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Numerical 1-D simulations on Single-Cylinder stationary spark ignition engine using Micro-Emulsions, gasoline, and hydrogen in dual fuel mode

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ABSTRACT

This work is contributing towards reducing the emissions from stationary spark ignition engine single cylinder by adopting the state of the Art Technology Hydrogen fuel and H_2O based Emulsion fuel in dual fuel mode. In addition, comparing its combustion, emissions, and performance with conventional 100% Gasoline fuel. This research work has been done on 1-D AVL Boost Simulation Software by using the single cylinder engine model setup. The main objectives of this research work is to comply with the strict emission rules Euro VII. This work predicted the overall combustion parameters, NOx, CO, and HC emissions, as well as several performance measures like power, torque, BSFC, and BMEP of stationary spark ignition engine test rig. Since Hydrogen is, zero carbon emission based fuel, so it is not creating any carbon-based emissions and has shown to be the most efficient source of energy. Although Hydrogen fuel showed no carbon emissions, but NOx emissions were slightly higher than micro-emulsion fuel. Since Hydrogen fuel burns at very high temperature, so it produced slightly more NOx emissions. The NOx emissions were 20% higher than emulsion fuel and 10% higher than Gasoline 100% fuel. The H_2O based emulsion fuel is also investigated which helped in reducing the emissions and improved the performance of single-cylinder stationary spark ignition test rig. The Brake power, BSFC, BMEP & Torque were also investigated power and showed greater improvement for emulsion fuel. At 60% load the Hydrogen fuel showed 50% increase in power as compared to emulsion fuel and 38% more power than Gasoline fuel. Exhaust emissions CO, HC, were compared for gasoline and emulsion fuel. The CO emissions are 18% lower for micro-emulsion as compared to Gasoline 100%, and HC emissions are 12.5% lower than gasoline 100% fuel at 20% load.

1. Introduction

It has been long ago since the researchers started working on Alternative Fuels in order to improve the Emissions, Combustion, and Performance parameters of Spark Ignition and Compression Ignition Engine. Most of the renewable fuel that have been used so far are only liquid fuels, some researchers also tried CNG, LPG in both spark ignition and compression ignition engine as an Alternative fuel. Still more work needs to be done in this sector for meeting the stringent emissions norms Euro VII. As demand for increasing fuel efficiency and less exhaust emissions have led the researchers to find many more alternatives for improving the performance parameters of IC engine and reducing the emissions (Kumar et al., 2003). One amongst many alternative fuels that is in high demand nowadays is Hydrogen fuel. This fuel is emerging again to cut back on the emissions and improve the performance of internal combustion engine (Changwei and Shuofeng, 2009). Hydrogen fuel has many advantages, since it has highest energy content with very few emissions. Hydrogen is a smooth electricity supply utilized for supplying the fuel to spark ignition engine to enhance combustion techniques and decrease emissions (Verhelst and Wallner, 2009). Karag oz et investigated the spark ignition engine and studied its emissions and performance (Karag¨oz et al., 2019). The results proved that Brake Power, thermal efficiency, specific fuel consumption, and emissions are all associated with the usage of hydrogen as an alternative fuel. Like CO, HC decreased and NOx emission increased. Wei et al. investigated the combustion laminar speed of blends of Biogas with hydrogen fuel. The results show that by adding hydrogen in biofuel it reduces its flame stability that is actually caused due to increase in instability and diffusion instability in hydrodynamics (Wei et al., 2019). The impact of Hydrogen fuel with ethanol blends have also been done by some researchers. The practicality of a pre-chamber device for a SI engine was examined by Santos et al. (Santos et al., 2019). They discovered that employing the pre-chamber cut time of combustion by 20%, accelerated Brake Thermal Efficiency by 5%, and cut CO and NOx by 33%. Hydrogen-rich ethanol fuel's overall performance was investigated by Ayad et al. (Ayad et al., 2020). Researchers tested a hydrogen-rich ethanol fuel's

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performance in a SI engine. Adding hydrogen to a spark-ignition engine increased performance, and lower specific energy use and lowers pollution, according to the findings. The effects of ethanol and water injection were studied by Senthil Kumar et.al (Senthil Kumar et al., 2018) to see how well hydrogen-biofuel engines work. The engine performance improved when the hydrogen-biofuel mode was used. The amount of hydrogen produced significantly lowered carbon monoxide, Hydrocarbon and emissions of smoke. According to Akansu et al. (Akansu et al., 2017), adding H_2 to ethanol-gasoline blended fuel improved the stability of combustion and improved thermal efficiency while lowering CO, Hydrocarbon, & CO_2. Amrouche et al. used an ethanol-hydrogen wankel rotary engine. (Amrouche et al., 2016) did a similar discovery. Greenwood et al. (Greenwood et al., 2014) showed that enriching ethanol with hydrogen could reduce NOx while stabilising and speeding up combustion. At a given ignition timing, Yousufuddin et al. (S Yousufuddin and Masood, 2009) found that when the amount of hydrogen in ethanol grows, the engine's BTE and BMEP (brake mean effective pressure) increase.

Some studies looked into the effects of H_2 on engine with n-butanol added. When excess air ratios were altered, Su et al. (T Su et al., 2018) evaluated the idling rotary engine with n-butanol/hydrogen performance. The findings of the experiments demonstrated that fuelling the engine with hydrogen limits the engine's instabilities as well as the fuel's energy flow rate. The combustion duration decreased as hydrogen was introduced, while the maximum temperature climbed. Carbon monoxide and hydrocarbon emissions were reduced by 3% after adding hydrogen fuel. CA10–90 & CA0–10 shortened when hydrogen fuel was added to the n-butanol rotary engine. BTE and Tmax, as well as HC & CO emissions were reduced according to literature (T Su et al., 2018). The hydrogen performance fuelled n-butanol engine was explored by Meng et al. (F Meng et al., 2018). Adding hydrogen increased BP and BTE while lowering BSFC. When hydrogen is added, carbon monoxide and hydrocarbon emissions decrease, however NOx show increase. When fuel hydrogen was added engine-fuelled n-butanol the lean burn limit was increased, which improved BTE while lowering HC and carbon monoxide emissions according to Zhang et al. (Zhang Bo et al., 2017). Kumar & Raviteja (S Raviteja and Kumar, 2015) examined the impact of adding stoichiometric hydrogen addition in butanol blends to examine the performance and emissions of a SI engine. According to the research, boosting the hydrogen concentration in the engine increases its efficiency. Carbon monoxide and hydrocarbon emissions showed decrease by 60% on average at a ten percent hydrogen concentration, but NO emissions nearly doubled. There was reduction in delay period and also the length of combustion was reduced, the combustion was improved, the temperature was increased, and there was increase in cylinder pressure, according to the combustion analysis. According to Yousufuddin et al. (S Yousufuddin and Masood, 2009), the BMEP rises as the amount of hydrogen in ethanol rises at a given ignition timing. The engine's (BMEP) and BTE increase. Hydrogen's impacts on n-butanol engines were investigated. Su et al. (T Su et al., 2018) examined the idling at various extra air ratios, the performance of n-butanol/hydrogen rotary engine.

The trials showed that adding hydrogen to the engine reduces the engine's instability and the fuel's energy flow rate. As hydrogen was supplied, the combustion duration reduced while it showed increase in temperature. Carbon monoxide and hydrocarbon emissions showed reduction by 3% with the addition of hydrogen. Adding H_2 with n-butanol rotary engine lowered CA10–90 & CA0–10, raised Brake Thermal Efficiency and max temperature (Tmax), & decreased Hydro Carbon and Carbon monoxide emissions, according to literature (T Su et al., 2018).Under lean-burn conditions, Meng et al. (F Meng et al., 2018) studied the performance of a hydrogen-powered n-butanol engine. The findings revealed that while hydrogen increased BP and BTE, it lowered BSFC.

In contrast, adding hydrogen reduces carbon monoxide and hydrocarbon emissions while dramatically boosting NOx emissions. The lean burn limit of the n-butanol engine was increased by adding hydrogen. Resulting in higher BTE and decreased Hydro Carbon and Carbon monoxide emissions, according to Zhang et al. (Zhang Bo et al., 2017). Raviteja and Kumar (S Raviteja and Kumar, 2015) investigated how adding hydrogen to a stoichiometric system affected performance and SI engine is produced in butanol blends. According to the research, boosting the hydrogen concentration in the engine increases its efficiency. Hydrocarbon and carbon monoxide emissions were reduced by 60% on average at a 10% hydrogen concentration, but NO emissions were nearly doubled. There was time delay and combustion duration was reduced, the pressure of cylinder was increased, there was increase in temperature and there was improvement in combustion according to the combustion analysis.

It can be seen that a lot of research has already been done by many researchers on various blended Alternative fuels using Hydrogen as one of the fuels, but we cannot see that H_2O based Emulsion fuel has been compared with 100% Hydrogen fuel used in Spark Ignition Engine. In this contribution, we are altogether interested in knowing the improvement in performance and reduced emissions using Micro-Emulsion fuel and 100% Hydrogen fuel in dual fuel mode.

In internal combustion engines, utilizing the available resources of renewable energy sources such as alcohols and hydrogen has a bright future for humanity's long-term development, and it can help Conservation of energy and protection of the environment. Joint use of hydrogen and alcohol fuel can optimise the benefits of both fuels while reducing the issues associated with single-fuel engines. Because of its high oxygen content and octane rating, fuel alcohols (ethanol, methanol, and n-butanol for example) will receive increased attention. In the future, combining hydrogen and alcohol in the engine will have a promising prospects. Also blending Compressed Natural Gas with Hydrogen fuel will be the promising fuel in future for spark ignition and compression ignition engines with the benefit of improved Emission characteristics and marvellous performance.

2. Methodology

This research work has been performed with AVL Boost One-dimensional simulation software.

The methodology adopted is using Alternative fuel micro-emulsions (G 90%+E8%+H_2O 2%), Gasoline 100%, and Hydrogen fuel in dual fuel mode. In this work, the water-based micro-emulsions were prepared in the lab and Hydrogen fuel was used computationally on software for checking its combustion, performance and emissions on single cylinder Spark Ignition Engine. The ingredients used for the micro emulsion fuel are Gasoline fuel 90%+ Ethanol fuel 8%+ Water 2%, and 100% Hydrogen fuel was also used in dual fuel mode, which finally was compared with Gasoline fuel 100%. The main aim to perform this work is to check if hydrogen fuel can be used all together 100% without blending with other Alternative fuels and can give better performance and lower emissions. This work utilizes the vibe-2-zone combustion analysis for better understanding the concept of combustion concept and emissions. The start of combustion is (−23) degree and combustion duration used is 69°, which has been set by AVL Boost Simulation software. In addition, woshnis Heat transfer correlation has been implemented for heat transfer analysis. In this work, the injector of the spark ignition engine is made as the global parameter by varying the mass flow rate from 10% to 100%. The properties of Gasoline, Ethanol and Hydrogen are given in Table 1.

3. Simulation setup

This project utilised a one-dimensional simulation setup. This contribution makes use of the licenced commercialised programme AVL Boost to forecast the performance, combustion, & emissions, of a single cylinder SI engine. For estimating emissions, combustion, and performance, all of the work is done on this software using 100% Hydrogen and micro-emulsion fuel in blended form Table 2.

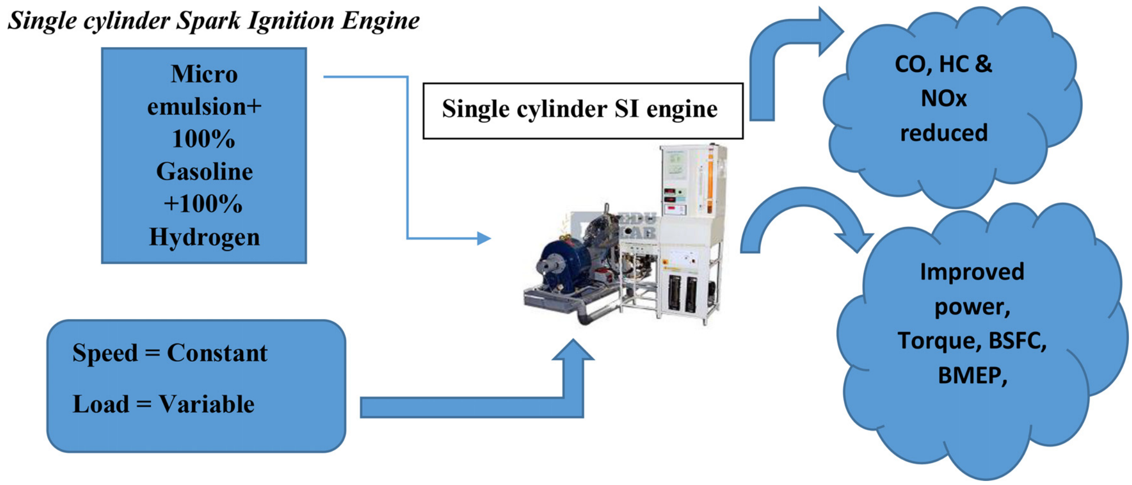

Fig. 1. Shows a diagram using Hydrogen 100%, Gasoline 100%, and H_2O based Emulsion fuel to reduce Emissions and Enhance Performance of Single Cylinder Spark Ignition Engine.

Table 1
Shows the properties of Hydrogen, Gasoline, & Ethanol (Al-Baghdadi, 2020).

Properties	Hydrogen	Gasoline	Ethanol
Chemical Formula	H_2	C_8H_{18}	C_2 H_6O
Stoichiometric Air/Fuel ratio	34.3:1	14.7:1	9:1
Temperatures for Auto Ignition C	585	300	365
Temperature at which water boils	−252.8	25–215	78.37
Density kg/m^3	0.08375	751	789 kg/m^3
Lower heating value MJ/kg	120	35–45	26.9
Octane No	>130	90	106

Table 2
Shows the Engine Summary of stationary Test Rig.

Parameter	Summary
Company	Stratton & Briggs
Title	4-stroke air cooled
Bore & Stroke	64.09 mm to 61.91 mm
CR	9
System for Cooling	Air Cooled
Rated Power	13 kW
Engine Displacement	206 cc
System for Ignition	Electronic Magnetron

This task is completed for the purpose to find out the best possible bio-fuel, for emission control and improvement in combustion characteristics and performance Table 1. shows the properties of Hydrogen, Gasoline and micro-emulsions Fig. 1. shows the description of blended emulsion fuel, Gasoline and Hydrogen usage in Single Cylinder SI engine with variable loads and speed constant at 2500 rpm. The Fig. 1 also illustrates how emulsion fuel and Hydrogen fuel reduces the emissions and improving the performance of SI engine. In this simulation work every fuel is tested individually on Avl Boost, software and all fuel were compared with each other particularly with Gasoline 100% fuel.

Single cylinder Spark Ignition Engine

In Fig. 2, AVL Austria Company verifies the engine model. In addition, this model has been used for simulation works on Avl Boost Software. This model is used to understand the predicted results, which have been generated after varying engine parameters. This model is made to work without catalytic convertor. Since for experimental test rig, there is no Catalytic convertor present. So in order to better understand the results the simulation model parameters were kept same as that of Experimental test rig. The woshni heat transfer model study's findings have been applied. In addition, the software is following the concept of First law of thermodynamics for open system by keeping both inlet and exhaust valves open. SB_1 is System boundary 1, SB_2 is system boundary 2, and CL_1 is cleaner of Spark Ignition engine used for cleaning air. In addition, C1 represents the cylinder of engine. Mp_1 to Mp_7 are measuring points. Finally, PL_1, PL_2 & Pl_3 are plenums for Air storage. Apart from those mentioned in the diagram there are also resistance points that are also used while performing the simulation.

4. Results and discussion

The plot 3 is between power and load percentage for micro-emulsions, gasoline & hydrogen fuel. Fuel 100% Hydrogen and 90% gasoline, 8% ethyl alcohol, and 2% water micro emulsion fuel compared to Gasoline fuel with a purity of 100 percent. In the plot for power v/s load the 100% Hydrogen fuel is displaying more power in comparison with gasoline 100% fuel and emulsion fuel with water added as an additive. This is because Hydrogen has more calorific value in comparison to traditional fuel. The emulsion fuel also shows similar kind of trend as conventional gasoline and Hydrogen fuel (Al-Baghdadi, 2020). Although micro emulsion fuel slightly shows lower value of power. The decline is due to the fact that micro-emulsion has ethanol added as blended fuel, which acts as co-surfactant. Its heating value is reduced because of this, results in lower value of power. From 20% to 60% load the Hydrogen fuel showed 50% increase in power as compared to emulsion fuel and 38% more power than Gasoline fuel. Afterwards it slightly showed some fluctuations in power. This is because at higher loads there is more fluctuations in mixing fuel with air as more cycles are working per unit time that is creating more noise and mixture turns towards leaner side that has a tendency to decrease power slightly.

In the plot of torque Fig. 4, shows the variation varying loads. As torque is known for engines output power. With addition of load, the torque shows increase for every fuel, but the highest torque obtained is for Hydrogen fuel. Since hydrogen, fuel has more heating value in comparison with conventional Gasoline and Ethanol fuel. As the load increases from 10% to 100%, additionally, the number of cycles per unit of time grows, which leads the final rise in torque. 100% Hydrogen fuel again proved to be very efficient fuel in terms of rise in torque (Sharma and Dhār, 2018). The rise in torque is followed by Gasoline 100% fuel, and then water based micro-emulsion fuel. The Torque remains 7% higher than 100% Gasoline fuel throughout the load on engine and in the range of 9% higher than water based emulsion fuel from 70% load to 100% load. The reason for this increase in torque at higher loads is more working cycles that leads to this increase. Figs. 3., 6, 7, 9-11

The plot between BMEP and Load percentage is shown in Fig. 5, it can be seen that the rise in BMEP is highest for 100% Hydrogen fuel,

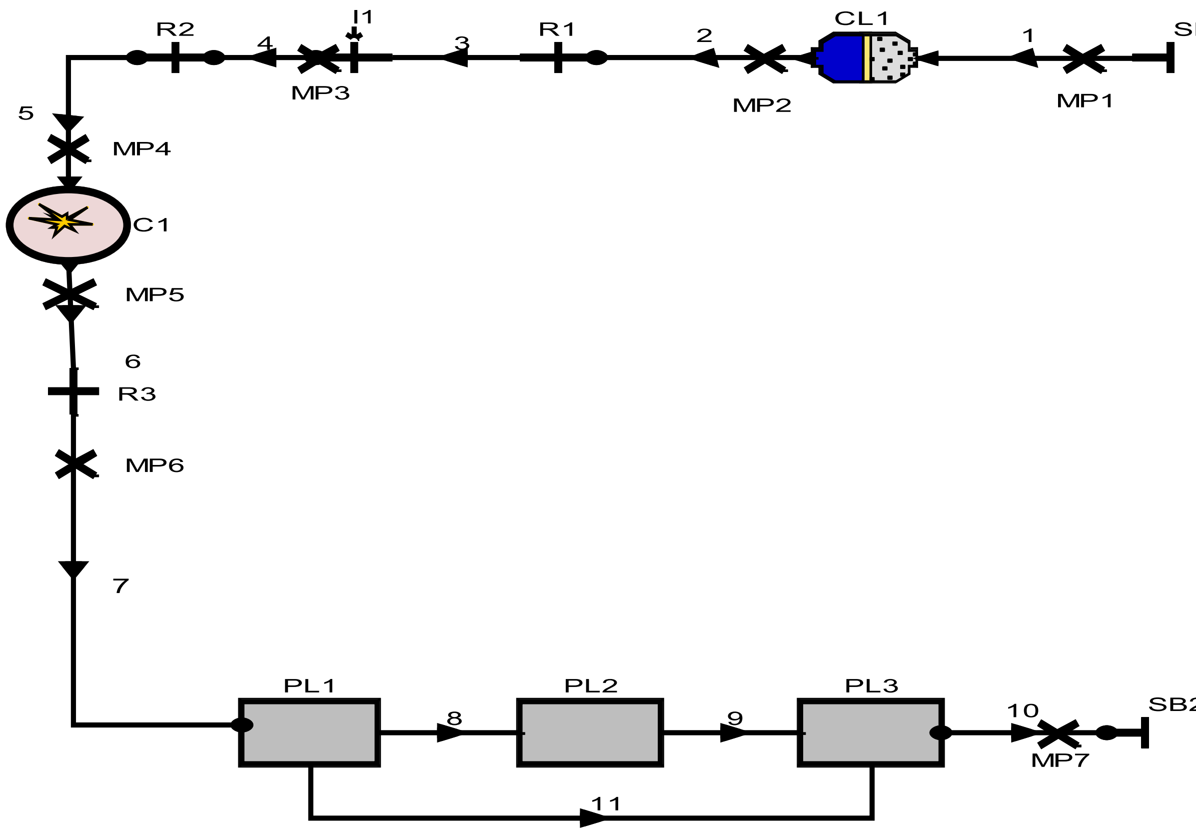

Fig. 2. Schematic diagram for AVL Boost Simulation Model in One-Dimension for Single Cylinder Spark Ignition Engine.

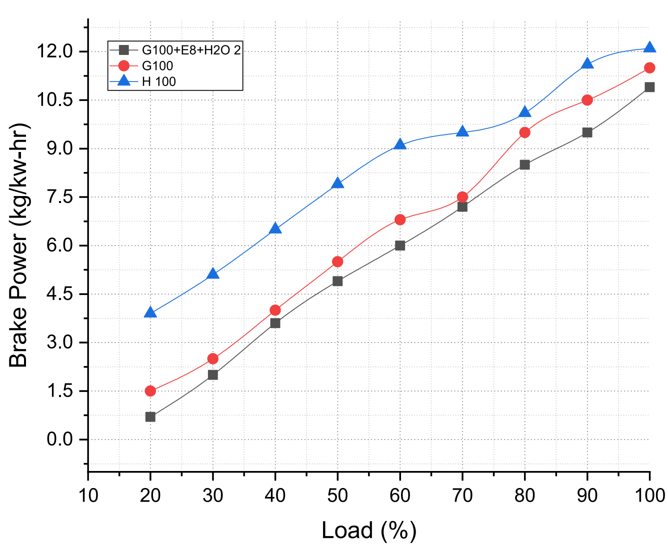

Fig. 3. Effect on Brake Power with percentage load using Emulsion fuel, Gasoline, in Dual-fuel mode with hydrogen.

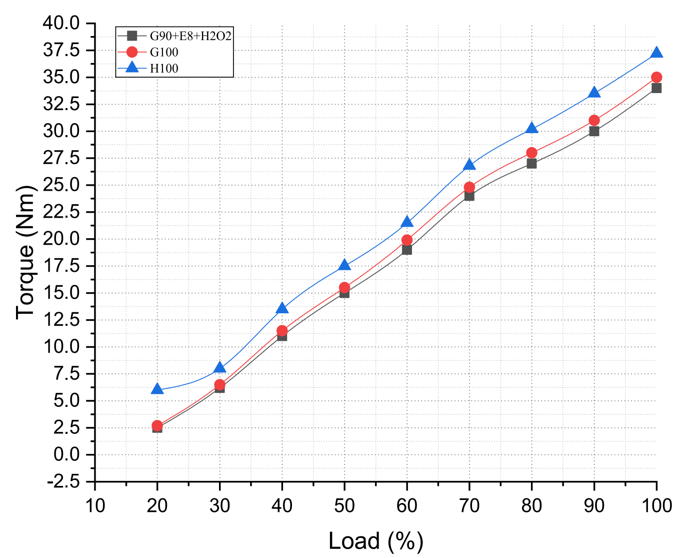

Fig. 4. Effect on Engine Torque with load percentage using Emulsion fuel, Gasoline, in Dual-fuel mode with hydrogen.

gasoline fuel, and micro emulsion fuel come in second and third, respectively. This rise in BMEP when the load is increased gives the indication that the engine is working towards better power output. Since BMEP is the average pressure that an engine is developing when uniform, pressure is applied on pistons inside cylinders. With rise in engine load the capacity of engine to produce torque also increases which leads to increase in pressure also and increases the BMEP of engine. As the Hydrogen, fuel burns quickly than Gasoline and Ethanol Fuel because of its higher auto-ignition temperature so the average pressure increases rapidly for Hydrogen as compared to conventional fuel (Yan et al., 2018).

The plot 6 demonstrates how the BSFC changes as the load increases. For all types of fuels, the BSFC drops as the load on the engine increases. This is owing to the fact that the air/fuel mixture tends towards leaner side and stoichiometric ratios. As the engine's load increases, the air supply also increases inside the engine, which makes the mixture leaner and completes the combustion, which utilizes less fuel and engine runs smoothly without causing any fluctuations inside the combustion cham-

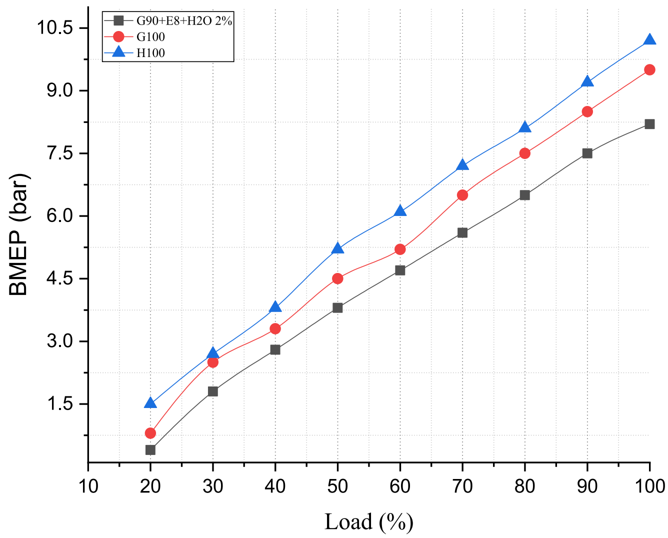

Fig. 5. Effect on BMEP with load percentage using Emulsion fuel, Gasoline, in Dual-fuel mode with hydrogen.

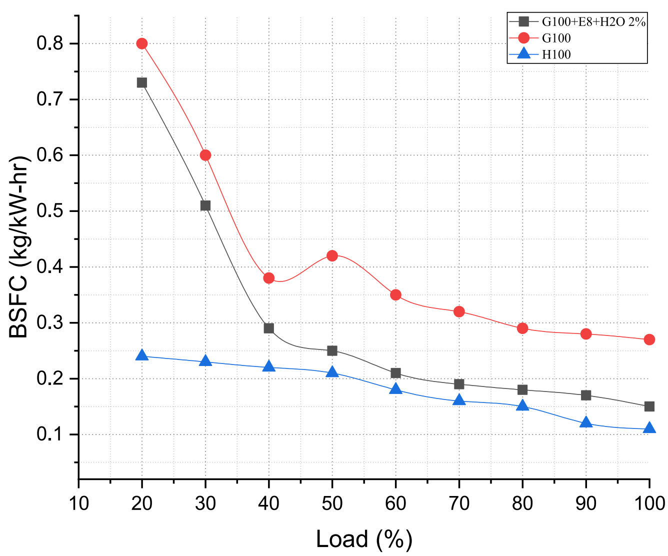

Fig. 6. Effect on BSFC with load percentage using Emulsion fuel, Gasoline, in Dual-fuel mode with hydrogen.

ber. When the fire first started, the air/fuel mixture is required to be rich that utilizes more fuel, also produces more noise, and the pressure and temperature inside the combustion chamber is increased. As it can be seen in the plot that Hydrogen fuel is the most efficient in terms of BSFC. Since Hydrogen has highest calorific value and it has also higher octane No as compared to Gasoline fuel. To obtain the same amount of energy, less fuel is required. At 20% load the BSFC showed 22% less BSFC for Hydrogen fuel as compared to 100% Gasoline (Heywood, 1998). Since at lower loads the engine needs more fuel supply for ignition process and Hydrogen fuel has highest calorific value and more auto ignition temperature, which is responsible for less fuel, is required at lower loads and it continuous at higher loads too.

Plot 7 depicts the pressure fluctuation as a function of crank angle. The variations in engine combustion pressure can be noted with crank angle variations. It can be seen that Hydrogen when compared to gasoline and micro-emulsion fuel, the peak pressure is higher. The combustion pressure for spark ignition engine is explained in three phases, since the flame propagation increases the pressure also inside the combustion chamber. This continuously happens until the peak pressure is obtained.

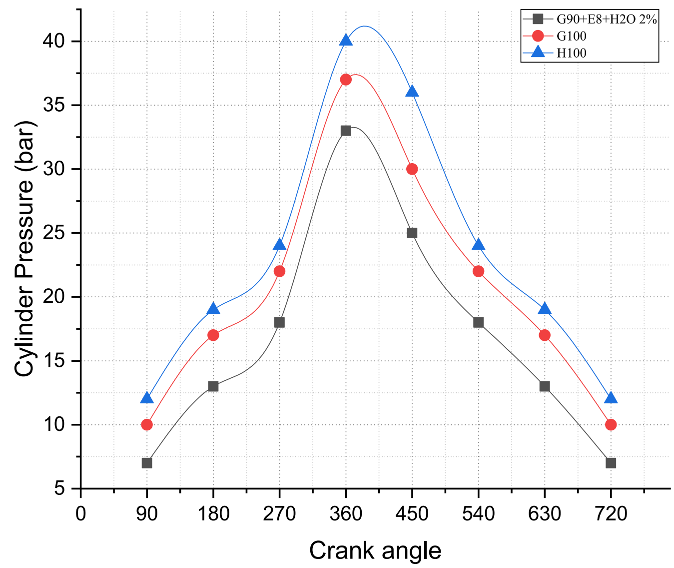

Fig. 7. Effect on combustion Pressure with crank angle using Emulsion fuel, Gasoline, in Dual-fuel mode with hydrogen.

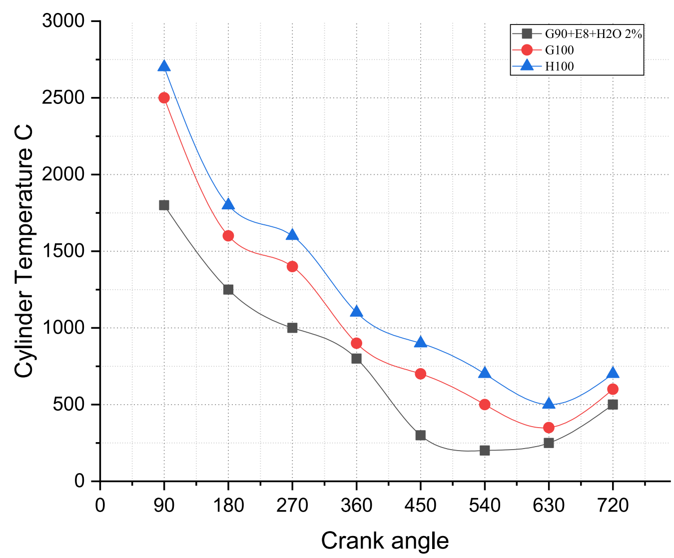

Fig. 8. Effect on Engine Temperature with load percentage using Emulsion fuel, Gasoline in Dual-fuel mode with hydrogen.

Then after burning takes place for some rich mixture until the pressure decreases and whole combustion cycle is completed. Since Hydrogen burns rapidly and quickly attains the peak pressure, which increases the efficiency of the engine and hence in terms of peak pressure, it has shown to be a very effective combustion analysis (Karagöz et al., 2015).

In the plot of Temperature v/s crank angle in Fig. 8, it can be seen that with each crank angle change, the temperature also changes and at the start of the combustion, the temperature is highest for hydrogen fuel as compared to gasoline and micro emulsion fuel. The possible reason for this high temperature at the start of combustion is because Hydrogen burns rapidly due to highest auto ignition temperature that increases the combustion chamber temperature and also it is expected that the temperature will rise because at the start the mixture is rich and for starting the combustion both temperature and pressure should be highest for making the piston move from TDC to BDC position. In addition, with increase in crank angle the temperature falls and attains the stability (Mansor et al., 2021).

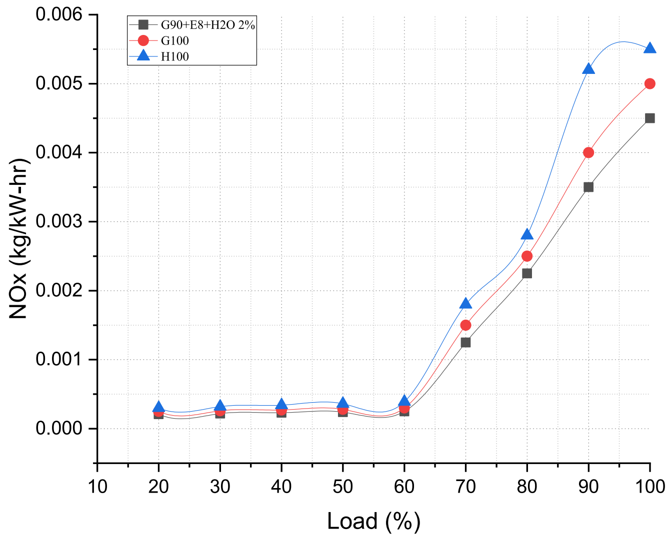

Fig. 9. Effect on NOx emissions with load percentage using Emulsion fuel, Gasoline and Hydrogen in dual fuel mode.

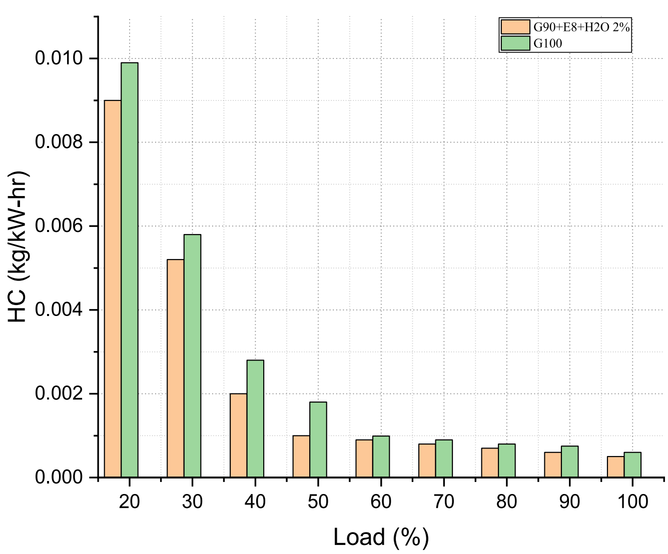

Fig. 10. Effect of Hydrocarbon emissions with load percentage using water based Emulsion fuel, & Gasoline.

5. Emissions

The variation of NOx with percentage load for Hydrogen, emulsion fuel, and Gasoline fuel has been compared computationally to determine which fuel is the most efficient in terms of NOx emissions. Since hydrogen is devoid of carbon atoms, the carbon-based emissions are not expected from Hydrogen fuel, which is the biggest advantage of using Hydrogen fuel results in zero emissions. Although the carboneous emissions are zero for Hydrogen fuel but the NOx emissions are produced significantly, since NOx emissions are not carbon based and are only produced when the internal temperature of the combustion chamber rises more than expected and forms NOx emissions. The Hydrogen fuel at higher loads after 60% shows continuous increase until 100% load is achieved (Mohamad et al., 2010).Water based micro emulsion fuel and Gasoline 100% also increases after 60% load. The cause of the increase in NOx emission is increase in temperature due to more number of Cycles running per unit time.

In Plot 10 the variation of Hydrocarbon, emissions have been compared to ordinary gasoline fuel. The bar chart can be easily understood.

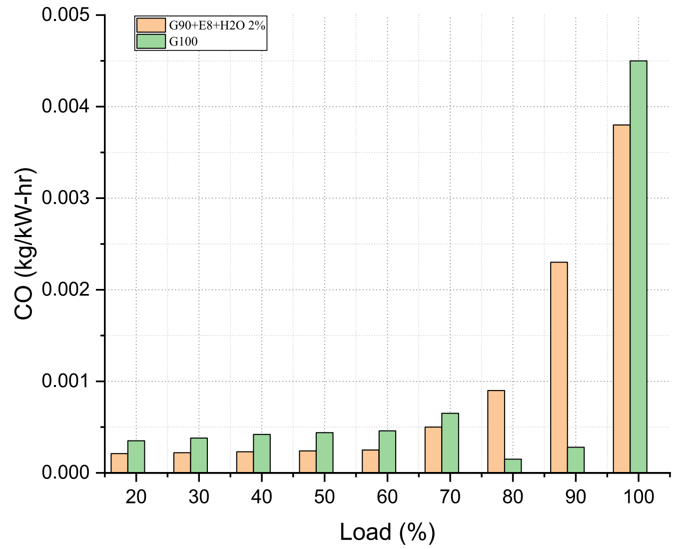

Fig. 11. Effect on Carbon monoxide emissions with load percentage using water based Emulsion fuel, & Gasoline.

At the lower loads, the Hydrocarbon emissions are highest for Gasoline fuel as compared to Micro-emulsion fuel. This is owing to the fact that the mixture is rich at first. Fuel is not getting sufficient time for complete combustion, and some fuel goes into the crevices, which also increases the Hydrocarbon Emissions. After the load on the engine increases, the Hydrocarbon emissions also show the decline. Since the combustion is being completed and mixture is also stoichiometric. At 20% load the H_2O based micro-emulsions showed 11% lower Hydrocarbon emissions as compared to 100% Gasoline fuel. Moreover, with rise in engine load the micro-emulsion fuel showed continuous decline in HC emissions as compared to Gasoline 100% fuel (Awad et al., 2018).

In plot 11, the variation of CO emissions has been compared with Gasoline and micro emulsion fuel. The plot clearly explains that at the starting loads, the Carbon monoxide is low and as the load increases, the carbon monoxide emissions rise. The possible reason for this increase is that at higher loads the fuel is not getting sufficient time for complete combustion of fuel, which results in increase in its carbon monoxide emissions (Qadiri, 2021). The H_2O based micro-emulsion fuel showed 18% lower value of carbon monoxide emissions as compared to 100% gasoline at 100% load. This lower value of Co emissions is because at higher loads, the mixture is lean and the H_2O molecule in emulsion fuel enhances the complete combustion of fuel the fuel results in lower carbon monoxide emissions (Qadiri, 2022).

6. Conclusions

The conclusion of this research can be drawn based on following points

- Ø In this work, the Hydrogen fuel 100% has been compared with micro-emulsion fuel and 100% Gasoline fuel. This work has been performed computationally on AVL Boost Simulation Software for predicting the performance of 100% Hydrogen fuel, Micro Emulsions, and comparing the same with 100% Gasoline fuel. The main purpose of this work is to understand the important parameters of Hydrogen fuel, water based emulsion fuel, and finally concluding in terms of performance, combustion, and emission characteristics, which fuel is more efficient. At 60% load the Hydrogen fuel showed 50% increase in power as compared to emulsion fuel and 38% more power than Gasoline fuel.
- Ø This work has concluded that 100% Hydrogen fuel is the most efficient fuel both in terms of power production and emission characteristics, particularly carbon based emissions since hydrogen showed

increase in Brake power around 30% more than conventional Gasoline fuel and 40% increase as compared to emulsion fuel.

Ø The BSFC and BMEP also showed significant improvement using 100% Hydrogen fuel. At 20% load the BSFC showed 22% less BSFC for Hydrogen fuel as compared to 100% Gasoline. In addition, micro emulsion fuel also showed improvement as compared to Gasoline fuel.

Ø The combustion properties of Hydrogen are better than emulsion fuel and gasoline fuel. Since the Hydrogen showed highest peak pressure with crank angle variations. This is followed by micro-emulsion fuel, which also predicted the combustion characteristics and showed significant rise in pressure. Closer to TDC position.

Ø The temperature for Hydrogen is highest as compared to micro-emulsion and Gasoline fuel, because of its highest auto ignition temperature. This high temperature is responsible for its higher NOx emission as compared to 100% Gasoline and water based emulsion fuel and proved more efficient.

Ø The carbon emissions showed zero emissions for Hydrogen fuel particularly CO and HC emissions, although NOx emissions were significantly higher than the conventional Gasoline and Water based emulsion fuels. The NOx emissions were 20% higher than emulsion fuel and 10% higher than Gasoline 100% fuel.

Ø The future prospects of this work is to use Hydrogen with various gaseous Alternative fuels CNG,LPG, and other alcohol based fuel in blended form for improving the performance and emission characteristics of Spark Ignition Engine.

Declaration of competing interest

No.

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