Explorative Investigation on Cashew Nut Shell Liquid Biodiesel blended with Ethanol and Hydrogen in Direct Injection (DI) Diesel Engine and prediction through Artificial Neural Network

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Abstract

Emission from the DI diesel engine is series setback for environment viewpoint. Intended for that investigates for alternative biofuel is persuaded. The important hitches with the utilization of biofuels and their blends in DI diesel engines are higher emanations and inferior brake-thermal efficiency as associated to sole diesel fuel. In this effort, Cashew nut shell liquid (CNSL) biodiesel, hydrogen and ethanol (BHE) mixtures remained verified in a direct-injection diesel engine with single cylinder to examine the performance and discharge features of the engine. The ethanol remained supplemented 5%, 10% and 15% correspondingly through enhanced CNSL as well as hydrogen functioned twin fuel engine. The experiments done in a direct injection diesel engine with single-cylinder at steadystate conditions above the persistent RPM (1500RPM). Throughout the experiment, emissions of pollutants such as fuel consumption rate (SFC), hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NOx) and pressure of the fuel were also measured. cylinders. The experimental results show that, compared to diesel fuel, the braking heat of the biodiesel mixture is reduced by 26.79-24% and the BSFC diminutions with growing addition of ethanol from the CNSL hydrogen mixture. The BTE upsurges thru a rise in ethanol proportion with CNSL hydrogen mixtures. Finally, the optimum combination of ethanol with CNSL hydrogen blends led to the reduced levels of HC and CO emissions with trivial upsurge in exhaust gas temperature and NOx emissions. This paper reconnoiters the routine of artificial neural networks (ANN) to envisage recital, ignition and discharges effect.

1. Introduction

Growing industrialization and modernization of developing countries is ensuing in increased the demand for fossil fuels worldwide. At present engine exhaust emissions or improvement in thermal efficiency can be attained with various preferences from both alternative fuels in vehicles and contribution energy storage in an assortment of features. The wide-ranging use of conventional fossil fuels to gratify the bulk of our energy demands has created a negative impact on our environment. The intensity of noxious matters like NOX, HC, CO, SOX, lead, particulate matter and photochemical oxidants in the atmosphere are comparatively very high and distressing. Limited temperament of fossil fuel sources motivates the interest amongst the researchers to pay attention for alternative fuels [1]. Therefore, good alternative fuels should be in connection with sustainable development, energy efficiency and more importantly energy conservation.

The oils derived from which environmentally benign vegetables is the best alternative source. Even if the focus on alternative fuels materialized in 1920 itself by Rudolf Diesel’s test on his engine by peanut oil it was not because of engine interrelated trouble[2]. There have been numerous ways noted for biofuel preparation in the course of transesterification, pyrolysis and catalytic cracking. The NOx drawn out from burning fuel that are Nitrogen-free can be designed in the course of the under set-ups: a) NOx updraft plot get the better of by the hotness of the burning fuels; b) the hasty NOx sensed at fuel comical blend and unburned air-fuel mixture prior to the incursion of the forefront-flame; and c) the N2O transitional mechanism taking place mostly at insignificant temperature produced in diesel engine[3]. When the engine is running at medium and high load, the maximum combustion temperature of the DI diesel engine is usually higher than the process input temperature of the NOx mechanism. Quite, the N2O intermediary convinced to promote NOx development in diesel engines at lesser heat conversion where the engine exhaust NO2-NOx ratio is known to surpass 15%[4]. Along with these, the payment of the rapid mechanism to the progress of NOx is quite significant. The development of NO2 has been explored by various researchers. It was perceived that the Nitrogen oxide moulded in the blaze section could be rehabilitated to NOx through retorts such as NO + HO2 <=> N O2 + OH[5]. Earlier researches showed the prominent role of HO2 in potentiating the conversion of NO to NO2 [6]. The HO2 segment can be intended by a new reaction H + O2 + M <=> HO2 + M. Routes devouring the impeding to perceptibly increase the HO2 were anticipated to cover the conversion of NO2. Such as, the HO2 particle systematized in the quite less heat unburned fuel area scheduled to the fore flame area[7]. The enhanced HO2 reacts with the NO elements transmitted through higher temperature combustion areas and boost the growth of NO2[8]. As available at an appropriate temperature, the unburned fuel components contain hydrogen possibly will oxidize with oxygen (O2) and delineate HO2, which forces enhance the progress of formation of NO2[9].

The burning of cashew nut oil having an extremely make higher calorific value and subsequently it was well deliberate capable with a possible fuel in diesel engine. This work engages expose of CNSL as biofuel with development for its formulation and production[10]. In this test, cardanol in CNSL oil was used to run a diesel engine with a number of mixtures, and the results and uniqueness of the emissions matched those of diesel. In the present and high-speed humankind, petroleum supported energy turn out to be significant with every progress. Yields resultant as of crude lubricate sustained as chief and serious basis of force that useful in energizing means of transportation throughout. Still, petroleum assets are inadequate as well as non-renewable. Throughout years, utilization of substitute energy in diesel engines established awareness. The vagueness of petroleum supported energy accessibility has shaped necessitate on substitute energy. Through several years, investigations exertion obligate to be dedicated mostly happening with enhanced engine strategy since the standpoint of dropping impurities discharge deprived of forfeiting recital and fuel budget. Presently, a prominence on dropping impurity discharges as of petroleum supported engines ensures striving progress plus analysis about numerous substitute fuels. The key impurities as of diesel devices are NOX, particulate matter and smoke[11]. Numerous fuels ought to be deliberated as replacements in place of hydrocarbon-based energy. Substitute energy facilitates interchange petroleum supported energies comprise additives, LPG, CNG, H2, vegetable oils, bio gas, producer gas and LNG. Amid all, H2 becomes durable sustainable and fewer contaminating energy.

Moreover, H2 be innocuous, unscented plus consequences while thorough burning H2 possibly will castoff like energy for IC engines both untainted otherwise intermingled through additional hydrocarbon fuels. Owing to these features, investigators stand converging their responsiveness on hydrogen to be substitute energy in internal combustion engines (ICEs) plus with expansion of energy chamber power-driven automobiles. Hydrogen can be cast-off for instance an exclusive fuel in spark ignition (SI) engine, both through carburetion and straight inoculation. Hydrogen driven ICE automobiles fabricated by existing expertise remain expensive through unreal fuel or methanol automobiles with coal ingestion or fuel charge[14].

The notion of consuming hydrogen like substitute fuel intended with diesel devices is topical. The personal detonation temperature of H2 is 858 K, thus hydrogen might not cast-off unswervingly with CI device deprived of trigger socket else spark socket. In front of the accumulative utilization of petroleum fuels, biofuels, like ethanol essentially noticed to reduce the fuel deficiency. Biofuels was being a replacement for fossil diesel necessitate by monoesters of fatty acids. Through related physical possessions to diesel fuel, no need in transforming diesel engine while run the test engine through biofuel blends[15]. Experiments through conventional diesel, the fuel-borne oxygen rich in biofuel might support the combustion process and thus reduce the particulates, carbonmonoxide and entire hydro carbon emissions in CI engine, whereas enhancing nitrogenoxides emission. Reproduction study heavy-duty engines as of diesel to biofuel blends, CO, HC, and PM diminished through 10–20%, 15–25% and 15–20% in that order, where NOx enhanced by about 5–10%.

Ethanol fuel, having an immense oxygen amount of 30–40%, has tendency to use in diesel engine as per ethanol and biofuel-diesel mixtures. Exhaust from the biofuel- ethanol blends in diesel engine delivered remarkable decrease with PM releases, thru inconsiderable hike of gaseous releases (NOx, HC, CO)[14]. Additionally, ethanol-biofuel blends usage overwhelms about hindrances for occurrence, and additive is obligatory for good interaction by dual fuels with fuel blends takes disposes the lubricity. therefore, the intention of present research is to analyse the consequence of ethanol addition on recital and releases of CNSL biodiesel-hydrogen operated DI diesel engine besides to relate further outcomes thru which attained as of straight diesel fuel[15]. In interpretation of the previous works summarized, the utilization of biodiesel thru usable alongwith nonusable lubricants in vehicle is evolving gradually as capable auxiliary for fossil fuel. Replacing the gassy fuels alike hydrogen and naturalgas by biodiesel, reduces limitation of volatility, emission, viscosity, farming area and manufacture price of biodiesel bound the custom of biodiesel in vehicles. Based on the assessment of several researches in this extent, copious experimentations were steered with concerns to preheating of vegetable oil, transesterification of vegetable oils hydrogen induction, and use of alcohols can be suitable options aimed at enlightening the recital and emanations of a vegetal oil operated CI engine. Study of pyrolysis method for producing bio diesel from different fuels also discussed in this chapter. Cylinder pressure data collection and heat release rate are also used for analysis related to engine combustion. Based on this experience, the second law of thermodynamics has been developed. According to Lord Kelvin, it is impossible to completely convert heat into work during the cycle without other effects.

In current research work, TCCNSL is produced mainly by thermal reactors designed of different temperatures, this fuel is mixed with diesel for testing. The blended fuel is tested with different hydrogen induction. Finally the ethanol is added with optimized hydrogen flow rate and CNSL blends. The biodiesel is flexible in adapting alcohols and diesel. The adding of biodiesel in mixture with ethanol and diesel fuels progresses mingling steadiness, fuel actuals and not permitted stage parting. The above study also specified thru augmented ethanol % in mixture results in marginal reduction in the drip scope of diesel–ethanol mixtures.

2. Materials And Methods

2.1. Thermally Split CashewNut Shell Liquid Biofuel

The cleansed routine TC-CNSL being principal step of treated renewed CNSL as exposed in Fig. 1. The TC-CNSL has 3% polymeric substance, and 78% cardanol further the residual supplementarying redients in capability base.

The thermal shattered CNSL (TC-CNSL) persisted resulting as Cardanol at high temperature spreading among 180ºC and 380ºC, lower atmospheric pressure. The temperature level increases gradually from 170 ° C to 390 ° C, with an interval of 50 ° C. CSNL's biofuel production peaked at a temperature of 330 ºC. The coal ash used as catalyst for cracking process based on its low cost and locally available. Various quantity of coal ash used like 50g, 100g, 150g and 200g with CSNL oil. From the results obtained 150g of coal ash gives the maximum yield of biofuel. The descriptive and specific system outlooks intended at preparing the TC-CNSL are exposed in Fig. 2.

2.2. Gas Chromatography – Mass Spectrum (Gc-Ms) Analysis

The arrangement of CSNL biofuel (B100) remained analysed through a Gas Chromatography – Mass Spectrum (GCMS) analyser, with the pier specification of 220°C effective temp, 3°C/min slope level, 4μl/min stream level with 70:1 splitting proportion. The GC spectrum of CSNL biofuel (B100) had shown in Fig. 3.

The characters of components were established through the reten`tion time, distinguished the peak of every compound by means of the standard database. In-depth inspection of their constitution discloses that CSNL biofuel is unsaturated hydrocarbon, possibly by means of longer hydrocarbon chain and intrinsic oxygen content in their configuration, which is comparable to erstwhile existing biofuels

The most common thermodynamic evaluation parameter is energy efficiency. An indicator is considered, the completion of the energy conversion or transfer process. However, this definition is not precise enough because energy efficiency does not take into account the internal irreversibility. Therefore, energy-based thermodynamic analysis only has the disadvantage, that is, although it can identify the loss of energy, is not sufficient to quantify the irreversibility of a given process.

2.3. Hydrogen Gas Production as of Fuel Cell

The chemical energy is renovated into electricity in the course of a chemical reaction by means of oxidizing agent through a fuel cell [18]. Hydrogen gas is the widespread fuel; however conventional hydrocarbons fuels for instance natural gas and methanol are for a moments utilized. The fuel cells are totally dissimilar from batteries as they necessitate a constant source of fuel and oxygen keep going the chemical response, however generate electricity incessantly provided that these inputs are abounding. The process of hydrogen production process in fuel cell is exposed in Fig.4.

2.4. Investigation of Thermal Cracked-CNSO

A sample of Thermal Cracked-CNSO was evaluated with Fourier Transform infrared analysis, Gas Chromatography analysis along with other necessary tests in advanced Investigative Mechanism at IIT-MADRAS, Chennai. The overall possessions of thermal cracked CNSL individually along with diesel is narrated in Table 1. Thereby it is found that the kinematic viscidness of cashew nut shell liquid oil was drastically reduced after the Thermal cracking process. Similarly, the flash point, fire point and calorific value was enhanced through the above process. TC-CNSL after being tested with fuel possessions, has the heaped kinematic viscosity (17.5 cP as by 32ºC), increased thickness (0.9336 g/cc) and heaped flash point (greater than 197ºC). The FTIR spectrum of diesel and Cashew nut shell oil biofuel are shown in Fig. 5 and Fig. 6 individually. From the Figures, important groups that stance for methylene plus carbonyl sets in the part amid 2931 to 2843 cm − 1 were identified; the 1st heap familiar with elongating shakings of the olefins group with terminal CH2[19].

The noteworthy analysis might done towards molarity of the compounds and their matching bandwidth given as a chart concerning transmittance (%T) and Infrared frequency range (cm−1). The Properties of Hydrogen Gas is given in Table 2.

The second peak was familiar with the reduction of the C-H and CH2 bonds paraffin groups. These bands prove resemblance between the fossil diesel fuel and CSNL biofuel.
The vibrational analysis of the particle analysis done in FTIR analysis. In overall, Chromatography denotes corporal parting technique established with spreading of modules amid agility stage and motionless stage. The procedure includes gas absorption thru exterior as well as functional with enduring gases parting and squat boiling point composites.

3. Experimental Structure And Technique

The investigational arrangement involves of engine, air ingestion system, and fuel amalgamation system, filling and measuring strategies. This arrangement was furnished through obligatory equipment, strategies and reins to obtain the diverse functioning constraints such as fuel stream, air drift, and cylinder force, exhaust-gas temperature plus drain discharge dimensions throughout the investigation. The several mechanisms of investigational arrangement are discoursed in this section. Figure 7 shows the representation outlook of investigational set up with Single cylinder, 4- stroke, vertical, water cooled, DI diesel engine and Fig. 8. Shows the precise view of experimental structure. The Engine specifications are tabulated in Table 3.

Use a hydrogen pressure regulator to supply hydrogen through a high-pressure steel cylinder at an outlet pressure of 2 bar. The outline view of hydrogen flow path is shown in Fig. 9 respectively. The properties of hydrogen gas are tabulated in Table 3. At a permanent engine speed of 1500 rpm, various stacks were tested in a stable phase.

Then the engine reaches a constant state and all readings are studied. During the entire motor process, the motor performance changes from zero load to 100% load in steps of 20%. The engine uses CNSL mixture and hydrogen-ethanol mixture. Under each load, the interpretation of air flow, EGT, fuel flow, CO, HC, and NOx emissions are recorded. The pressure crank angle data is also recorded. Process these data to obtain the average change in crankshaft pressure angle. HRR is calculated using formulas. 1.

$$Q_{app} = \frac{\gamma}{\gamma-1}[PdV] + \frac{1}{\gamma-1}[VdP] + Q_w \text{ Equ. (1)}$$

Where,

P – Cylinder-pressure (bar)

Qw- Heat-transfer to the wall (J)

Qapp-Apparent-heat release rate (J)

V- Immediate capacity of the cylinder (m3)

γ- Specific temperatures proportion

Cp-Specific-heat at perpetual pressure (J/Kmol-K)

An uncertainty investigation is very important to determine the genuineness of investigational outcomes resulting as of a precise study by diesel engine. The faults and indecisions devise after the choice of tools, scrutiny, working state, and ecological situations as listed in Table 4. The belongings of ethanol are tabulated in Table 5.

The ANN technique was cast-off to envisage diverse engine productivity retorts. The ANN outcomes spectacles as like a virtuous association amongst the ANN prophesied ethics and the investigational ethics for numerous engine recitals, ignition bounds and dissipate discharge features. The root mean square error value (RMSE), regression value of R2 for authentication, preparation and analysis are 0.005721, 0.98631, 0.97821 and 0.9841 respectively whereas the complete significance is 0.97193. The proposed prediction analysis using ANN layers as shown in Fig. 10.

4. Results And Discussion

4.1. Experimental Characteristics Study of Hydrogen + CNSL + Diesel Blends

4.1.1. Brake Specific Fuel Consumption

Figure 11 shows the difference in braking specific fuel consumption (BSFC) under the influence of braking under various hydrogen flow loads. BSFC is reduced by increasing the accumulation of 8 lpm of hydrogen. The full capacity 4 lpm hydrogen accumulation associated with diesel reaches the lowest BSFC. This is due to the hydrogen fuel being premixed by air because it has high diffusibility and undergoes constant exchange through air after enhanced incineration. Between diesel and hydrogen flow frequency of 4 lpm, the BSFC reduction rate was experimentally maintained at 12%.

4.1.2. Brake Thermal Efficiency

Figure 12 shows the brake thermal efficiency discrepancy through diverse stream charges of hydrogen.

The 8 lpm hydrogen accumulation occasioned the maximum brake thermal competence of 37.5% associated to diesel and B20 at full capacity. The upsurge in brake thermal efficiency is owing to hydrogen's advanced calorific rate and enhanced intercourse thru air in accumulation to its quicker flame rapidity features [12]. It stood experiential that the hydrogen accumulation thru inlet air exhibited the upgraded recital by related to usual neat diesel procedure.

4.1.3. Exhaust gas temperature

The disadvantages of the exhaust gase temperature to the braking force with hydrogen mixed with CNSL and diesel mixtures are shown in Fig. 13. Exhaust gas temperature by adding hydrogen using the CNSL mix increases [13].

The reason for the increase in EGT during the hydrogenation process may be due to the increase in the burning rate of hydrogen.

4.1.4. Emission of NOx

Figure 14 shows the variance of nitrogen oxides through brake power. NO_X procedures at topmost incineration temperature and higher oxygen absorptions. NO_X establishment is advanced per 8 lpm associated to straight diesel, B20 and further stream degree of hydrogen. As the hydrogen proportion upsurges, the flame speed and henceforth incineration competence augmented .The proportion of upsurge of NOX is 34% at complete capacity once associated straight diesel.

4.1.5. Emission of HydroCarbon

The variance of HC discharges for diverse standards of hydrogen enhancement is exposed in Fig. 15.

The Unburned hydrocarbon diminutions expressively since hydrogen fuel does not comprise carbon. It is perceived that the HC release values of 4lpm, 8lpm and 12lpm hydrogen stream frequency through diesel fuel process are 210 ppm, 199 ppm and 203 ppm correspondingly at full capacity.

The lowermost HC release remained attained 199 ppm thru 8 lpm hydrogen stream percentage related to 215 ppm for diesel The decrease in HC is owing to the advanced scorching rapidity of hydrogen, which augments the diesel burning. The lack of carbon in hydrogen fuel moreover decreases the HC releases to a better scope.

4.1.6. Emission of CO

The difference between CO emissions and engine stopping power and the different hydrogen enhancement ratios is shown in Fig. 16.

The lowest CO emissions reached 0.05% at 8 lpm, compared to 0, 11% of diesel.[10]. With 8 lpm, CO emissions are less than the additional costs from hydrogen streams and direct diesel processes. The reduction in CO in the 8 lpm hydrogen-powered dual-fuel engine is due to the lack of carbon in the hydrogen fuel. However the oxygen deliberation decreases suggestively and in accumulation owing to slighter response interval it outcomes in a noteworthy upsurge in CO foundation degree, which sorts the whole CO deliberation to upsurge at full capacity associated to diesel.

4.1.7. Variation of combustion in-cylinder pressure with crank angle degree

Variation of combustion pressure in cylinder with crank angle is shown in Fig. 17. Studies have shown that hydrogen (12 lpm) and CSNL 20% biofuel (B20) fuel modes provide higher peak pressures at full load compared to conventional fossil diesel fuel operation. With diesel fuel, the maximum pressure in the cylinder was observed to be 55 bar, while with a mixture of hydrogen fuel and 12 lpm biofuel, the maximum pressure was observed to be 61 bar. The maximum hydrogen cylinder pressure is 4 ° C higher than the cylinder pressure of a single diesel fuel. Compared to hydrogen enhancement, due to its lower combustion rate, the increase in cylinder pressure is always less in the case of diesel operation.

4.1.8. Variation of combustion in-cylinder heat release rate with crank angle degree

The disparity of in cylinder heat-release rate for CSNL biofuel blend with hydrogen combustion with 8 to12 lpm hydrogen enhancement at full-load is illustrated in Fig. 18.

It is obvious that in cylinder heat release for hydrogen fuel with CSNL biofuel is more rapid than that of fossil diesel. It is examined that the highest heat release rate is found as 70 J/ (°CA) for 12 lpm hydrogen fortification compared to neat fossil diesel of 54 J/(°CA)[20].

This is by reason of the immediate combustion that takes place with hydrogen blended CSNL biofuel (B20CSNL + 12LPM H2). The premixed fuel be ablaze rapidly and liberates a massive extent of heat trailed by the well-ordered heat-release rate. The heat-release through the premixed combustion in the case of B20CSNL + 12LPM H2 is accountable for the maximum peak-pressure.

4.2. Experimental Characteristics Study of Ethanol + Hydrogen + CNSL + Diesel Blends

4.2.1. Brake Specific Fuel Consumption

The BTE upsurges through a rise in engine capacity as shown in Fig. 19. The BTE of 5% ethanol addition with biodiesel hydrogen blends increases, compared to other percentage of ethanol addition namely10% and 15%. Therefore, the variance in BTE among the diesel fuels and other blends are precise noteworthy by extreme capacity. The upsurge of BTE is owing to the enhancement of the incineration procedure in view of ethanol addition with fuels. The quicker incineration procedure with merged fuels and diesel through entire approaches might be a provider of the upsurge in BTE. Ethanol devours inferior stoichiometric air/fuel proportions compared to biodiesel and diesel-fuel, hence amalgamating further ethanol into biodiesel primes to thinner incineration.

4.2.2. Brake Thermal Efficiency

The BSFC was diminutions by an upsurge in engine capacity as shown in Fig. 20. Aimed at CNSL biodiesel-hydrogen plus ethanol mixtures, the BSFC is lower compared of diesel fuel and CNSL- hydrogen dual fuel. Per engine capacity, the BSFC declines by the percentage of ethanol in the merged fuel. Abridged BSFC remains institute by all ethanol mixtures exist owing to the quicker boiling degrees plus added heat discharge degree. The 10% ethanol addition reduced the BSFC, Compared to 5% and 15% ethanol addition. This is due to enhancement of combustion by ethanol at particular percentage with biodiesel and hydrogen blends.

4.2.3. Exhaust gas temperature

Figure 21 indicates the disparity of Exhaust Gas temperature against brake-power with hydrogen blended with CNSL and Diesel Blends.

Compared with pure diesel, CNSL discharge oil temperature is lower due to private combustion.

4.2.4. Emission of NOx

The NOx discharges are exposed in Fig. 22. The NOx discharges upsurge thru upsurge in the engine capacity. Related by the diesel and CNSL hydrogen, 10% ethanol addition blends, gives more NOx emissions. Additionally, by upsurge of ethanol in the CNSL hydrogen mixtures, the NOx releases diminution at squat engine heaps, although at intermediate engine heaps, nearby is no noteworthy variance amongst the ethanol mixtures. Consequently the key features disturbing NOx creation are incineration temperature, confined oxygen deliberation and residence period in the great temperature sector.

Perceptibly, by biodiesel and ethanol, the incineration temperature along with the oxygen substances might be greater, foremost to the advanced NOx productions. However, ethanol can reduce the cetane content in the fusion fuel, which means a longer take-off delay and more fuel is burned in a premixed manner, thereby releasing NOx earlier. The high-grade oxygen-containing substances in ethanol will correspondingly increase the release of NOx.

4.2.5. Emission of HydroCarbon

Figure 23 displays the difference of HC discharges. Alike to the CO discharges, through an upsurge in the engine capacity, the HC releases also increase.

Related through diesel plus CNSL hydrogen blends, the ethanol mixtures provide inferior HC releases. The HC discharges of 10% ethanol addition gives the maximum reduction of HC compared to 5% and 8% ethanol addition. It is specially designed for adding 10% ethanol. A small amount of ethanol can increase the oxygen content, reduce the viscosity and density of the molten fuel, highlight the improvement of pulverization and atomization, and improve the incineration, thereby reducing CO and HC emissions. Whereas for 15% ethanol addition, the chilling outcome of ethanol might decrease the in-cylinder gas temperature, foremost to inferior oxidation response degree and therefore upsurge in CO and HC releases at squat engine heaps.

4.2.6. Emission of CO

The CO discharges are shown in Fig. 24. As seen in the figure, the discharges rise with upsurge of engine capacity, owing to opulent fuel air assortment. Related thru the diesel fuel and CNSL hydrogen blends, the CO emissions for ethanol blends remain inferior, as of the lower evaporation temperature of the ethanol which might advance the incineration procedure.

This is owing to quicker incineration procedure in all means, which might subsidize to the decrease of CO release. For 8% ethanol addition, the CO discharge is inferior to that of 5% and 10% ethanol addition. The greater the percentage of ethanol in the merged fuel is, the advanced the CO releases.

4.2.7. Variation of combustion in-cylinder pressure with crank angle degree

The peak cylinder pressure deviations in combustion cycles were assessed each 0.1°CA. subsequent to the stabilization of the engine at 100% load, the 120 successive cycles were marked out and their middling values were noted. Figure 25 point out the deviations of cylinder pressure during combustion for CSNL biofuel blend + Hydrogen with different proportions of ethanol. B20CSNL + 12LPM H2 resulted in lower peak pressure of 35.56 bar at full load when compared with B20CSNL + 4LPM H2 and B20CSNL + 8LPM H2 fuel blends. Simultaneously fossil diesel fuel had the peak pressure of 59.24 bar.

The difference between B20CSNL + 12LPM H2 and B20CSNL + 4LPM H2 cracked biofuels peak pressure has an increasing trend.

With the intention of make clear these trend, the heat release rates of test engine fuelled with CSNL biofuel blend + Hydrogen were analyzed. The higher peak pressure rates were found in the cases of B20CSNL + 4LPM H2 when compared with CSNL biofuel blend + Hydrogen cases. Diesel engine combustion is carried out in three uninterrupted stages: premixed combustion, diffusion combustion and post-combustion. After the injection begins, the fuel droplets are mixed with air, and the mixing stage is controlled by the turbulence and viscosity of the fuel.

4.2.8. Variation of combustion in-cylinder heat release rate with crank angle degree

Highly volatile fuels have the ability to mix well with air, and high viscosity fuels tend to produce large droplets, resulting in a lean air-fuel mixture, as shown in Fig. 26. During the stroke of compression, the air-fuel mixture reaches the self-ignition condition and is obtained by combustion, the premixed fuel will burn abruptly due to the large amount of oxygen and the large contact surface between the fuel and the air droplets. Generally, the premixed combustion phase ends before the end of the fuel injection; therefore, the fuel injected by the injector will burn off due to diffusion.

At the end of the fuel injection, the fuel continues its combustion by the late combustion stage. The mixture of biofuels CSNL + hydrogen leads to the beginning of the above combustion. However, during the period of ignition delay, the result of high viscosity and low volatility. Biofuel fueling Aviation Fuel Mix of Biofuible Biofuel CSNL. The higher heat release rate was found in the case of cracked B20CSNL + 8LPM H2 biofuel blend as 73 kJ/°CA followed by diesel value 54.21 kJ/°CA.

5. Conclusion

In the current research work, the mixture of cashew nut shell liquid biodiesel (CNSL), hydrogen and ethanol (BHE) is still being validated in single-cylinder direct injection diesel engines to check engine performance and emission characteristics. Ethanol is maintained at 5%, 10%, and 15% supplements through the improved CNSL and hydrogen functional dual-fuel engine accordingly. During the experiment, pollutant emissions such as fuel consumption rate (SFC), hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NOx), and cylinder pressure were measured. The experimental results showed the following observations.

- An average reduction of 4% in BTE was observed in 100% walnut shell oil biodiesel. The viscosity, density and certain amount of cashew nut shell liquid biofuel play a vital role in the performance of the engine.
- Compared to diesel, an average increase of 0.26% in CO emissions and 102 ppm of HC was observed in 100 tallow shell oil biofuels, and an average reduction of CO emissions and 56 ppm was observed. 0.16% HC in 20% blended fuels.
- By adding 20% to 100% walnut shell oil biofuel, NOx emissions were reduced by 3.57–18.06%. Diesel fuel exhibits moderate levels of NOx emissions. It has been observed that for lower NOx emissions, higher viscosity and density are the most ideal characteristics of biodiesel.
- Lower in-cylinder pressure and lower heat release rate was found in all the biofuel cases.
- The Brake thermal efficiency of the hydrogen and biodiesel fuel procedure stood rather greater compared to the diesel fuel procedure. In 8 lpm hydrogen stream proportion, the brake thermal

competence is augmented.

- Brake Specific fuel consumption diminutions through upsurge in hydrogen proportion above the complete sort of exercise.
- NOx release augmented over 8lpm of hydrogen stream point, associated to B20 and diesel procedure.
- The carbon monoxide discharge augmented in full capacity state. The deepest CO release stayed attained through 8lpm hydrogen accumulation, related to diesel and B20 fuels.
- The HC discharge for 8lpm flow rate of hydrogen decreased associated near diesel at full capacity. The exhaust gas temperature augmented in lieu of 8lpm adding hydrogen stream charges commonly associated to diesel at complete capacity.

For the most part the aforementioned stood resolved that hydrogen enhanced biodiesel engines accomplish thriving and release fewer effluence associated to well-ordered diesel fuel. Henceforth, hydrogen enhancement in a CI engine can be observed equally an eco-friendly substitute fuel to diesel. The performance and emissions of a diesel engine operating on CNSL hydrogen blends and ethanol blends are investigated and compared with neat diesel fuel. Based on the experimental results, the conclusions can be summarized as follows.

- The BSFC decreases with an increase in ethanol addition with CNSL hydrogen blends.
- The brake thermal efficiency increases with an increase in ethanol percentage with CNSL hydrogen blends.
- The HC and CO emissions are decrease with increasing the blend ratio of ethanol with CNSL hydrogen blends.
- The exhaust gas temperature and NOx emissions are increased with increasing the ethanol blends ratio.
- On the whole the ethanol blends give lower HC, CO and BSFC. But the NOx emissions are higher for ethanol addition, compared with the neat diesel fuel. But the addition of more ethanol with CNSL hydrogen blends has no significant improvement in the emission levels.

The following scopes are proposed as future work for the investigations on the utilization of CNSL and Hydrogen with Diesel Blends and Ethanol. Pyrolysis CNSl may be preheated and can be used for increasing engine combustion efficiency. The cetane improver should be optimize to get the low viscosity biofuel. Apart from ethanol, other alcohol fuels can be used to enhance the combustion and use of optimizing software for optimizing the blends.

Declarations

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Tables

Table 1 Properties of TC-CNSL

Properties	Measurement standards	Diesel	TC-CNSL (cardanol)	(TC-CNSL)
Density at 25°C (g/cc)	ASTM D1298	0.8/0.84	0.9326	0.821
Flash point (°C)	ASTM D 93	80	198	<28
Calculated cetane index	ASTM D 976	52	28	45
Boiling point (°C)	ASTM D1160	180- 340	225	180-380
Kinematic viscosity at 30 °C (cP)	ASTM D 445	2.0 to 4.5	17.2	4.43
Calorific value (kJ/kg)	ASTM D 240	44000	39600	41780

Table 2 Properties of Hydrogen Gas

Property	Hydrogen
Formula	H_2
Density at 1 atm and 300 K(kg/m^3)	0.082
Stoichiometric air fuel ratio (kg/kg)	34.3
Higher Heating Value (MJ/kg)	141.7
Lower Heating Value (MJ/kg)	119.7
Kinematic viscosity at 300 K(mm^2/s)	110
Thermal conductivity at 300 K (W/mK)	182.0
Diffusion coefficient into air at NTP (cm /s)	0.61
Specific gravity	0.091
Boiling point(K)	20.27
Cetane number	-
Molecular weight(g/mole)	2.015

Table 3 Stipulations of Engine

Style	Single-cylinder, vertical, water Cooled, 4-stroke diesel engine
Bore	80 mm
Stroke	110 mm
Compression ratio	17.5:1
Displacement volume	550CC
Supreme power	3.7 kW
Speediness	1500 rpm
Injection-timing	23°C before TDC

Table 4 List of uncertainty for different

Measurement (%)	uncertainty
Load	±0.2
speed	±0.1
Time	±0.2
Manometer	±1
CO	±0.2
HC	±0.1
NO_x	±0.2
Smoke	±1
Pressure pickup	±0.1
Crank angle encoder	±0.2

Table 5 Properties of Ethanol

Property	Value	Unit
Acidity (pKa1)	15.9	
Boiling Point	351.39	K
Density (gas) at 0.08 bar	3.15	mol/m^3
Density (liquid)	17046	mol/m^3
Flash point	286	K
Specific-heat capacity, Cp (isobaric) (gas)	74	J/mol K
Specific-heat capacity, Cp (liquid)	118	J/mol K
Specific-heat capacity, Cv (isochoric) (gas)	65	J/mol K
Specific-heat capacity, Cv (liquid)	100	J/mol K
Heat(enthalpy) of combustion (gas)	1336.8	kJ/mol
Heat(enthalpy) of formation (gas)	-234	kJ/mol
Heat(enthalpy) of fusion at -173°F/-114°C	4.9	kJ/mol
Heat(enthalpy) of evaporation	42.32	kJ/mol
Melting point	159.01	K
Molecular Weight	46.069	g/mol
Thermal Conductivity	0.167	W/m K
Viscosity, dynamic (absolute)	1.074	cP

Figures

Figure 1

Distilled Technical Thermal-Cracked

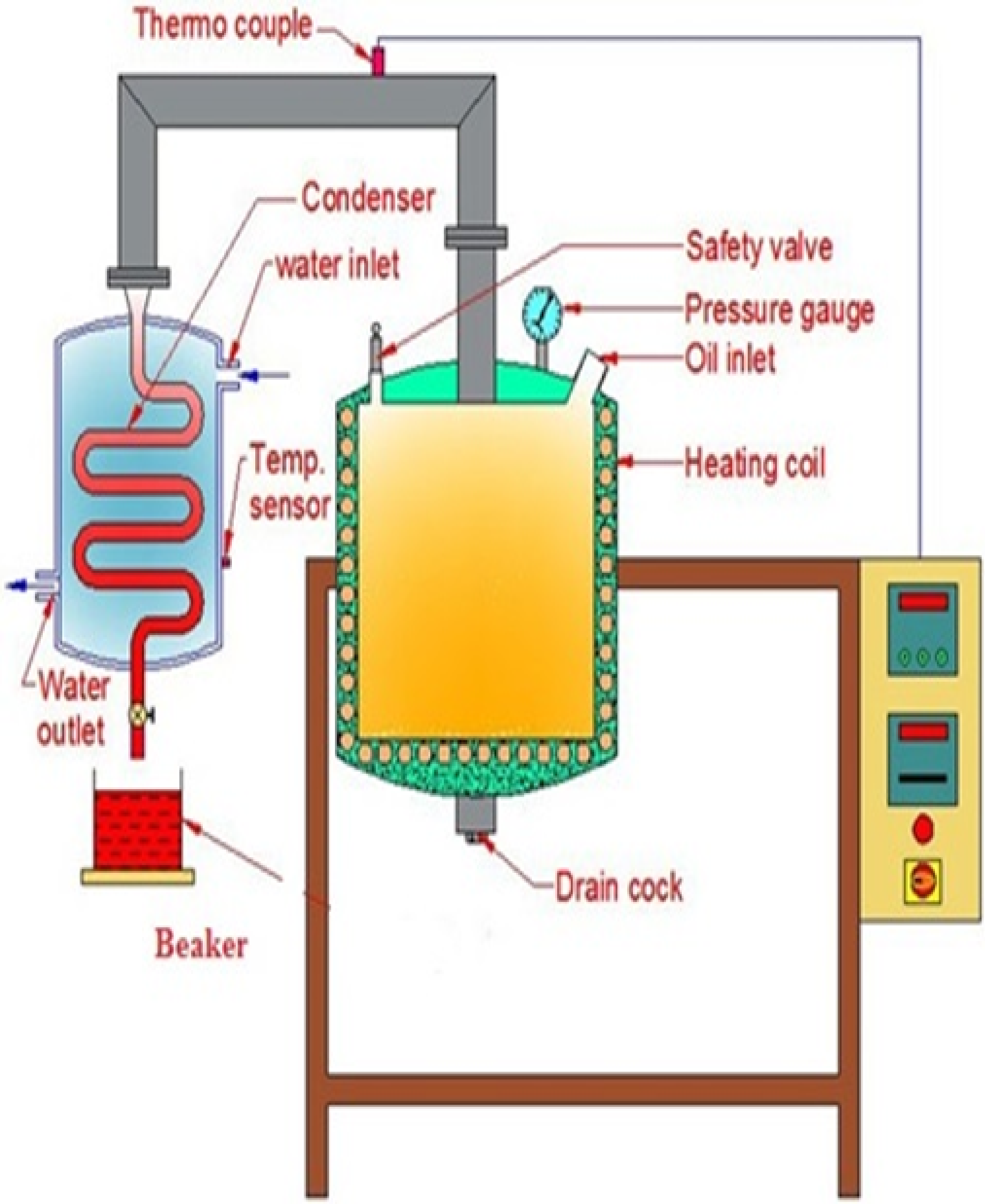

Figure 2

Schematic view of Thermal cracking reactor

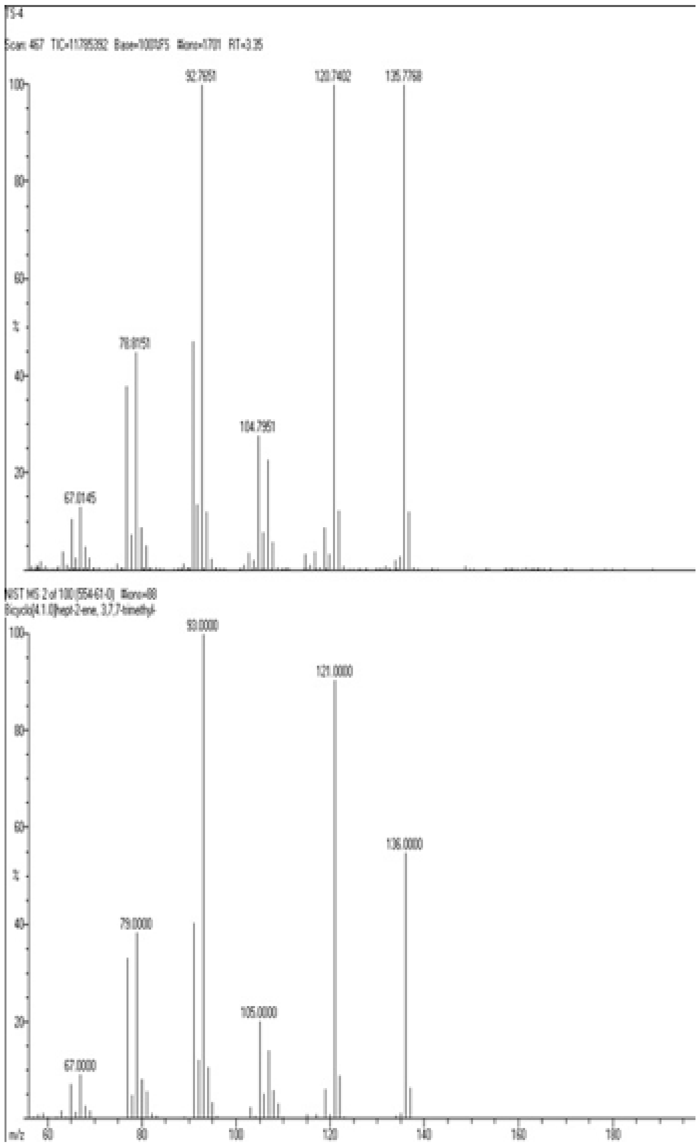

Figure 3

GC spectrum of CSNL biofuel (B100)

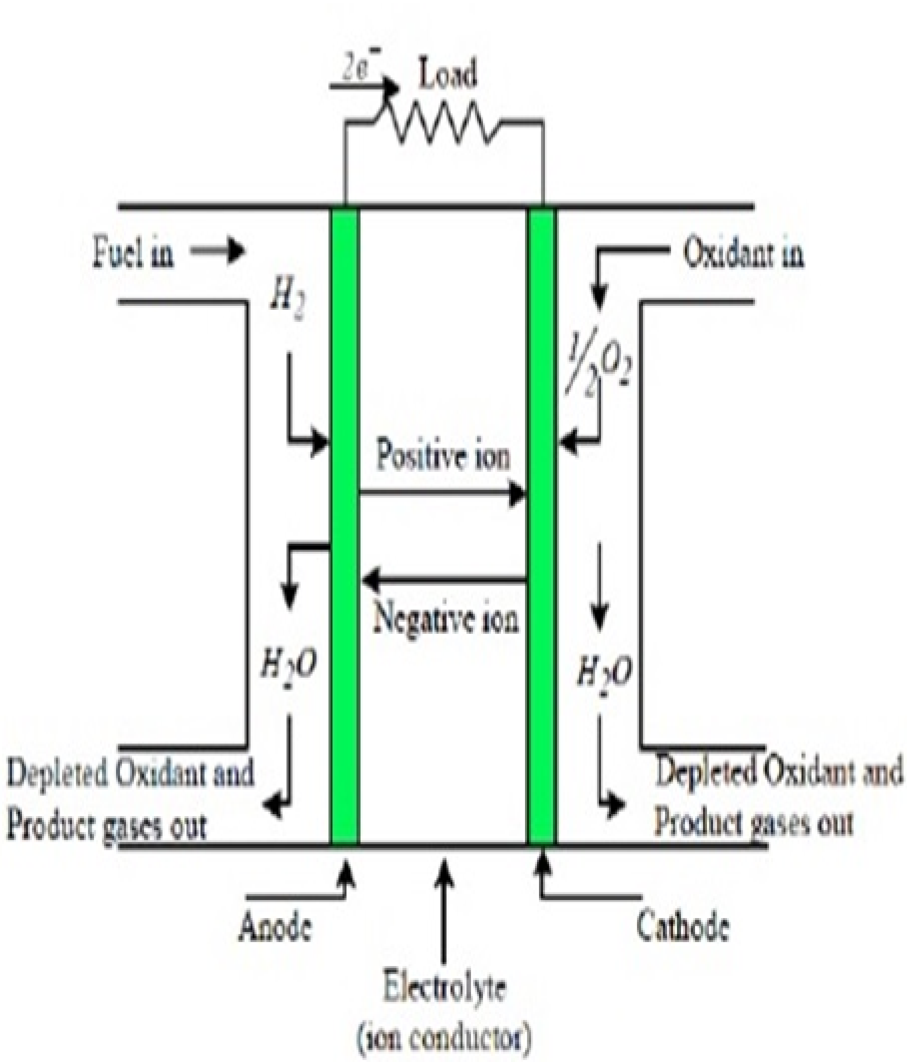

Figure 4

Hydrogen production process in fuel cell

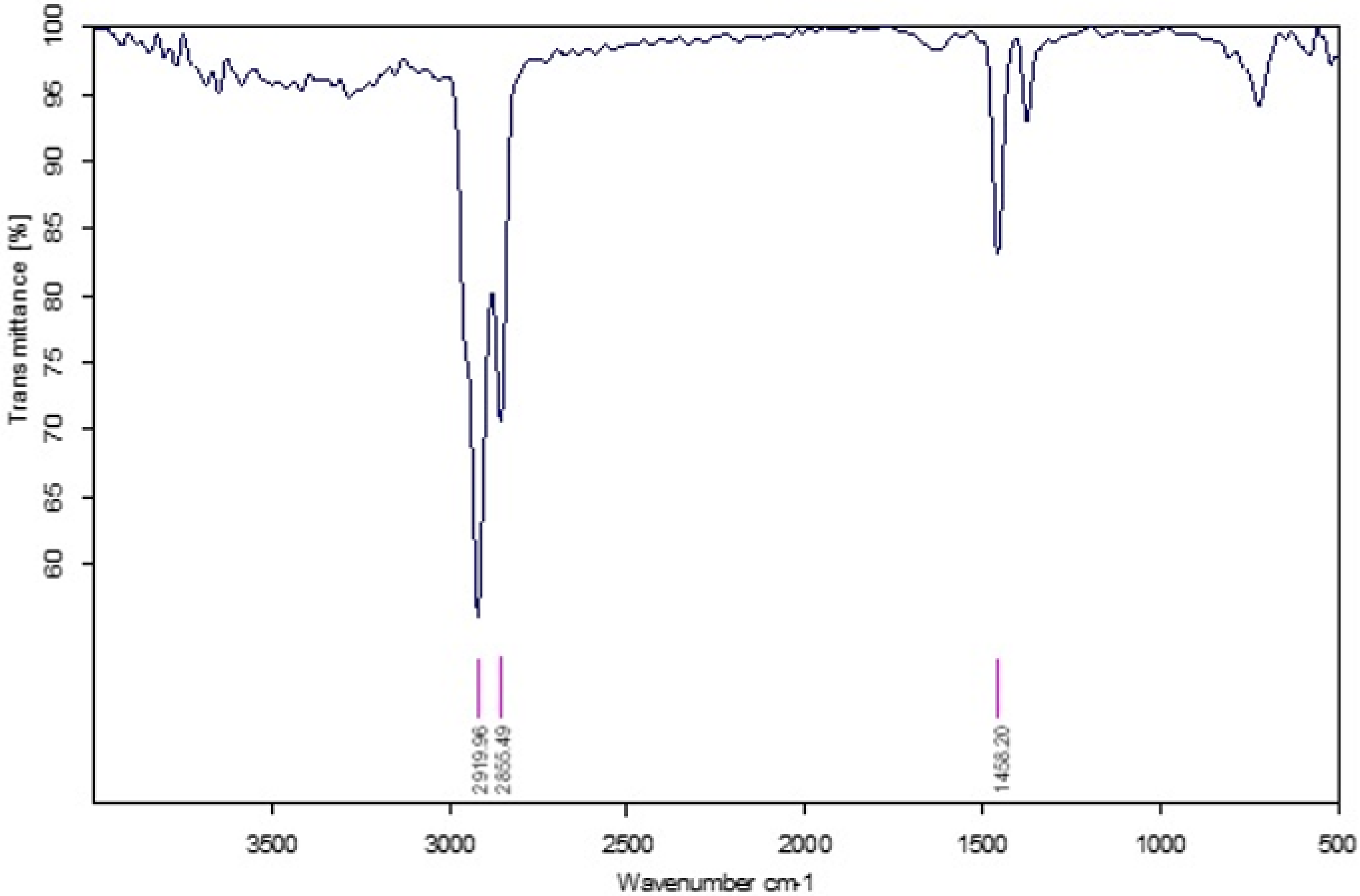

Figure 5

FTIR spectrum image of diesel fuel

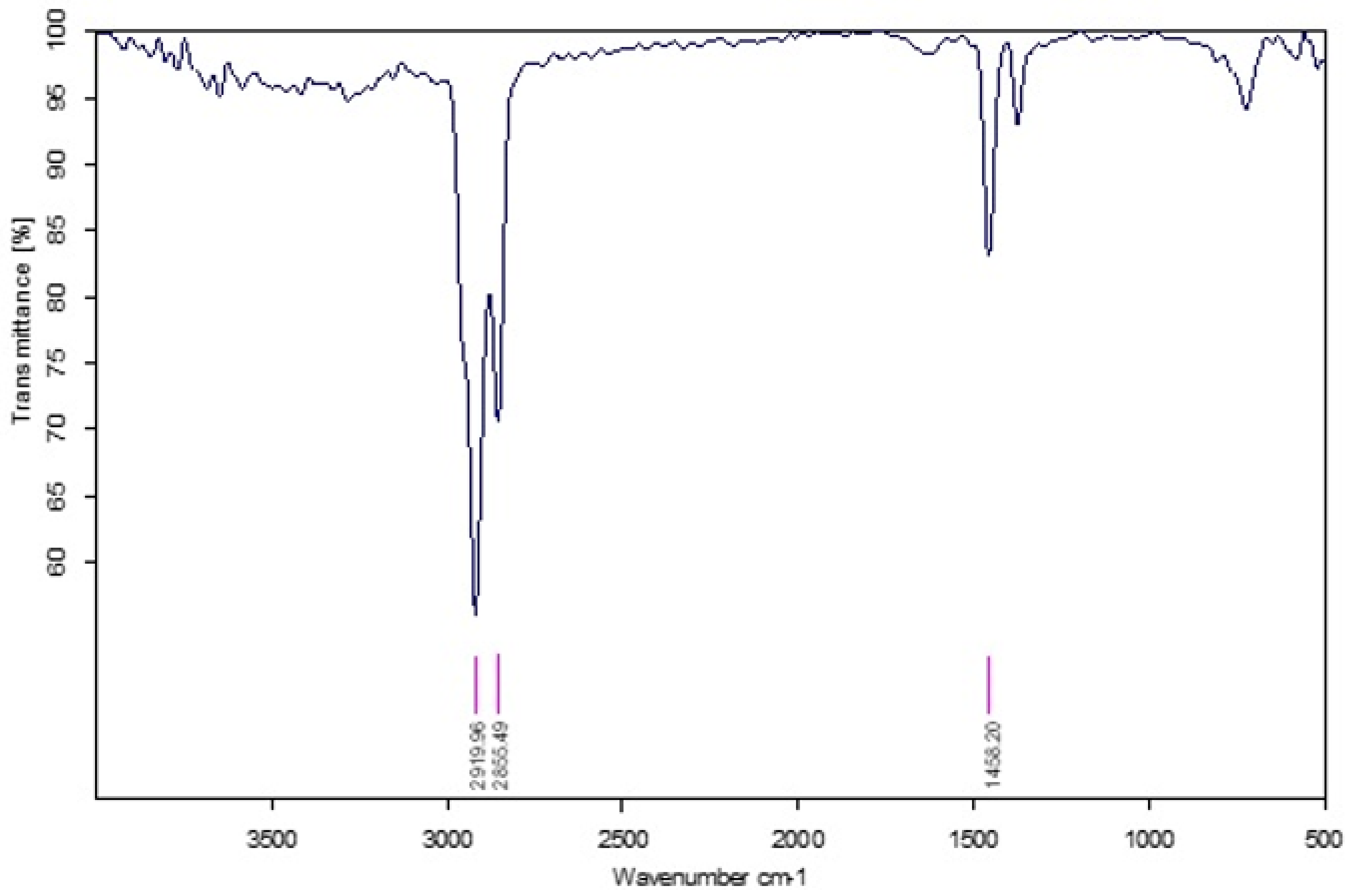

Figure 6

FTIR spectrum image of diesel fuel

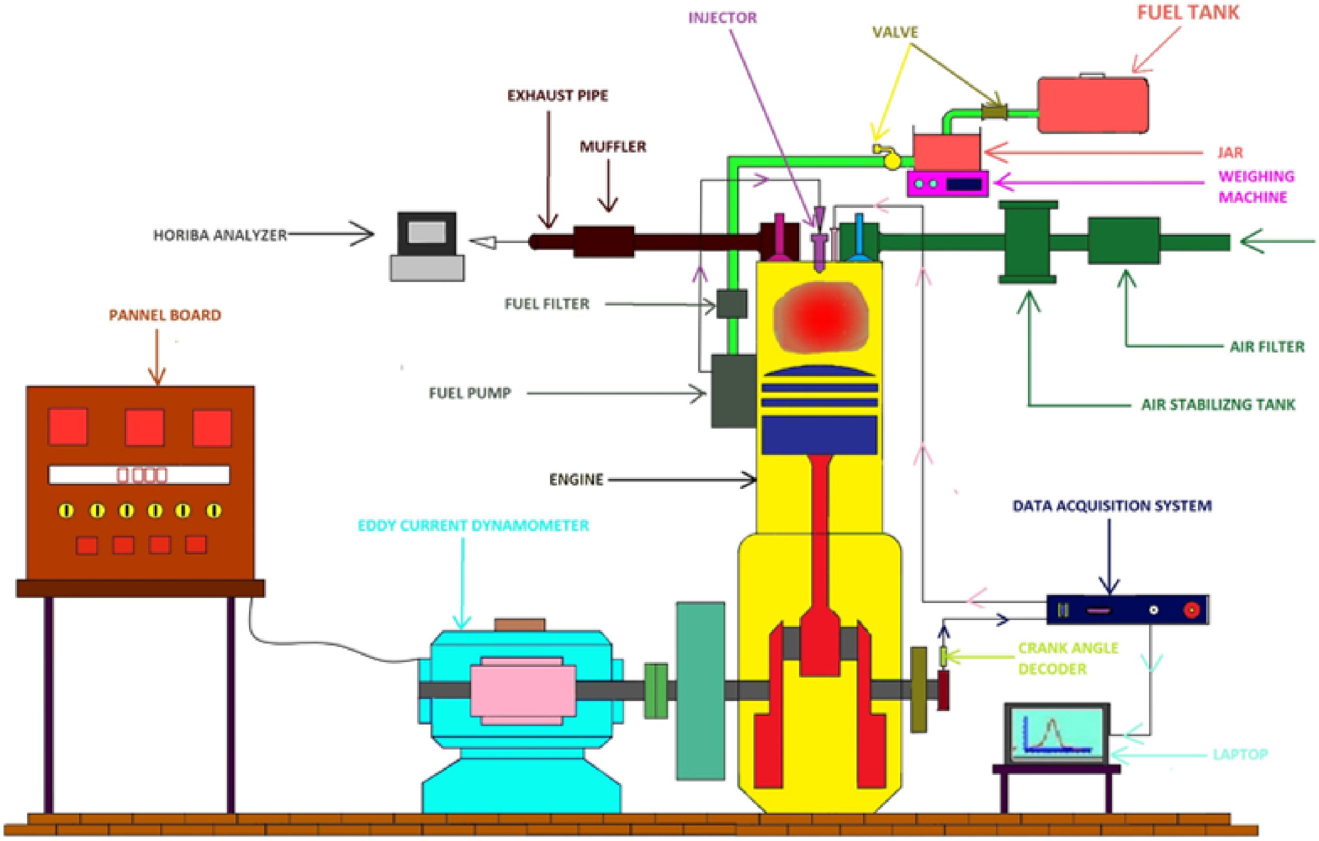

Figure 7

Schematic view of experimental setup

Figure 8

Photographic view of experimental setup

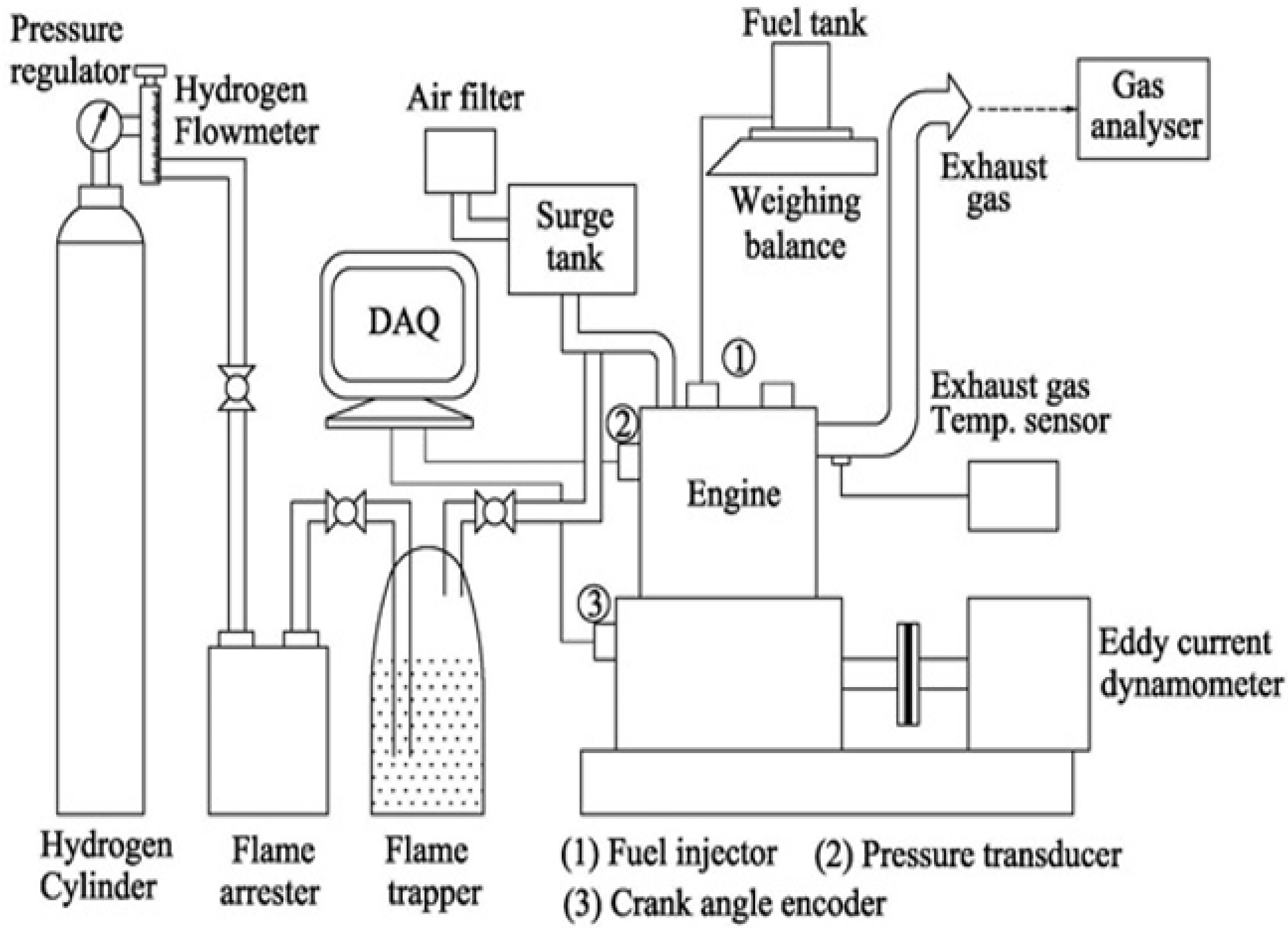

Figure 9

Schematic hydrogen flow line experimental setup

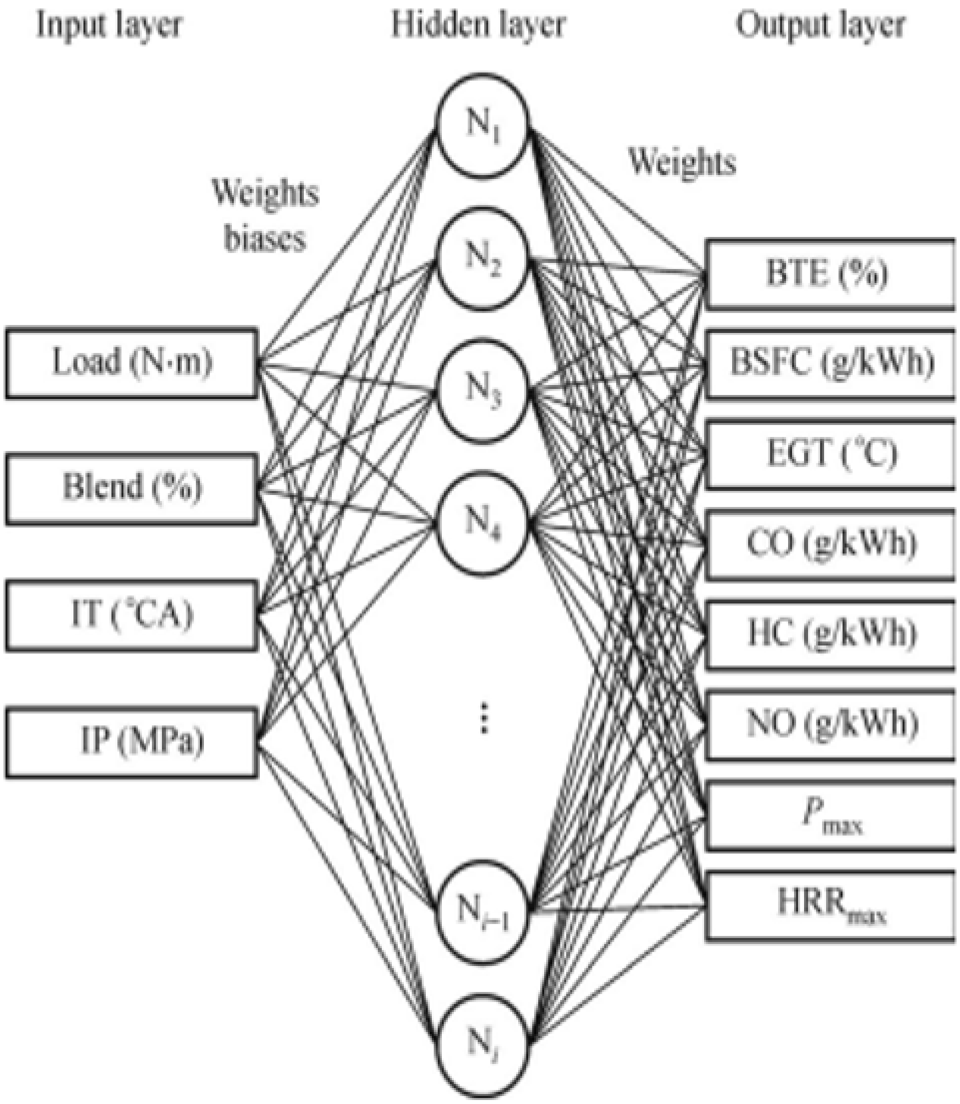

Figure 10

Prediction Layers with ANN

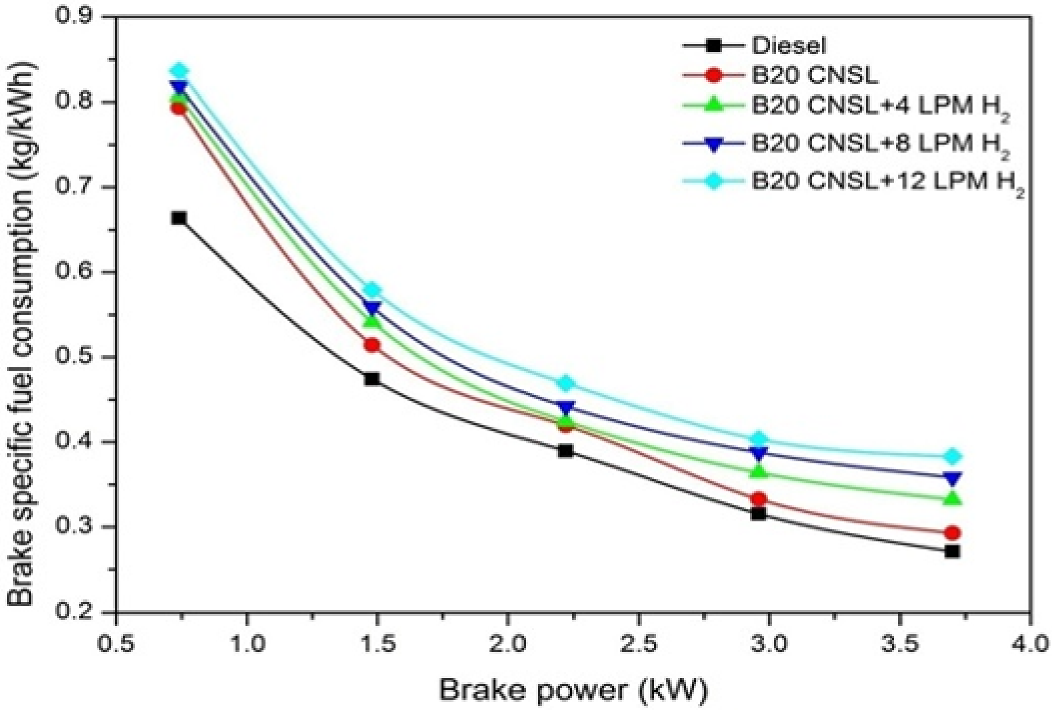

Figure 11

BFSC against brake power with CSNL fuel + Hydrogen

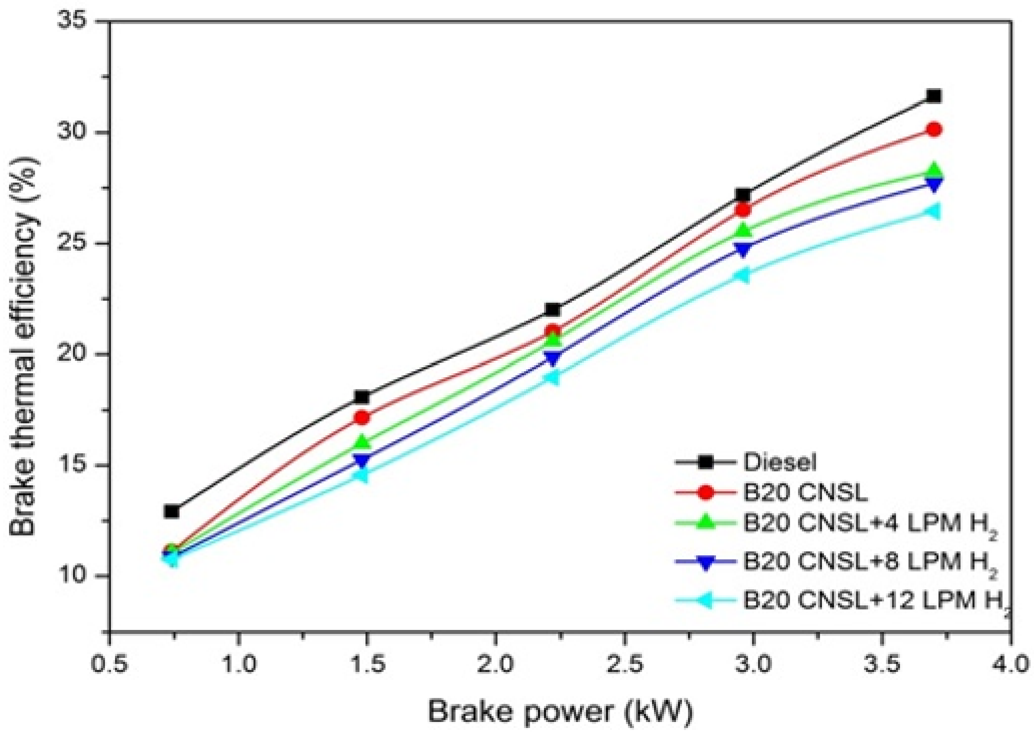

Figure 12

BTE against brake power with CSNL fuel + Hydrogen

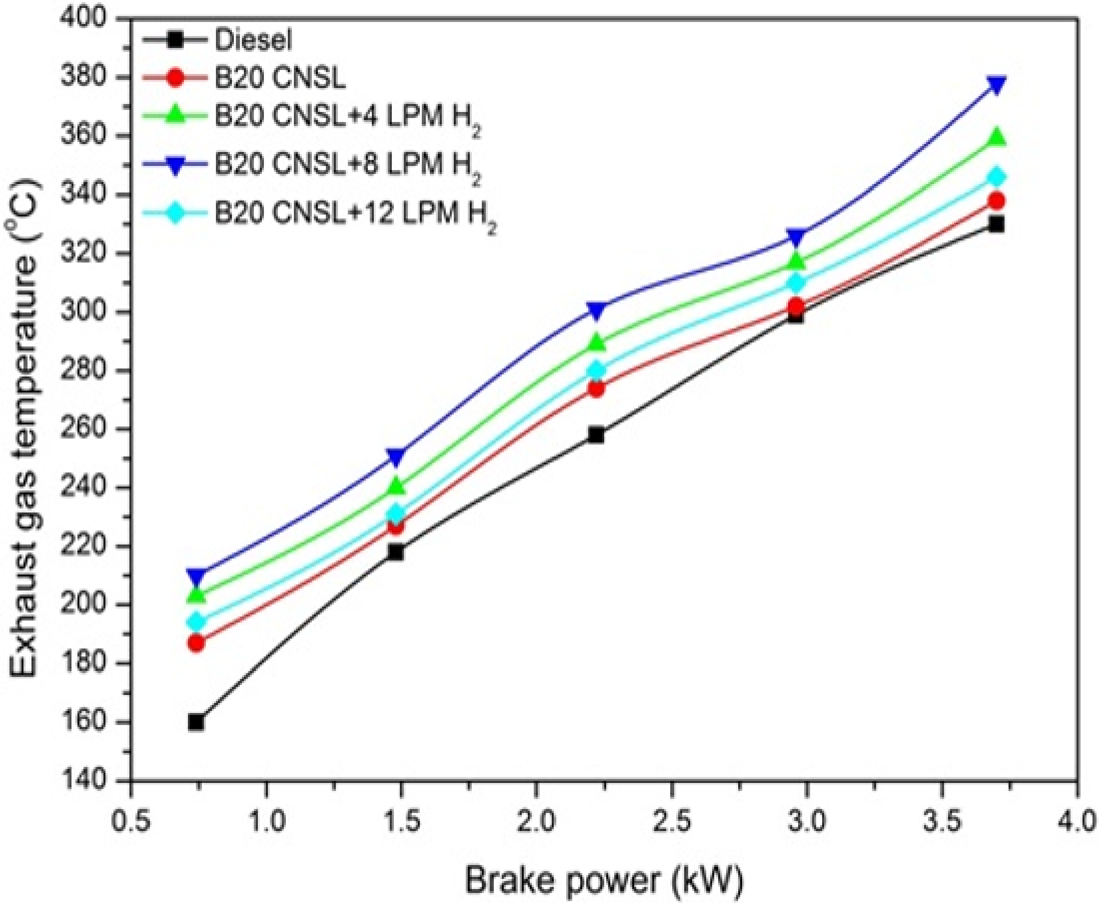

Figure 13

EGT against brake power with CSNL fuel + Hydrogen

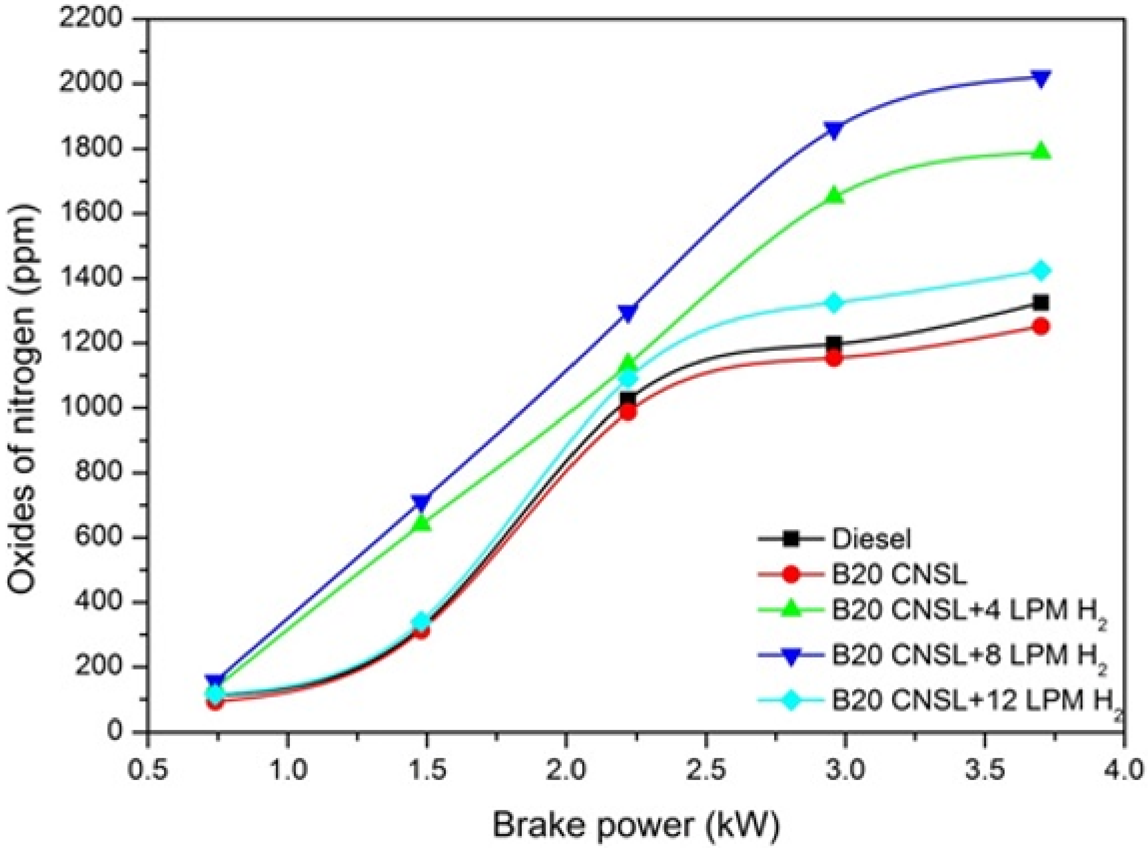

Figure 14

NOx emission against brake power with CSNL fuel + Hydrogen

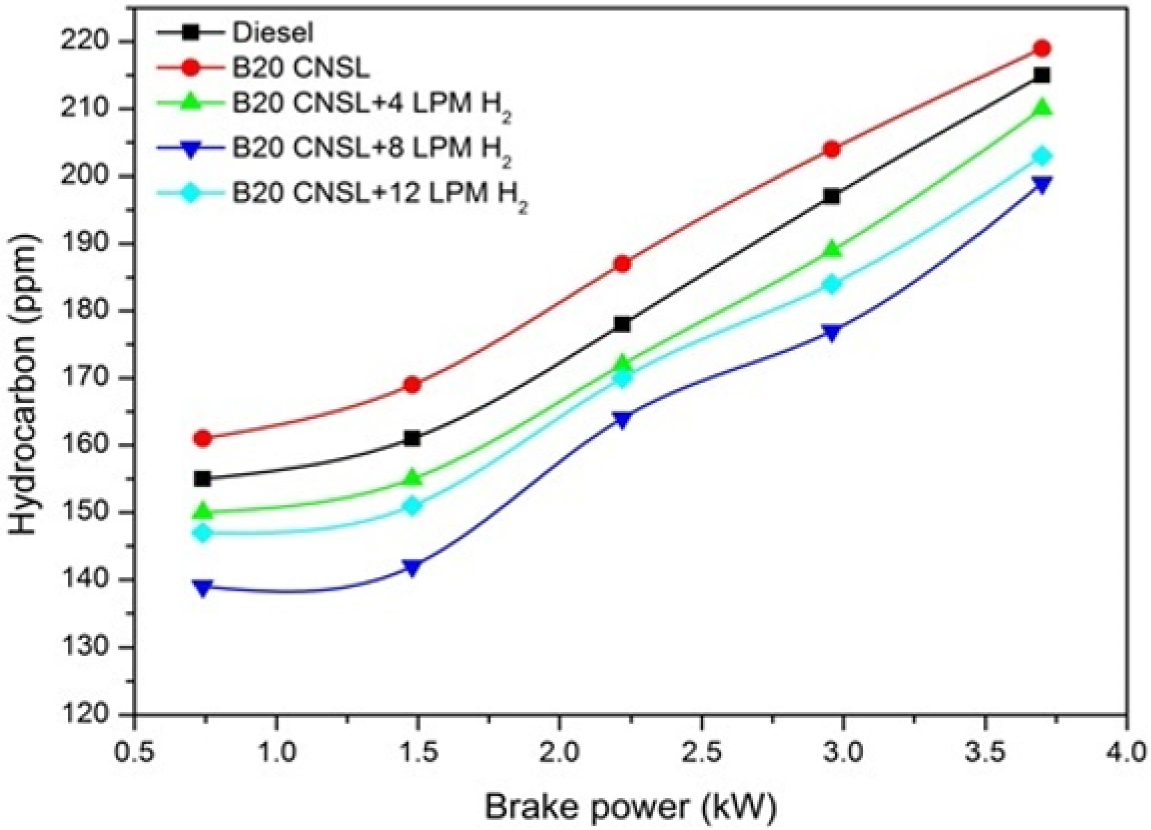

Figure 15

HC emission against brake power with CSNL fuel + Hydrogen

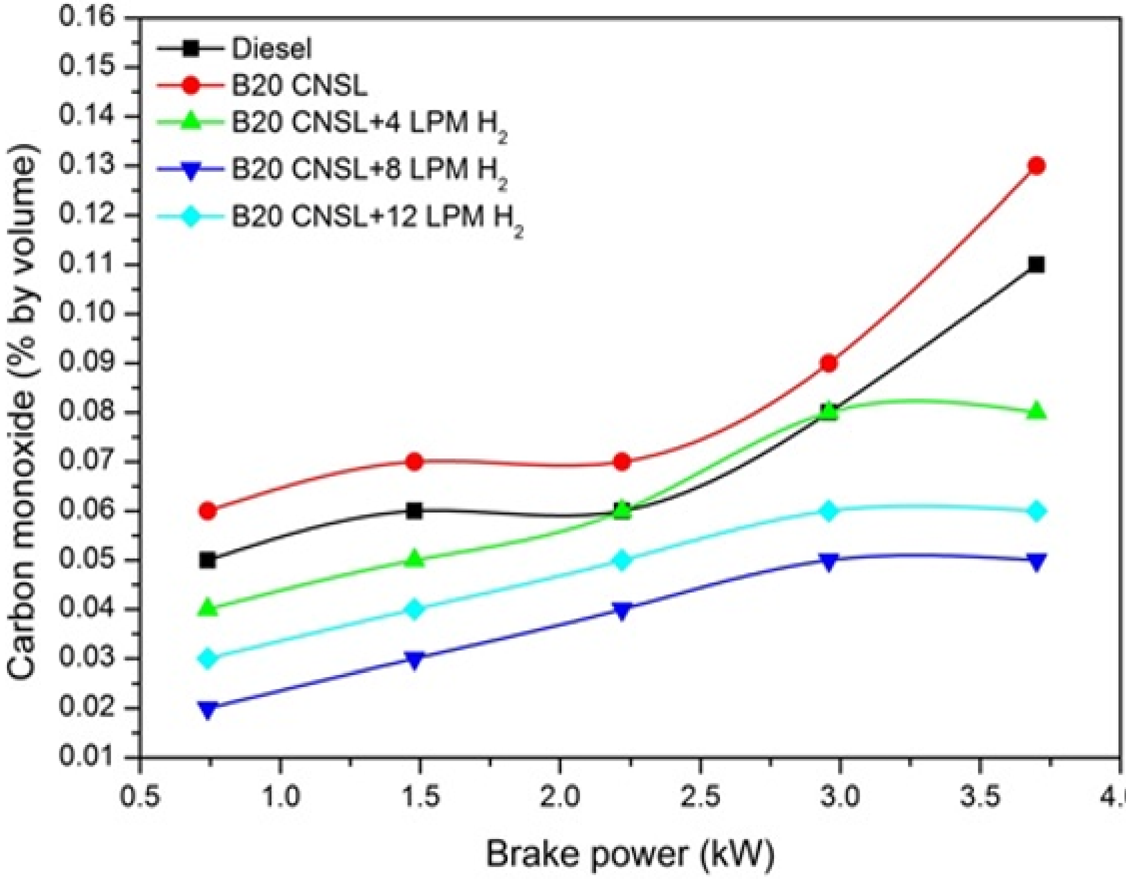

Figure 16

CO emission against brake power with CSNL fuel + Hydrogen

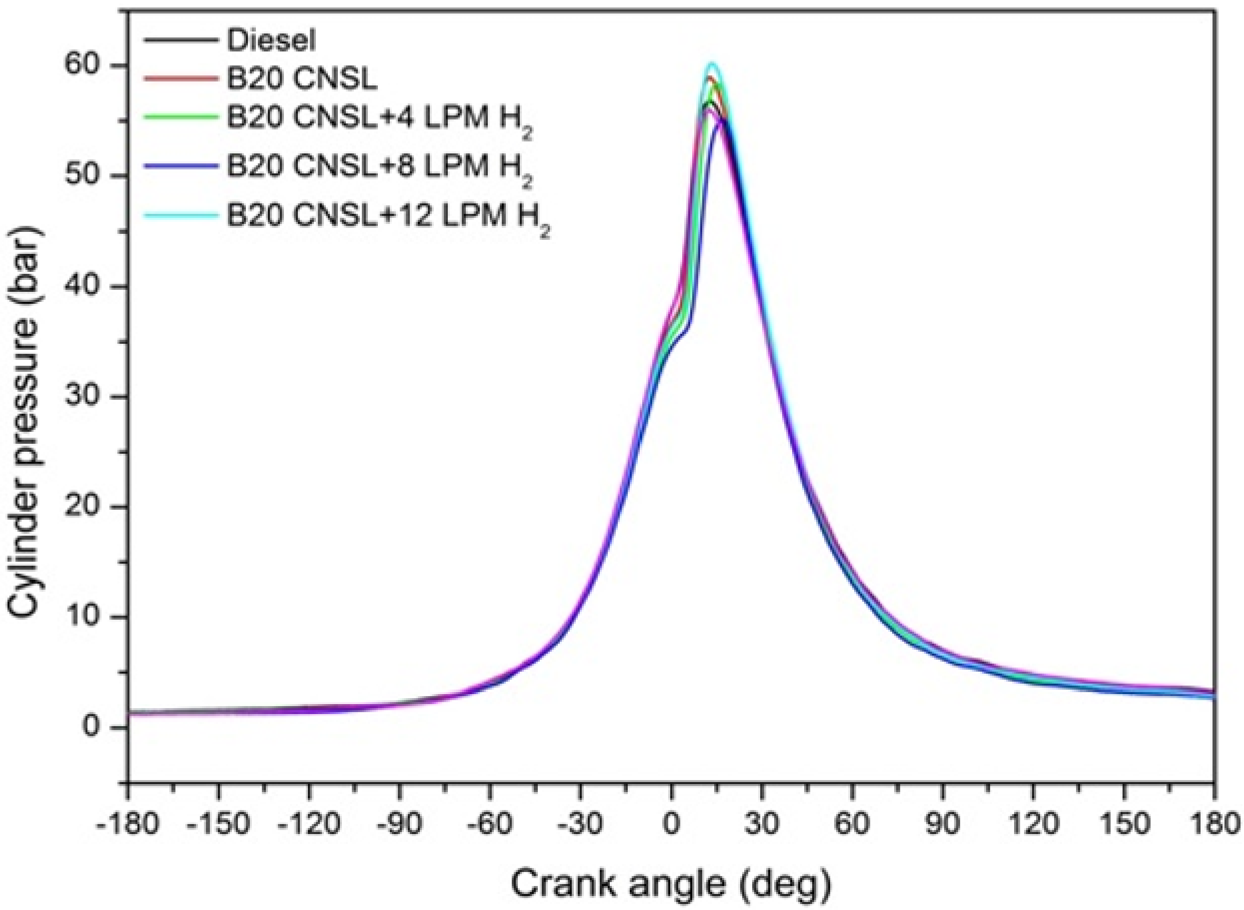

Figure 17

In-cylinder pressure against crank angle with CSNL fuel + Hydrogen

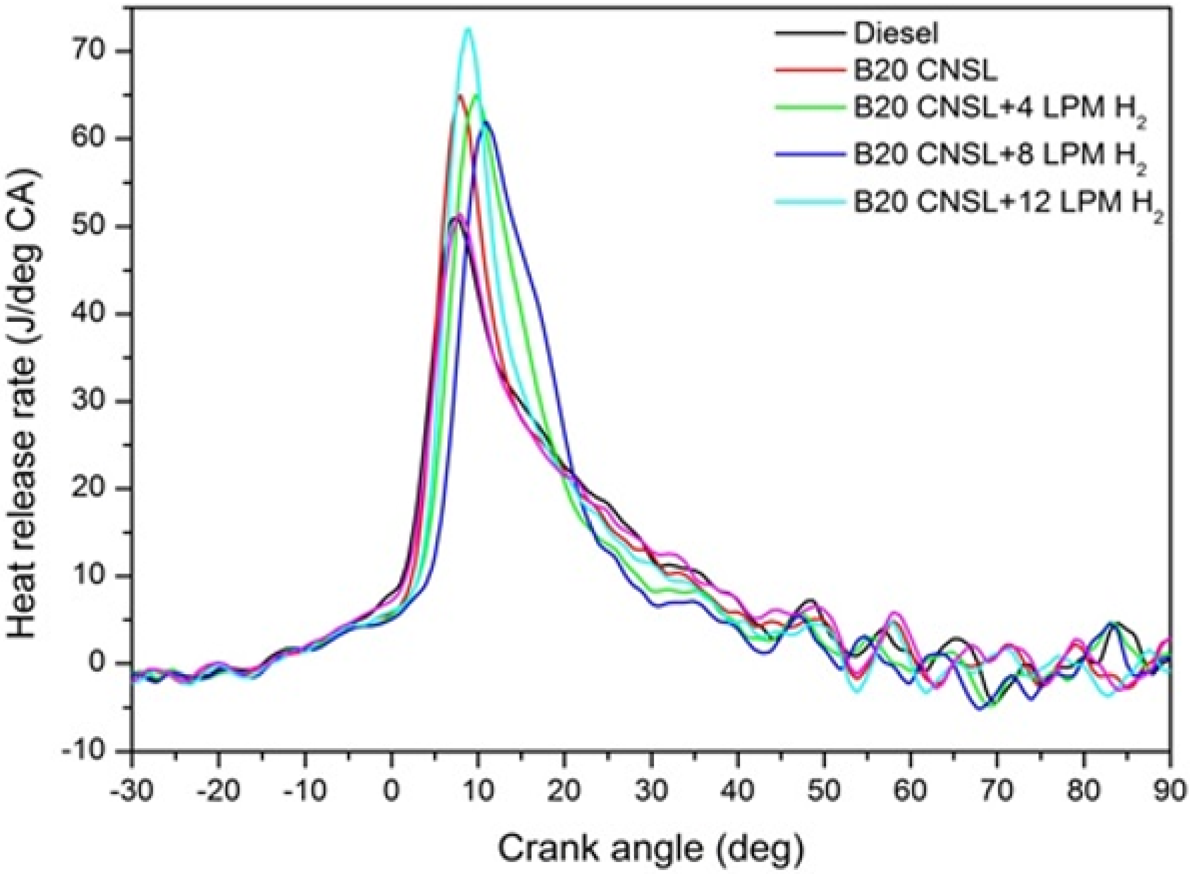

Figure 18

Heat release rate against crank angle with CSNL fuel + Hydrogen

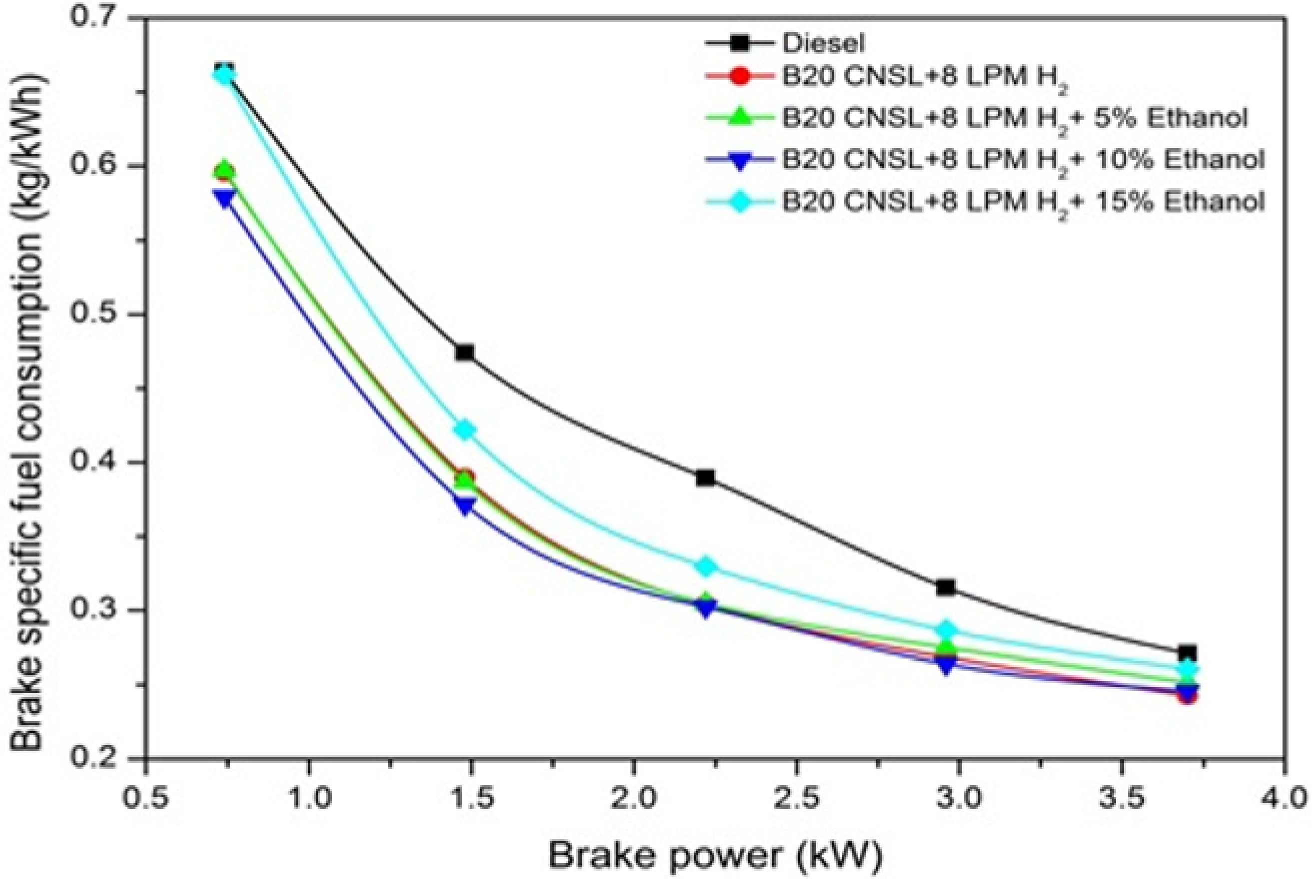

Figure 19

BFSC against brake power with CSNL fuel + Hydrogen+ Ethanol fuels

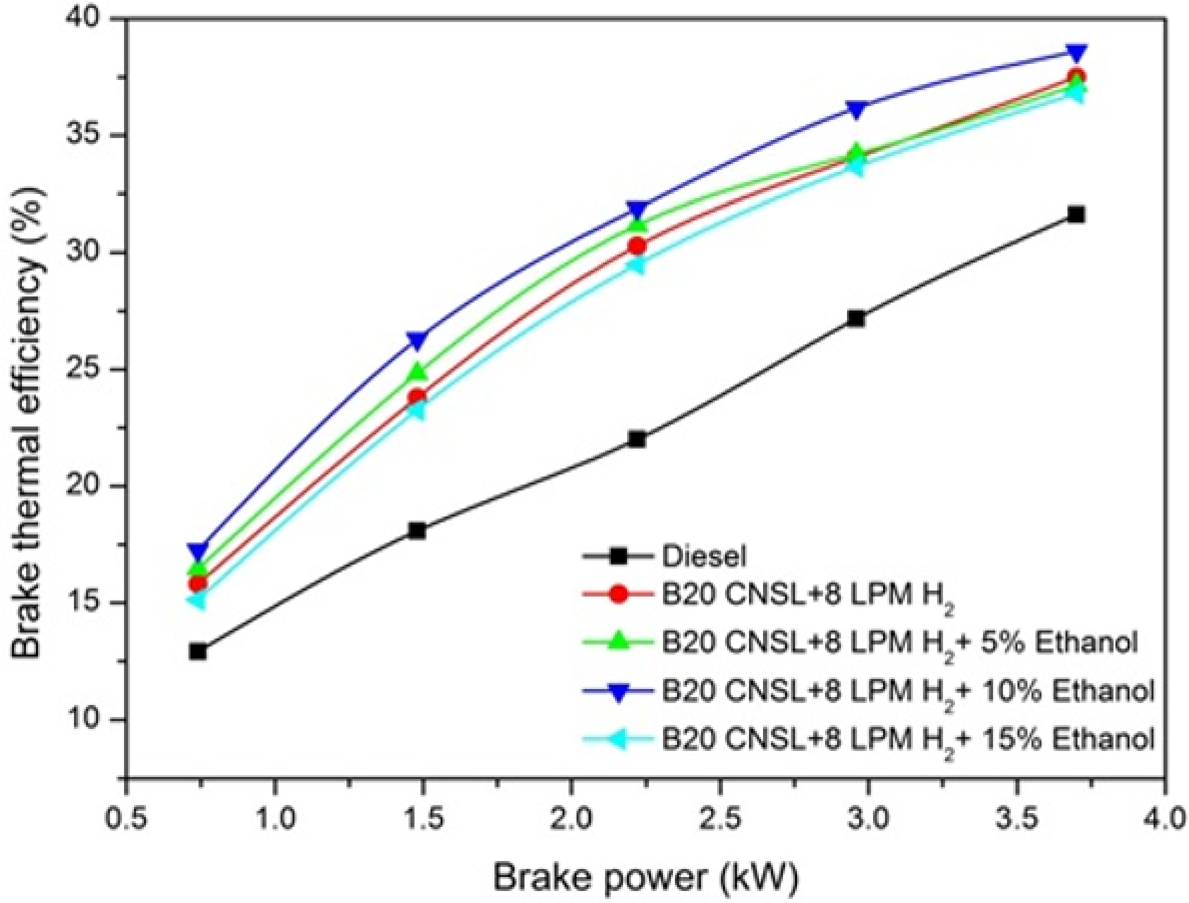

Figure 20

BTE against brake power with CSNL fuel + Hydrogen+ Ethanol fuels

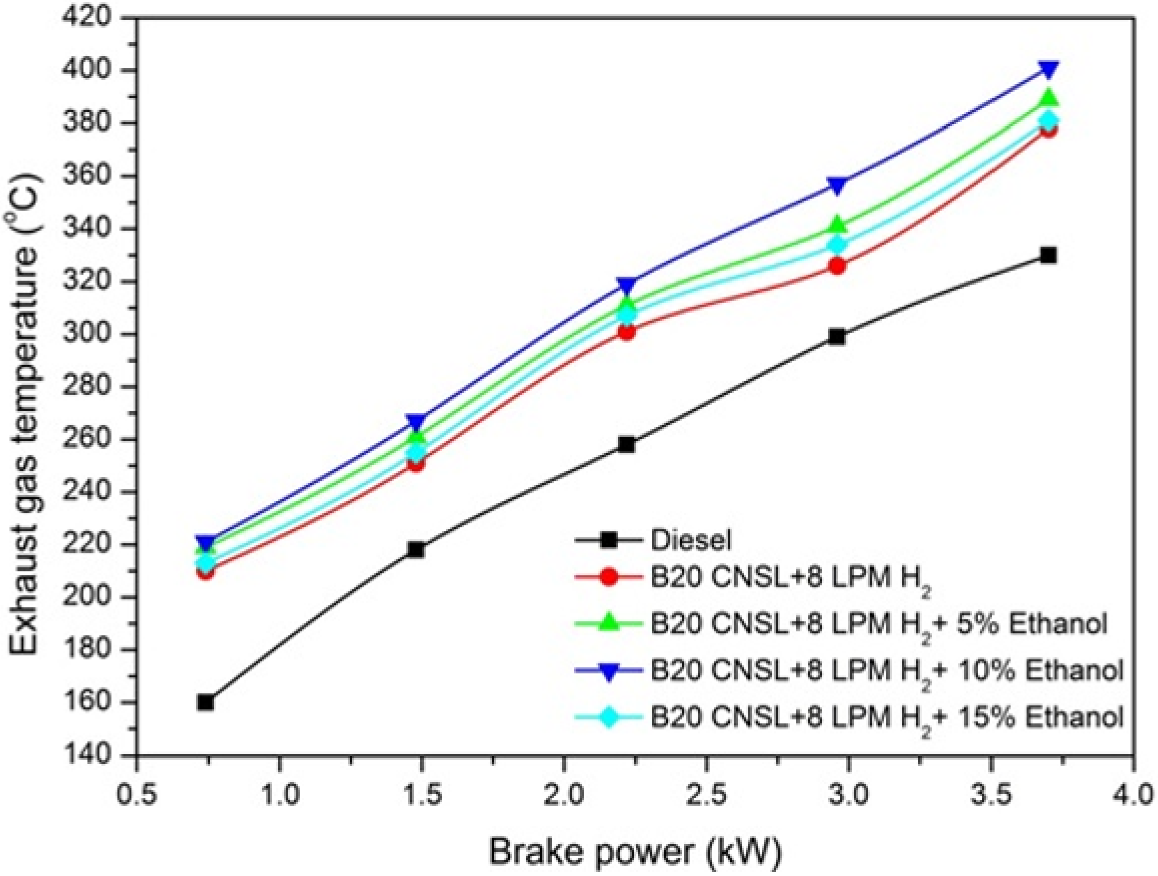

Figure 21

BTE against brake power with CSNL fuel + Hydrogen+ Ethanol fuels

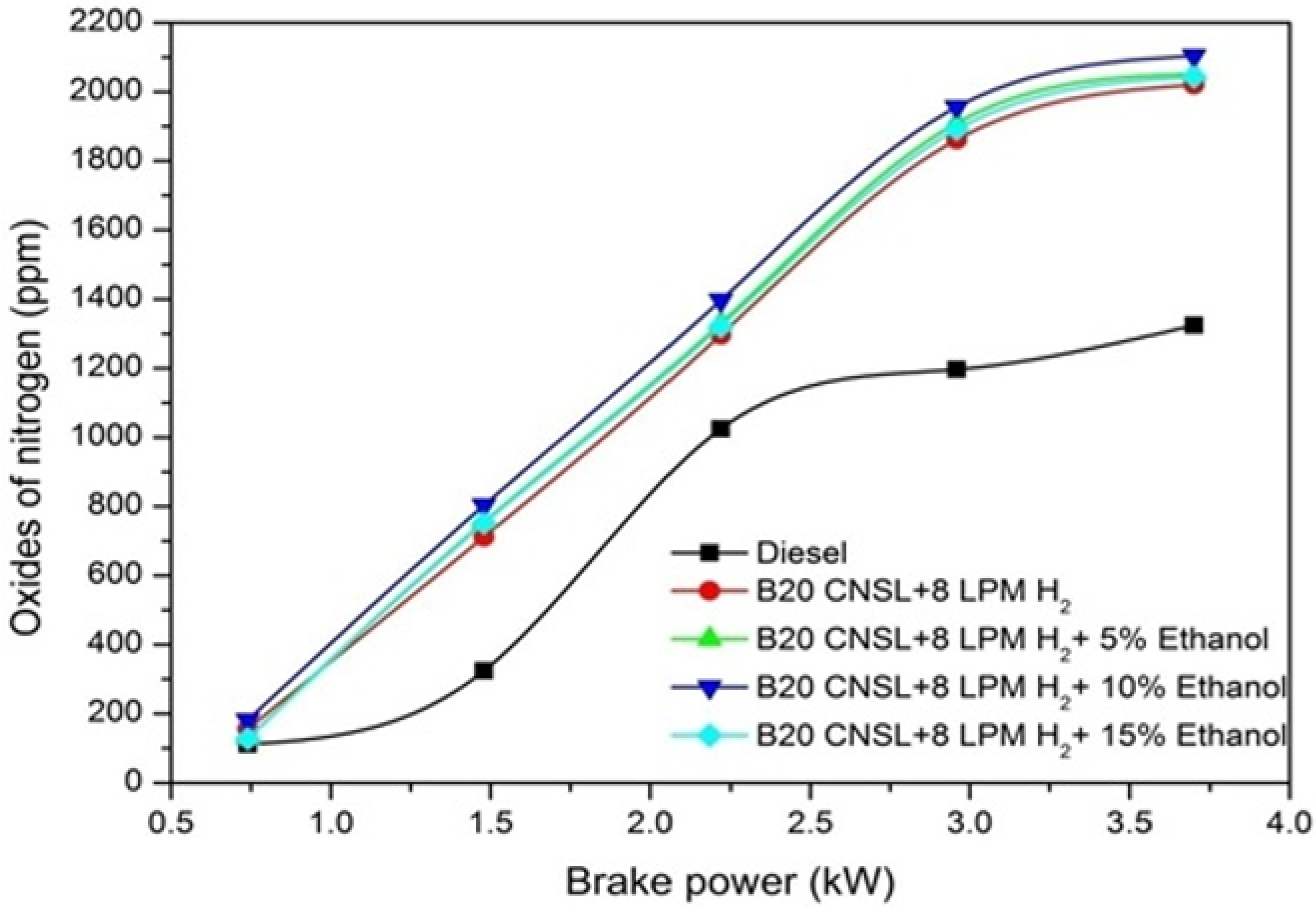

Figure 22

NOx emission against brake power with CSNL fuel + Hydrogen+ Ethanol fuels

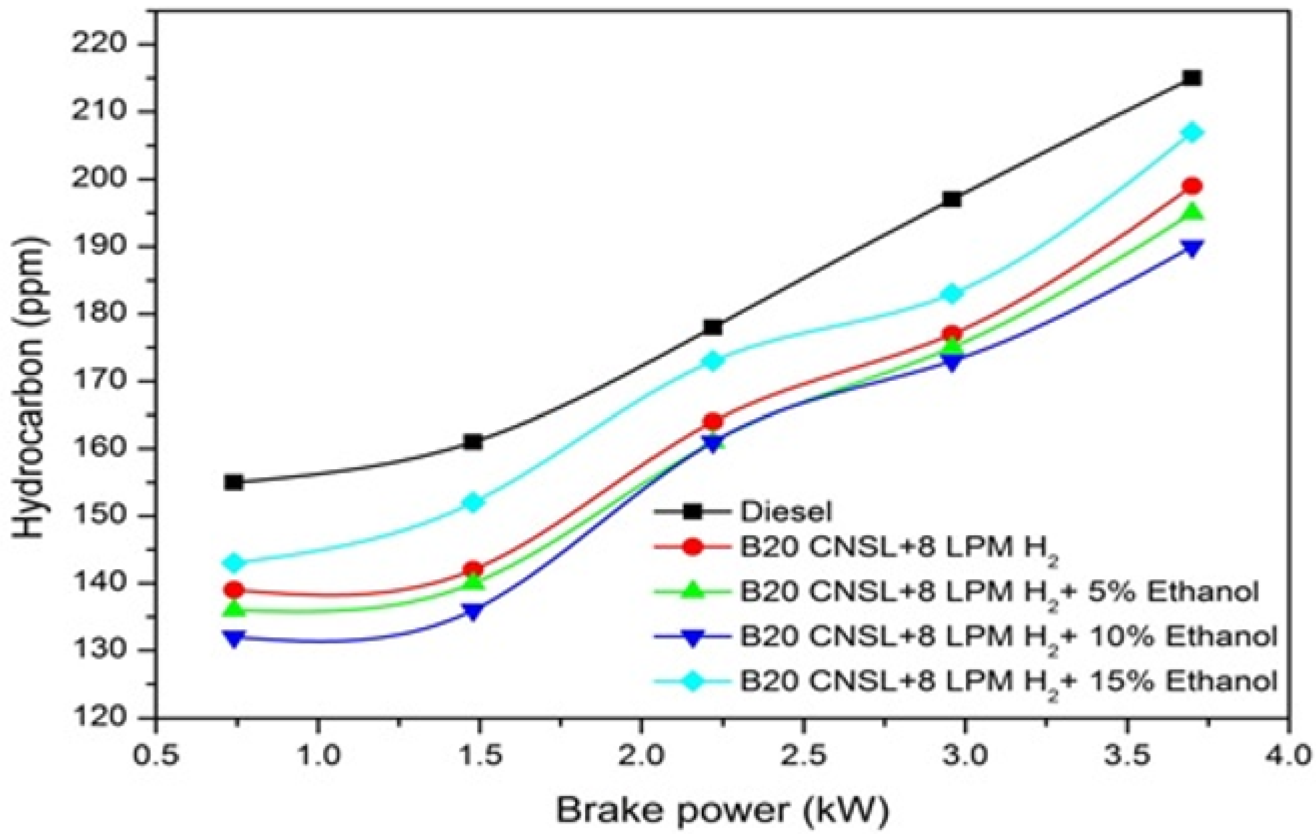

Figure 23

HC emission against brake power with CSNL fuel + Hydrogen+ Ethanol fuels

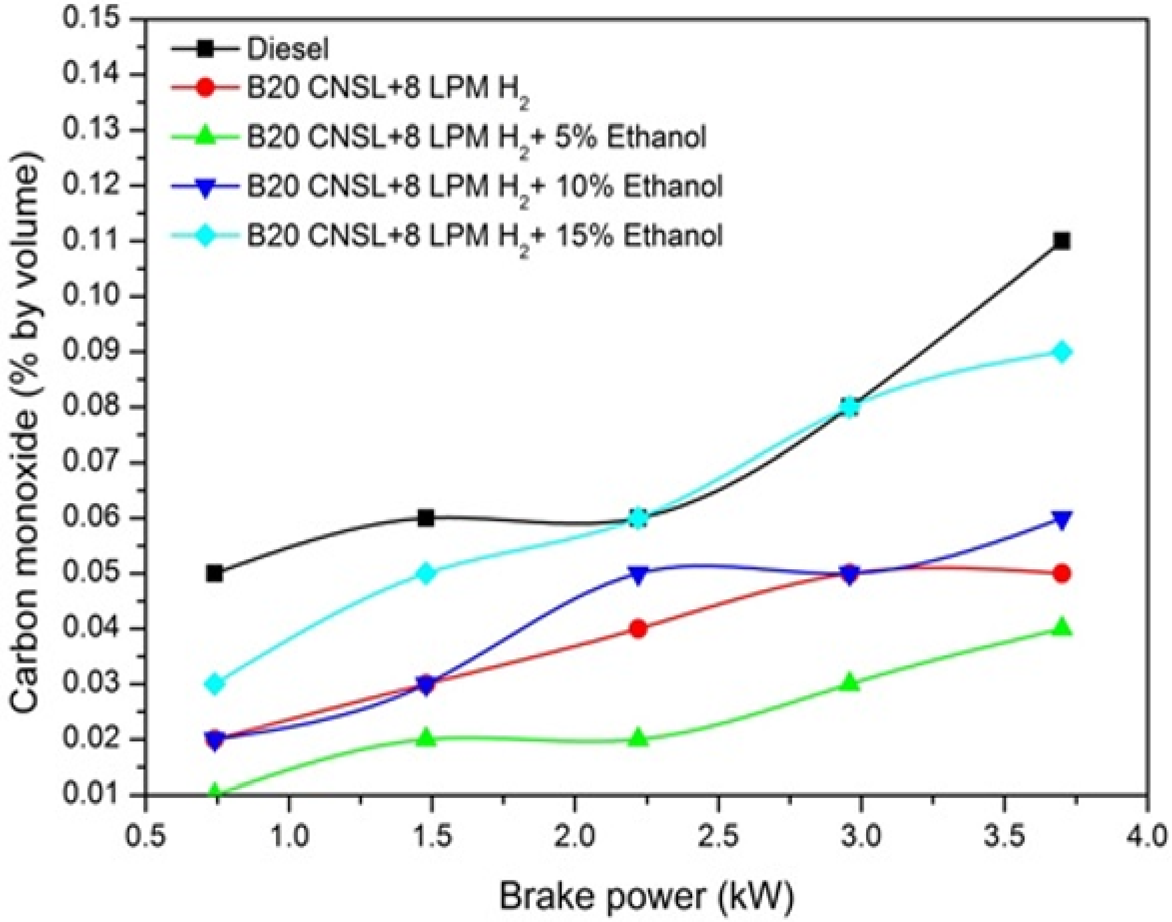

Figure 24

CO emission against brake power with CSNL fuel + Hydrogen+ Ethanol fuels

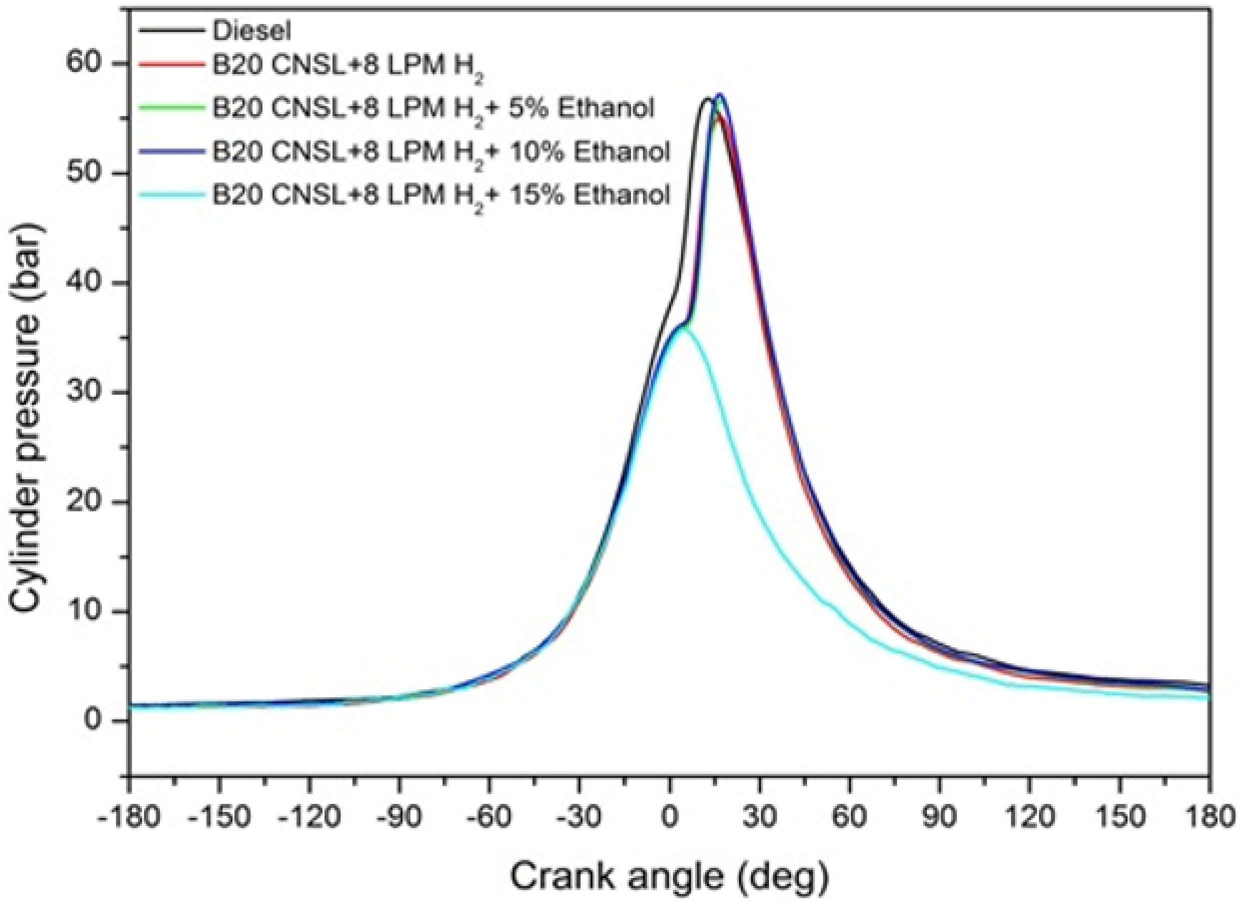

Figure 25

In-cylinder pressure against crank angle with CSNL fuel + Hydrogen+ Ethanol fuels

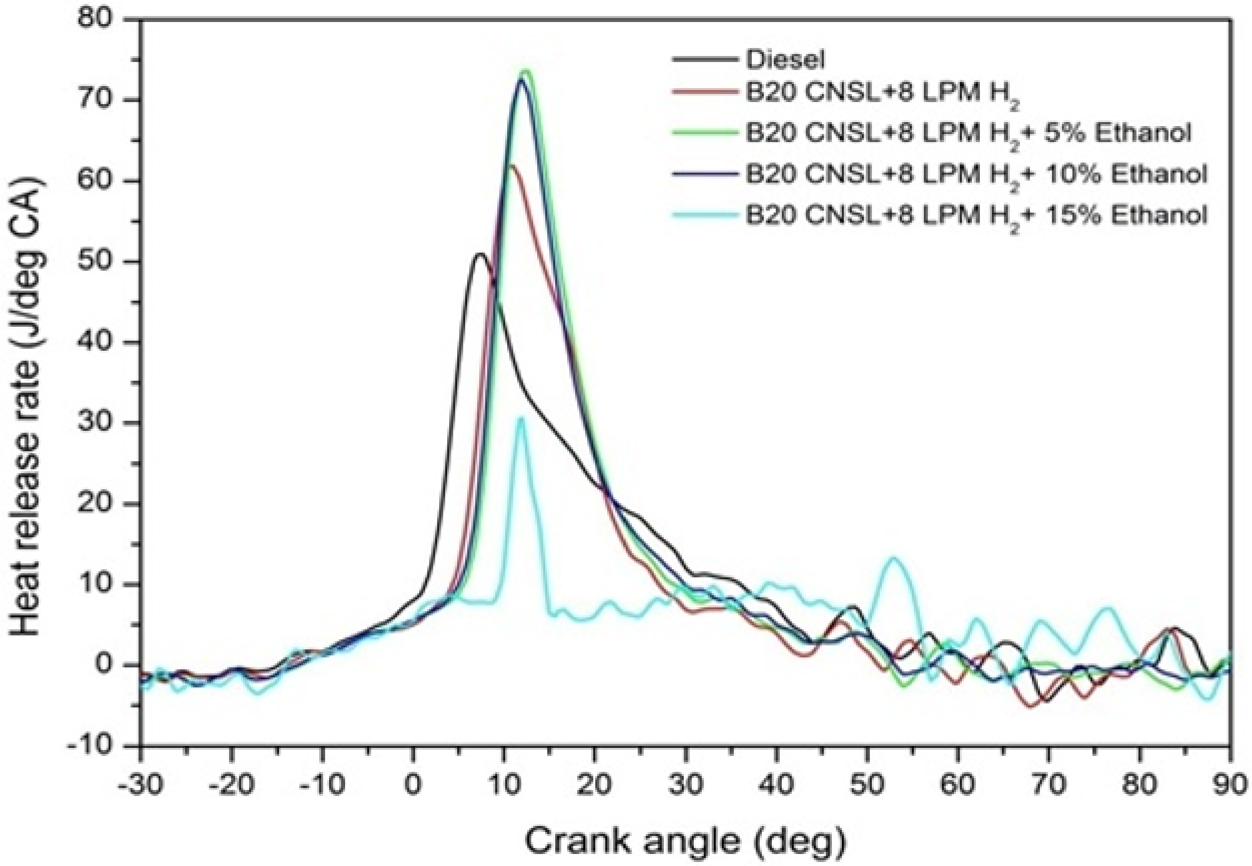

Figure 26

Heat release rate against crank angle with CSNL fuel + Hydrogen+ Ethanol fuels