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Analysis of Combustion Characteristics and Emission Characteristics of Alternative Fuels Worldwide

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Opinion Article

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ABSTRACT

The combustion characteristics and emission characteristics of the commonly used alternative fuels in the fuel process are reviewed, the three types of alternative fuels are: Alcohols alternative fuel, biological alternative fuel and gas alternative fuel. The three alternative fuels have their own advantages and disadvantages in combustion characteristics and emission characteristics. The dual fuel blended with alcohols has a higher burning rate than pure diesel or gasoline, and emits fewer soot particles. When biofuel is blended into traditional fuel, the thermal efficiency is improved, and the particle diameter of the emitted particles is smaller than that of pure diesel. The use of hydrogen fuel increases the power of the engine, and significantly reduces the content of CO and CO_2 in the emissions. With the increase of the proportion of hydrogen, the amount of soot emitted becomes less, but the amount of nitrogen oxide emissions increases. Each of the three types of alternative fuels has its own characteristics and advantages.

Keywords: Alternative fuel; emission characteristics; nitrogen oxides.

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1. INTRODUCTION

In order to cope with the upcoming energy depletion problem, many scholars have conducted research on energy regeneration and exploring new energy sources, such as the development of new fuels and new energy sources. Traditional diesel and gasoline have certain restrictions on people's use at this stage. For example, mining, environmental pollution and strict standard emission regulations are issues that cannot be ignored at this stage. In order to deal with the pollution emissions caused by the combustion of traditional diesel and gasoline, many scholars have conducted research on new fuels, such as alternative fuels such as biofuels, alcohols fuels, and natural gas fuels.

Research on alcohols fuels and other aspects has been explored by many scholars, and it is also the mainstream of the use of alternative fuels. Mohammed A. Fayad [1] and others conducted research on diesel alternative fuels. They used gasoline-liquid (GTL) and ethanol-methanol-diesel blends as alternative fuels for single-cylinder diesel engines. Hamid Omidvarborna [2] et al. used low-sulfur diesel and biodiesel fuel as raw materials to carry out mixed combustion experiments with different ratios in the combustion chamber of the laboratory. Zhiqin Jia [3] et al. studied the combustion of dual-fuel diesel heavy-duty engines with three different methanol injection devices. Jeongwoo Lee [4] and others used a dual direct injection heavy-duty single-cylinder diesel engine as the engine, and studied the effect of different ethanol substitution rates on engine performance and emissions under dual-fuel combustion conditions. Alan C. Hansen [5] et al. reviewed the ethanol-diesel blended fuel.

Biofuels are also the focus of current scholars' research, and many scholars have carried out in-depth research on biofuels. Swarup Paul [6] et al. elaborated on the application of multi-criteria decision-making (MCDM) in biofuel selection, including fuel performance, engine performance, and emissions. V. Venkatesan [7] et al. conducted an experimental study on a light biofuel pine oil blended with pine nut oil as the main raw material and methyl esters with saponified nut oil as the main raw material.

There are three types of gas fuels currently used. Liquefied is petroleum gas, natural gas and hydrogen. Among them, hydrogen is mainly mixed with diesel. Different hydrogen mixing ratios can increase the power and thermal efficiency of the engine in different degrees. Das [8] summarized the combustion characteristics of H2 and its application in engines, and believed that H2 burns fast and has a wide range of flammability, which can improve the combustion performance of other petroleum fuels such as natural gas. Hydrogen can be used as a fuel for compression ignition engines in dual fuel mode and based on it to reduce engine vibration and carbon emissions [9]. At present, hydrogen fuel engines and hydrogen fuel cell vehicles are the mainstream research directions of alternative gas fuels.

This article reviews the current mainstream alternative fuels, including alcohol fuels, biofuels, and natural gas fuels, in terms of thermal efficiency and emission characteristics. Alcohol alternative fuels are currently the most practical for methanol and ethanol, both of which have their own characteristics. Alternative biofuels are mostly refined from animal fats or plant seeds, and they come from a wide range of sources. Alternative gas fuels mainly include liquefied petroleum gas, natural gas and hydrogen fuel. The article analyzes the use and characteristics of hydrogen fuel.

2. ALCOHOLS ALTERNATIVE FUEL

Alcohol substitute fuels are currently used more frequently. Alcohol substitute fuels mainly include methanol and ethanol, which are divided into ethanol gasoline, methanol diesel, methanol gasoline and so on. Alcohol substitute fuel has a higher octane value than gasoline, and can adopt a high compression ratio to improve thermal efficiency; it is liquid at room temperature, easy to operate and convenient to carry; wide flammable limit, fast combustion speed, and can achieve lean combustion; and traditional engine technology Inheritance. But the shortcomings are also obvious. Alcohol fuel has a low calorific value. The calorific value of methanol is only 48% of gasoline, and the calorific value of ethanol is only 64% of gasoline. Compared with gasoline and diesel, under the same thermal efficiency, alcohol thermal fuel has the same thermal efficiency. The economy is worse; secondly, methanol is toxic and harmful to the body; in addition, the alcohol mixed fuel is prone to stratification, so a co-solvent is required. But on the whole, alcohol fuels are the most commonly used alternative fuels for vehicles.

Jeongwoo Lee [4] et al. found that in terms of particulate matter emission, with the increase of ethanol substitution, the emissions of nitrogen oxides and particulate matter decreased, and the average emissions of particulate matter decreased. In addition, they studied the heat release characteristics of the engine under the average effective pressure (IMEP). Under the same low load conditions (IMEP 0.2 and 0.4MPa), the heat transfer of dual-fuel combustion is higher than that of pure diesel.

In the review, Alan C. Hansen [5] studied the mixing properties of fuels, such as stable viscosity, lubricity, safety and material compatibility, which are important factors in commercial use. The influence of fuel on engine performance, durability and emissions is also considered. They reported that when the proportion of ethanol is 10% or less, compared with the direct use of diesel, there is no significant difference between the performance reported by the market and the use of diesel fuel.

Tie Li [6] et al. studied the non-evaporation, evaporation and combustion characteristics of anhydrous ethanol diesel emulsified fuel. Through experiments, it was found that under 21% of the ambient oxygen concentration, with the addition of water-containing ethanol, changes in fuel composition such as the increase in oxygen content in the fuel, the decrease in aromatics content, and the decrease in hydrocarbon ratio, have an effect on soot reduction relatively bigger.

Mohammed A. Fayad [1] et al. studied the effects of GTL and ethanol-methanol-diesel blends as diesel alternative fuels on the characteristics of inhalable particulate matter (PM) and gas emissions. The results show that ethanol blends have an effect on in-cylinder pressure and heat. The release rate is 4% and 13% higher than that of GTL fuel and diesel fuel, respectively. In addition, compared with other fuels, ethanol blends produce smaller soot particles and fewer primary soot particles.

Fig. 2 shows the comparison of the heat release rate (ROHR) of ethanol blend fuel, diesel fuel and GTL fuel with CAD data. The ROHR produced by ethanol blends is greater than that of diesel. This is because the oxygen atoms belong to the hydroxyl groups of the bio-alcohol blends, which improves the thermal efficiency of the bio-alcohol blends.

Zhiqin Jia [3] et al. studied the three injection devices of the intake manifold's fuel injection port, intake stroke direct injection (DI_E) and compression stroke direct injection (DI_L) respectively. By changing the methanol substitution percentage in the DI_L configuration, it can be found that reducing the reactivity of the global mixture to a level similar to the reactivity used in the DI_E and port configurations will result in the later stages of combustion, longer combustion duration, and excessive undesirable effects and excessive unburned HC and CO emissions.

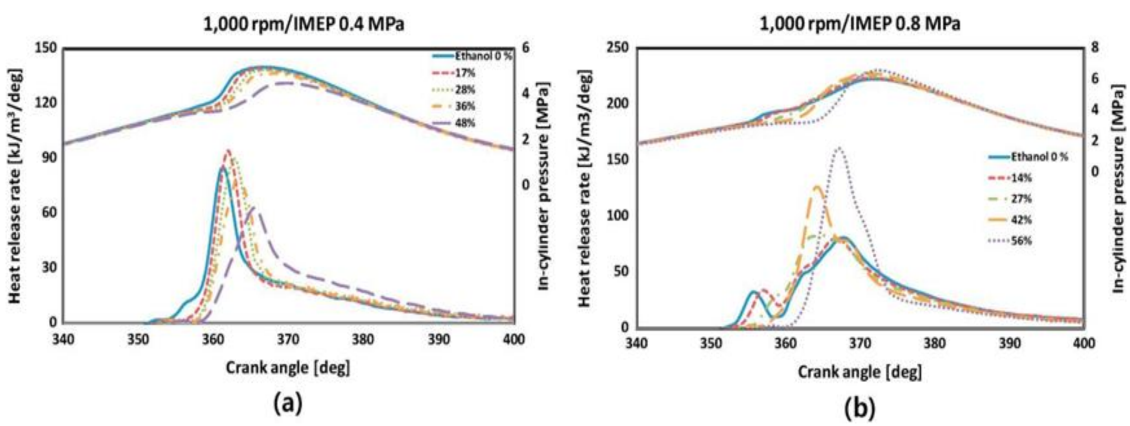

Fig. 1. Heat release rate and in-cylinder pressure trace IMEPS 0.4 (a) and (b) 0.8 MPa at 1000 hag RPM for various ethanol fractions [4]

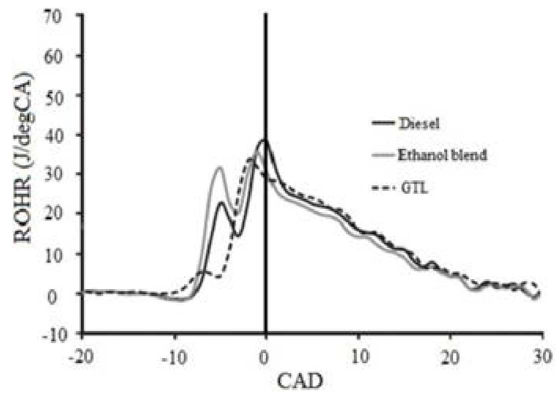

Fig. 2. The effect of different fuels on different CAD heat release rates (ROHR) [1]

3. BIOFUELS

Biodiesel is generally prepared from vegetable oil seeds, vegetable fats, animal fats, waste edible oils, etc. Among them, biodiesel prepared from oil seeds is of considerable importance, thereby reducing the dependence on crude oil and petroleum imports. This can increase agricultural income and create rural employment. However, biofuels also have certain disadvantages, such as high viscosity, clogged injector nozzles, carbon deposits on the cylinder wall, gum formation in the presence of oxygen, and thickening of lubricating oil.

It has been reported in the literature [10] that the addition of butanol and biodiesel seems to be a fuel that can replace traditional diesel, which can replace traditional diesel in terms of engine emissions and performance. Vinod BabuM [11] reviewed the effects of two biofuels, butanol and pentanol, on the combustion, performance and emissions of compression ignition (CI) engines under various test conditions. For decades, researchers have been trying to solve major problems related to biofuels, such as continuous research on emission characteristics, engine characteristics, and combustion characteristics.

Hamid Omidvarborna [2] and others use biodiesel as raw materials: soybean methyl ester (SME), tallow oil (TO) and waste edible oil (WCO). The experiment collected the soot particles produced during the combustion process and characterized the biodiesel raw materials. The experimental results showed that the soot particles emitted by biodiesel were significantly smaller than ultra-combusted diesel (ULSD). Through the FTIR analysis of soot particles, it is confirmed that the additional oxygen content in biodiesel can reduce the size of soot particles by enhancing oxidation, making the size distribution of soot particles narrower than ULSD. Transmission electron microscopy (TEM) observed oxidized soot particles and found that SME is a highly unsaturated biodiesel, which emits smaller soot particles than WCO and TO.

V. Venkatesan [7] et al. studied the performance, combustion and emission characteristics of agricultural tractor engines that completely replaced traditional diesel fuel with biofuels. The engine’s braking thermal efficiency (BTE) is inversely proportional to the braking specific fuel consumption and depends on the fuel characteristics and combustion parameters. Fig. 3 shows the variation of the braking thermal efficiency of diesel, pure pine oil and pine nut biodiesel under different loads with engine load. It can be seen from Fig. 3 that as the proportion of pine oil in the blend increases, the braking thermal efficiency increases.

K. Masera [12] et al. reviewed the test results of the performance, combustion and emission characteristics of thermal barrier coating engines running on biofuels. Through research, we found that when biofuels or biofuel blends are used in thermal barrier coating engines, compared with uncoated engines, the torque is increased by 4.6%, the power output is increased by 7.8%, and the braking specific fuel consumption is increased by 13.4. %, the braking specific energy consumption has increased by 15.4%, and the braking thermal efficiency has increased by 10.7%.

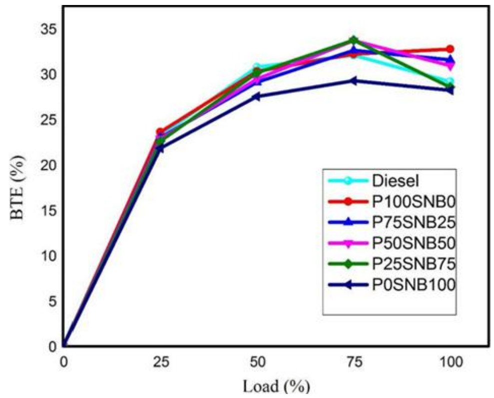

Fig. 3. Variation of braking thermal efficiency with load [7]

G. Ospina [13] and others conducted a combustion test on the Ricardo E6 single-cylinder variable compression indirect injection engine, and compared the combustion performance of three different liquid biofuels with the benchmark diesel fuel. Biofuels include jojoba methyl ester (JME), seaweed methyl ester (AME) and chocolate waste methyl ester (CME). It is found through experiments that the injection time between 25° TDC and 30° TDC has the best performance for JME, CME and AME, but the advantages of each fuel are different.

György Szabados [14] et al. on the effects of traditional biodiesel (FAME) and new TBK biodiesel (TBK-biodiesel named as the first character of the surnames of the three inventors of Thész, Boros, and Kiály) on the particulate matter related emissions of compression ignition engines The impact was studied and evaluated. As the mixing ratio of bio-derived test fuels (standardized biodiesel and non-standardized TBK biodiesel) that can be used in internal combustion engines with fossil diesel continues to increase, the particle quality is increasing. That is, when the mixing ratio of diesel increases, the particles of emissions gradually increase.

B. Ashok [15] and others studied and compared the performance, emission and combustion characteristics of two different biofuels on a common rail direct injection engine. Through experiments, it was found that compared with 10% of the amount of pilot fuel, for 30% of the amount of pilot fuel, the fuel efficiency of orange peel oil (OPO) and lemon peel oil (LPO) decreased by 10.74% and 4.72%, respectively.

Through the research of different scholars on biofuels in engines, it can be known that the application of biofuels in engines can improve the performance of engines. The extra oxygen contained in biofuels enhances the combustion process of biofuels. Oxidation, in turn, reduces the size of soot particles during the emission process. In addition, the utility of biofuels also improves the thermal efficiency of the engine, which is much higher than that of the traditional engine, but with it, the fuel consumption rate also increases.

4. GAS ALTERNATIVE FUEL

At present, most gaseous fuels used in the market are divided into two types: liquefied petroleum gas and natural gas fuel. Among them, liquefied petroleum gas fuel mainly includes LPG, and natural gas is mainly GNG (compressed natural gas) and LNG (liquefied natural gas). Compressed natural gas (CNG) is an alternative fuel because it is much richer than oil. It has a high H/C ratio and a high research octane number, which is cleaner than the exhaust gas produced by traditional fuel combustion. It also has higher explosion resistance, but lower flame speed and shorter flammability range [16].

Hydrogen does not contain carbon and does not produce CO2 after combustion. Moreover, hydrogen can be obtained from renewable energy sources such as solar energy and wind energy, and is considered to be the most ideal energy source or energy carrier at present. When hydrogen is used as internal combustion engine fuel, it is easy to achieve lean combustion, emit less pollutants, and have high thermal efficiency. There are also reports [17] that hydrogen fuel has good physical and chemical properties and can be used as a sustainable fuel and a suitable alternative fuel for future internal combustion engines. It is mentioned in the literature [18] that hydrogen has a higher heating value, higher flame propagation speed and lower ignition energy, and is considered a high energy source. It contains no carbon atoms and is an important source for controlling emissions and improving the performance of CI engines. Traditional petroleum fuels such as gasoline and diesel are subject to emission regulations, and their prices continue to rise, leading to the use of alternative fuels, which has led to the promotion of natural gas fuels and hydrogen fuels. Natural gas is rich in resources and clean in nature, and can be used in automobile engines. There is a slight improvement to the increase of the hydrogen energy share and the delayed injection timing mode of the compression ignition engine.

S. Khandal [19] has shown through experimental research that the effect of adding hydrogen to dual-fuel engines using renewable fuels is better. When the injection timing is 27°BTDC, NOx emissions are reduced by 26-28%. T. Sandalcı [20] studied the effect of ethane concentration on the performance, emissions and combustion characteristics of compression ignition engines. The results show that when the engine speed is high, compared with pure diesel, the maximum braking power is increased by 14.25% by replacing 50% of ethane.

Andrei Laurentiu Niculae [16] and others used the thermal combustion model established by AVL BOOST software to evaluate the pollutant emissions and performance of Renault k7 -710 spark ignition engine fueled by compressed natural gas, hydrogen, and a mixture of compressed natural gas and hydrogen (ethane). And efficiency parameters were evaluated. Experiments show that the use of ethane blends improves engine performance and efficiency, significantly reduces CO and THC, but increases NOx emissions and peak fire pressure. In addition, when the mass fraction of hydrogen is 20% and the mass fraction of methane is 80%, compared with pure gasoline, the power is increased by 10.4%, the brake specific fuel consumption is reduced by 37.1%, the CO is reduced by 80.9%, the THC is reduced by 31.3%, and the NOx is increased by 11.1%. Fire pressure increased by 11.3%.

Exhaust gas recirculation (EGR) is the most commonly used method to reduce the NOx emissions of dual-fuel engines, mainly by reducing the oxygen concentration of the intake [21-22] and increasing its heat capacity. Literature [23] pointed out that the more hydrogen in the engine cylinder, the less smoke and dust emitted, the higher the thermal efficiency, and the higher the nitrogen oxide emissions. Sarthak Nag [24] studied the effects of hydrogenation and enhanced exhaust gas circulation on the compression ignition performance of diesel engines. The addition of hydrogen helps to reduce particulate matter in a large amount, and also reduces CO and CO2 emissions. The addition of EGR reduces the oxygen concentration, lowers the temperature in the cylinder, and inhibits the oxidation of soot, leading to an increase in soot emissions. On the other hand, EGR reduces the emissions of nitrogen oxides.

Nicolas Castro [25] et al. conducted a study on the maximum replacement amount of hydrogen in a turbocharged four-cylinder direct-injection diesel engine. Studies have shown that under the conditions of 30% engine load and 80% hydrogen replacement, the maximum reduction in diesel consumption relative to 100% diesel is 54.2%. Ozgur Balli [26] and others studied the influence of hydrogen fuel on the exergy performance of a military trainer turbojet engine. The research results show that after using hydrogen fuel, the engine's exergy efficiency dropped from 15.40% to 14.33%, and the waste fire rate rose from 6196.51 kW to 6669.4 kW.

Alternative gas fuels still have great potential at present, especially hydrogen fuel and natural gas fuel. Especially for hydrogen fuel, adding a certain amount of hydrogen to traditional gasoline and diesel can increase the power of the engine, and the fuel consumption rate is significantly lower than that of pure diesel and pure gasoline. In addition, after adding hydrogen, there will be a lot less hydrocarbon emissions, and CO and CO_2 emissions will also be reduced to varying degrees.

5. CONCLUSIONS

This article summarizes the combustion characteristics and emission characteristics of three types of alternative fuels for vehicles. The three alternative fuels are: alcohol alternative fuels, biological alternative fuels and gas alternative fuels. These three types of alternative fuels have their own special features and advantages: Alcohols alternative fuels are widely used. Its octane number is higher than gasoline, and its burning speed is faster, which is inherited from traditional engine technology. The disadvantages are also relatively obvious. Alcohol alternative fuels have lower calorific value than traditional fuels. Under the same efficiency, the thermal efficiency of alcohol fuel is much worse; Alcohol alternative fuels are rich in oxygen molecules, which can fully oxidize during the combustion process to improve fuel utilization. Incorporating a certain amount of alcohol fuel into traditional fuels can improve engine thermal efficiency, as well as nitrogen oxides and particulate matter. Reduced emissions, and reduced average emissions of particulate matter; Diesel or gasoline mixed with a certain amount of biofuels can improve the thermal efficiency of the engine, and the oxygen molecules in the biofuels promote the oxidation process of the combustion process, which reduces the diameter of the soot particles during the emission process. , And as the proportion of bio-alternative fuels increases, nitrogen oxide emissions also decrease; Gas alternative fuel, adding hydrogen to traditional diesel or gasoline can increase the power of the engine to a certain extent, but the peak pressure in the engine cylinder will also increase. The more hydrogen in the cylinder, the more soot will be emitted. Less, the higher the thermal efficiency; The addition of hydrogen fuel greatly reduces the content of CO and CO2 in the emissions, but with it, the emissions of nitrogen oxides increase. The addition of EGR can effectively reduce the emissions of nitrogen oxides.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Mohammed A. Fayad, Athanasios Tsolakis, Francisco J. Martos. Influence of alternative fuels on combustion and characteristics of particulate matter morphology in a compression ignition diesel engine. Renewable Energy. Available online 16 October 2019.
2. Hamid Omidvarborna, Ashok Kumar, Dong-Shik Kim. Variation of diesel soot characteristics by different types and blends of biodiesel in a laboratory combustion chamber. Science of The Total Environment. 2016;544:450-459.
3. Zhiqin Jia, Ingemar Denbratt. Experimental investigation into the combustion characteristics of a methanol-Diesel heavy duty engine operated in RCCI mode. Fuel. 2018; 226:745-753.
4. Jeongwoo Lee, Sunyoup Lee, Seokhwan Lee. Experimental investigation on the performance and emissions characteristics of ethanol/diesel dual-fuel combustion. Fuel. 2018;220:72-79.
5. Alan C. Hansen, Qin Zhang, Peter W. L. Lyne. Ethanol–diesel fuel blends — a review. Bioresource Technology. 2005; 96(3):277-285.
6. Tie Li, Xiao-Qing Zhang, Bin Wang, et al. Characteristics of non-evaporating, evaporating and burning sprays of hydrous ethanol diesel emulsified fuels. Fuel. 2017;191:251-265.
7. Swarup Paul, Bijan Sarkar. An exploratory analysis of biofuel under the utopian environment. Fuel. Volume 262, 15 February 2020, 116508.
8. Das L. Hydrogen-oxygen reaction mechanism and its implication to hydrogen engine combustion [J]. Int J Hydrogen Energy. 1996;21(8):703-715.
9. Ozcanli M, Akar MA, Calik A, Serin H. Using HHO (Hydroxy) and hydrogen enriched castor oil biodiesel in compression ignition engine. Int J Hydrogen Energy. 2017;42:23366-23372.
10. Jeya Jeevahan, Sriramanjaneyulu G, Durairaj RB. Experimental investigation of the suitability of 1-butanol blended with biodiesel as an alternative biofuel in diesel engines. Biocatalysis and Agricultural Biotechnology. 2018;72-77.
11. Vinod Babu M, Madhu Murthy, KAmba Prasad Rao G. Butanol and pentanol: The promising biofuels for CI engines – A review. Renewable and Sustainable Energy Reviews. 2017;78:1068-1088.
12. Masera K, Hossain AK. Biofuels and thermal barrier: A review on compression ignition engine performance, combustion and exhaust gas emission. Journal of the Energy Institute. 2019;92(3):783-801.
13. Ospina G. Mohamed Y. E. Selim. Salah A. B. Al Omari, et al. Engine roughness and exhaust emissions of a diesel engine fueled with three biofuels. Renewable Energy. 2019;134:1465-1472.
14. György Szabados, Ákos Bereczky, Tibor Ajtai. Evaluation analysis of particulate relevant emission of a diesel engine running on fossil diesel and different biofuels. Energy. 2018;161:1139-1153.
15. Ashok B, Nanthagopal K. Bhaskar Chaturvedi. A comparative assessment on

Common Rail Direct Injection (CRDI) engine characteristics using low viscous biofuel blends. Applied Thermal Engineering. 2018;145:494-506.
16. Andrei Laurentiu Niculae, Lucian Miron, Radu Chiriac. On the possibility to simulate the operation of a SI engine using alternative gaseous fuels. Energy Reports. Available online 13 November 2019.
17. Chintala V, Subramanian K. Hydrogen energy share improvement along with NOx (oxides of nitrogen) emission reduction in a hydrogen dual-fuel compression ignition engine using water injection. Energy Convers Manag. 2014;83:249-259.
18. Chinmay Deheri, Saroj Kumar Acharya, Dhirendra Nath Thatoi. A review on performance of biogas and hydrogen on diesel engine in dual fuel mode. Fuel. 2020;260:116337.
19. Khandal S, Banapurmath N, Gaitonde V. Effect of hydrogen fuel flow rate, fuel injection timing and exhaust gas recirculation on the performance of dual fuel engine powered with renewable fuels. Renew Energy. 2018;126:79-94.
20. Sandalcı T, Isın O, Galata S, Karagoz Y, Guler I. Effect of hythane enrichment on performance, emission and combustion characteristics of an ci engine. Int J Hydrogen Energy. 2019;44:3208-3220.
21. Roy MM, Tomita E, Kawahara N, Harada Y, Sakane A. An experimental investigation on engine performance and emissions of a supercharged H2-diesel dual-fuel engine. Int J Hydrogen Energy. 2010;35:844-853.
22. Banerjee R, Roy S, Bose PK. Hydrogen-EGR synergy as a promising pathway to meet the PM-NOx-BSFC trade-off contingencies of the diesel engine: a comprehensive review. Int J Hydrogen Energy. 2015;40:12824-12847.
23. Abdulhakim I. Jabbr, Umit O. Koylu. Influence of operating parameters on performance and emissions for a compression-ignition engine fueled by hydrogen/diesel mixtures. International Journal of Hydrogen Energy. 2019;44(26): 13964-13973.
24. Sarthak Nag, Priybrat Sharma, Arpan Gupta. Experimental study of engine performance and emissions for hydrogen diesel dual fuel engine with exhaust gas recirculation. International Journal of Hydrogen Energy. 2019;44(23):12163-12175.
25. Nicolas Castro, Mario Toledo, German Amador. An experimental investigation of the performance and emissions of a hydrogen-diesel dual fuel compression ignition internal combustionengine. Applied Thermal Engineering, 2019;156:660-667.
26. Ozgur Balli, Yasin Sohret, Hikmet T. Karakoc. The effects of hydrogen fuel usage on the exergetic performance of a turbojet engine. International Journal of Hydrogen Energy. 2018;43(23):10848-10858.

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