteristics," *Journal of Physics: Conference Series,* vol. 2616, p. 012017, 2023/11/01 2023.

[69] H. Alm ElDin Mohamad, E. Abd elhamid, M. Elkelawy, and O. Hendawi, "Experimental Investigation on the Effect of using Oxy-Hydrogen Gas on Spark Ignition Engines Performances, and Emissions Characteristic," *Journal of Engineering Research,* vol. 7, pp. 32-41, 2023.

[70] A. M. Elbanna, X. Cheng, C. Yang, M. Elkelawy, H. Alm-Eldin Bastawissi, and H. Xu, "Statistical analysis of ethanol/diesel dual-fuel combustion of compression ignition engines in RCCI mode using multi-injection strategies," *Sustainable Energy & Fuels,* vol. 7, pp. 2749-2763, 2023.

[71] V. Karaman, S. Yildizhan, M. Ozcanli, and H. Serin, "Calculation and optimizing of brake thermal efficiency of diesel engines based on theoretical diesel cycle parameters," *International Journal of Engineering Technologies IJET,* vol. 2, pp. 100-104, 2016.

[72] B. Šarkan, T. Skrúcaný, and Z. Majerová, "Possibilities of measuring the brake specific fuel consumption in road vehicle operation," *Machines. Technologies. Materials.,* vol. 8, pp. 19-21, 2014.

[73] M. Elkelawy, E. Abd elhamid, H. Alm ElDin Mohamad, S. Abo-Samra, and I. Abd-Elhay Elshennawy, "Nanoparticles Additives for Diesel/Biodiesel Fuel Blends as a Performance and Emissions Enhancer in the Applications of Direct Injection Diesel Engines: A comparative Review," *Journal of Engineering Research,* vol. 7, pp. 112-121, 2023.

[74] M. Elkelawy, H. Alm ElDin Mohamad, E. Abd elhamid, and M. A. M. El-Gamal, "Experimental Investigation of the Biodiesel Direct Injection and Diesel Fuel as Premixed Charge on CI-Engine Emissions, Performance, and Combustion Characteristics," *Journal of Engineering Research,* vol. 7, pp. 177-187, 2023.

[75] H. W. H. Wei and Z. W. Z. Wang, "A weighted average formula for efficient inductance and resistance extraction," pp. 996-999.

[76] H. Ahmed and A. K. Nandi, *Condition monitoring with vibration signals: Compressive sampling and learning algorithms for rotating machines*: John Wiley & Sons, 2020.

[77] M. Petyt, *Introduction to finite element vibration analysis*: Cambridge university press, 2010.

[78] B. Boashash, *Time-frequency signal analysis and processing: a comprehensive reference*: Academic press, 2015.

[79] Z. Feng, X. Yu, D. Zhang, and M. Liang, "Generalized adaptive mode decomposition for nonstationary signal analysis of rotating machinery: Principle and applications," *Mechanical Systems and Signal Processing,* vol. 136, p. 106530, 2020.

[80] B. S. Talikoti, S. N. Kurbet, and V. V. Kuppast, "A review on vibration analysis of crankshaft of internal combustion engine," *International Research Journal of Engineering and Technology (IRJET),* vol. 2, pp. 2395-0056, 2015.

[81] C. M. Santana, J. E. M. Barros, and H. A. de Almeida, "Analysis of vibration and noise of an internal combustion engine by application of test and experimental analysis of the frequency spectrum," SAE Technical Paper 0148-7191, 2013.

[82] C. Sujatha, "Equipment for Measurement and Generation of Vibration," in *Vibration, Acoustics and Strain Measurement: Theory and Experiments,* ed: Springer, 2023, pp. 67-159.

[83] S. Hassani and U. Dackermann, "A Systematic Review of Advanced Sensor Technologies for Non-Destructive Testing and Structural Health Monitoring," *Sensors,* vol. 23, p. 2204, 2023.

[84] J. N. Haus, W. Lang, T. Roloff, L. Rittmeier, S. Bornemann, M. Sinapius, *et al.*, "MEMS vibrometer for structural health monitoring using guided ultrasonic waves," *Sensors,* vol. 22, p. 5368, 2022.

[85] S. V. Gawali, S. S. Naik, K. S. Kamepalli, and R. Yadav, "Implication of Condition-based Maintenance in Roller Bearing of the Paper Industry," 2021.

[86] A. Hake, "Piezoelectric MEMS Accelerometers for Sensing Ossicular Vibration," 2021.