International Journal of Advance Research in Science and Engineering
Volume No. 14, Issue No. 03, March 2025
www.ijarse.com
IJARSE
ISSN 2319 - 8354

Hydrogen addition to producer gas derived from redgram stalk and biodiesel for diesel engine operation

N.T.Kambar[a*], K.M.Akkoli[b], D.A.Kakati[c]

[abc*]*Hirasugar Institute of Technology, Nidasoshi, India*

ABSTRACT

The substitution of fossil fuels by alternative renewable fuels for engine applications such as biofuels is providing promising solutions for environmental and economic issues. The present work is the use of biofuels such as producer gas (PG) and biodiesel instead of diesel in the IC engines and its performance enhancement with the addition of hydrogen (H_2). The influence of H_2 on the performance, combustion and emission characteristics of diesel engines running on diesel/Honge oil methyl ester (HOME) and PG has been investigated. Hydrogen was introduced during suction stroke through the inlet manifold at varying flow rates ranging from 4 to 12 litres per minute (lpm) with steps of 4 lpm. The operation of the engine revealed that the addition of H_2 to the low calorific value PG significantly affected the combustion and emission characteristics of the diesel engine. The results of the investigation showed that the H_2 of 8 lpm induction resulted in an improvement in brake thermal efficiency (BTE) by 5.5%, reduction in carbon monoxide (CO), smoke, hydrocarbon (HC) emissions by 22 - 25%. The ignition delay and combustion duration for the HOME-PG operation with H_2 addition has been increased by 15.6% and 20.4%, respectively compared to the diesel-only operation.

Keywords- *Break Thermal Efficiency (BTE), Biodiesel, Hydrogen Addition, Honge oil methyl ester (HOME), Producer gas.*

1. INTRODUCTION

The world is continuously striving hard for achieving energy sufficiency with the lower effect to the nature. The prompt increase in the population and growth in the industries to fulfill the needs of that mass of humans is demanding a drastically higher power. The fossil fuel source of energy is suffering from major drawbacks such as the uncertainty about the availability in the future and increasing environmental pollution posing many difficulties such as increased temperature, the spoil of ozone, uneven rainfall and other natural disasters [1]. Thus the many countries are making continuous effort into effective utilization of alternative and renewable energy sources because of their benefits such as less environmental effect and inexhaustibility. The major alternative and renewable energy sources presently being using are solar, wind and biofuels. Solar and wind energy are cyclic, regional and can be used for specific applications [2]. Biofuels are one of the important renewable and alternative energy sources available throughout the world and can be used for many applications. The biodiesels and producer gas derived from biomass are popular for engine applications for partial or complete replacement of petroleum fuels [3].

Biodiesels from different sources can be used to operate IC engines in single fuel mode or dual fuel mode with diesel. The biodiesel properties are not the same as diesel but comparable to diesel and can be used in a diesel engine with few modifications in the operating and physical conditions. The biodiesels can be derived from different non-edible oils extracted from abundantly available oilseeds of Honge, Jatropha, Karanja and Neem etc. in India Transesterification is the process of conversion of non-edible oils into their biodiesels [4]. The producer gas derived from biomass can be used along with diesel or biodiesel to operate a diesel engine in dual fuel mode. The biomass from various sources such as forest residue, agricultural residues and industrial wastes are used for PG generation through gasifiers. The petrol engines can operate in single fuel mode with the producer gas and diesel engines can operate in dual fuel mode with producer gas and diesel/biodiesel [5] [6]. Many researchers carried out work on biodiesel and producer gas engine operation and found that there is a reduction in engine power along with reduction in NOx emissions, in fact higher smoke, CO and HC emissions. The lower power was due to the lower heating value of biodiesel and producer gas and slow-burning of PG [7]. Few researchers are tried for triple fuel operation of diesel/biodiesel and PG with the addition of rich energy fuels like LPG, CNG and H_2 [8]. Improving the combustion with the addition of other gaseous fuels increased the power output and enhanced confidence for further developments in the alternative fuel utilization [9] [10].

1.1. Present Work

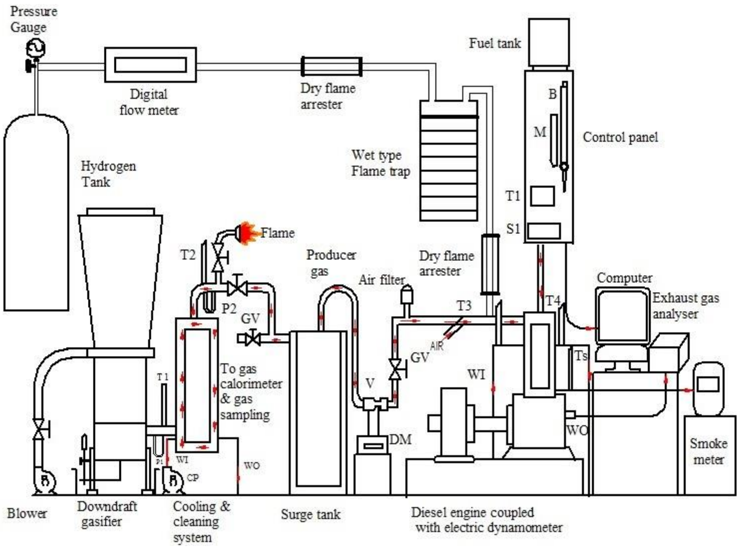
Several researchers have reported results of experimental investigations on the utilization of either hydrogen or producer gas only as a secondary fuel in diesel engines. Literature showed that numerous researches on dual-fuel engines using diesel/ biodiesel-hydrogen using various induction and injection methods. Less work has been undertaken on hydrogen addition to producer gas derived from agricultural residues operating on dual fuel mode. In this view, an effort has been made to evaluate the feasibility of Honge oil methyl ester (HOME) and producer gas derived from redgram stalk agricultural residue with H_2 addition for diesel engine operation. Experiments were conducted on a single-cylinder, four stroke, direct injection diesel engine operated in dual-fuel mode using biodiesel and producer gas derived from redgram stalk with and without the addition of H_2. The engine used for the study consists of a mechanical fuel injection system with 3 holes of 0.25 mm diameter. For the present experimental investigation, the compression ratio and IT were kept constant at 17.5 and 27^0 bTDC respectively. Injection pressures for the diesel-PG and HOME-PG operations were changed to 205 and 230 bar respectively. Optimum parameters such as compression ratio, IT and increased injection pressure have been reported in earlier studies [18, 19].

2. EXPERIMENTAL SETUP AND PROCEDURE

The gasifier-engine system was run on a dual fuel mode at different engine loads at a fixed speed of 1500 rpm. The gasifier-engine system is shown in Figure 1 in which the engine is coupled to an eddy current dynamometer for loading. The specifications of the engine and gasifier are provided in Table 1. The downdraft gasifier is a closed top gasifier and the gas leaving at the bottom is appropriately cooled and cleaned and then mixed with air in a mixing chamber before entering into the inlet manifold during suction stroke. The downdraft gasifier for the engine unit of 5.2 kW typically takes 10 kg/h of biomass with a hopper capacity of 40 kg. Solid combustible biomass derived from redgram stalk was loaded in the downdraft gasifier to generate combustible PG. A calibrated venturimeter provided with a digital gas flow meter was utilized to measure the flow rate of gas. Exhaust gas composition during the steady-state operation was measured through a Hartridge smoke meter and five-gas analyzer. Throughout the experimental campaign, the engine speed was fixed. Problems were faced during the

International Journal of Advance Research in Science and Engineering
Volume No. 14, Issue No. 03, March 2025
www.ijarse.com
IJARSE
ISSN 2319 - 8354

flow rate of gas measurement because the gas quality was changing intermittently. To enhance the performance of HOME-PG operation, the fuel mixture is enriched with different quantities of H_2 stored in a high-pressure storage tank at a pressure of 150 bar at 30^0C. During the operation, hydrogen pressure was reduced to 1.5 bar by using a two-stage pressure regulator and was passed through a shutoff valve. A flow regulator in the H_2 flowline helps to control the hydrogen flow rate and the digital flow meter measures the flow rate of H_2. Finally, the H_2 was allowed to inlet the manifold of the engine through the carburettor. Dry-type flame arrestors and wet type flame traps were used in the hydrogen flow line. The dry type flame arrestor used can act as a non-return valve, which is capable of preventing the reverse flow of H_2. To determine the optimum flow rate of H_2, it was varied from 4 to 12 lpm in steps of 4 lpm because of safety and knocking issues. Initially to start the engine diesel/biodiesel fuel was used and then PG- hydrogen mixture was inducted. In this present work, the PG was naturally aspirated along with air through a parallel flow gas entry carburettor shown in Figure 2(a). Further, hydrogen was inducted through a 0.6mm hole diameter carburettor which was connected in the inlet manifold at the length of 30cm from the inlet port to enhance mixing of H_2 with air-PG mixture shown in Figure 2(b).



(a)

(b)

Fig. 1 Schematic (a) and photographic view (b) of the gasifier-engine system test rig

2(a)Hydrogen induction and PG supply facility made in DF operation

2(b)Hydrogen gas induction

Fig. 2 Hydrogen and PG gas induction through the carburetor

Table 1 Specifications of the compression ignition engine and downdraft gasifier [20]

	Diesel engine		Downdraft gasifier	
Sl. No.	Parameters	Specifications	Parameters	Specifications
1	Type of engine	Kirloskar single cylinder 4 stroke DI diesel engine	Supplier	Harith Avani Technologies Pvt Ltd. Bangalore
2	Nozzle opening Pressure	205 to 240 bar IOP	Capacity and gas flow	62735 kJ/h and 15 Nm^3/h
3	Rated power	5.2 kW @1500 rpm	Mean gas heating value	19 MJ/kg
4	Cylinder diameter	87.5 mm	Rated biomass consumption	10 kg/hr
5	Stroke length	110 mm	Hopper storage capacity	40 kg
6	Compression Ratio	17.5: 1	Conversion efficiency	70-80%

3. RESULTS AND DISCUSSIONS

This section presents experimental results obtained by conducting experiments on a CI engine test set-up converted to operate in tri-fuel mode using diesel/biodiesel as injected fuel and H_2-PG mixture as inducted fuel. The results of the investigation obtained from H_2-PG and HOME combination, and baseline data (diesel-PG) were compared and analyzed.

3.1 Performance characteristics

Brake thermal efficiency of dual and tri-fuel operation at different loads is presented in Figure 3. The increase in BTE was observed with continuous H_2 induction and is revealed to be higher at high loads. Results showed that the BTE of an engine operated on HOME-PG with and without hydrogen addition is revealed to be lower compared to diesel-PG operation. For the HOME-PG operation, BTE at a flow rate of 4, 8 lpm and 12 lpm of H_2 and without hydrogen addition is found to be 17.15, 18.5, 17.8% and 15.12% compared to 20.25% for diesel-PG operation at 80% load. It is observed that hydrogen addition to producer gas and at maximum operating conditions, HOME-PG combination have operated marginally near to 90% load due to reduced power derating and boosted the thermal efficiency by 3.38% compared to the dual-fuel operation (without hydrogen addition). In general, BTE for HOME-PG operation without H_2 addition is found to be 5.43% lower than diesel-PG operation. It is attributed to the properties of the injected and inducted fuels that have a major impact on the engine characteristics. The equivalence ratios for HOME-PG operation with 4, 8 and 12 lpm H_2 and without addition were found to be 0.58, 0.64, 0.62 and 0.52 respectively, compared to 0.66 for diesel-PG operation at 80% load. It emphasizes that the nearly full combustion of the HOME-PG combination is limited by insufficient air supply. To enhance the combustion of producer gas during dual fuel operation, a small quantity of hydrogen was added to producer gas. The addition of hydrogen beyond 8 lpm led to engine knocking with increased emissions. Hence with 8 lpm of hydrogen in producer gas, the results were found to be encouraging.

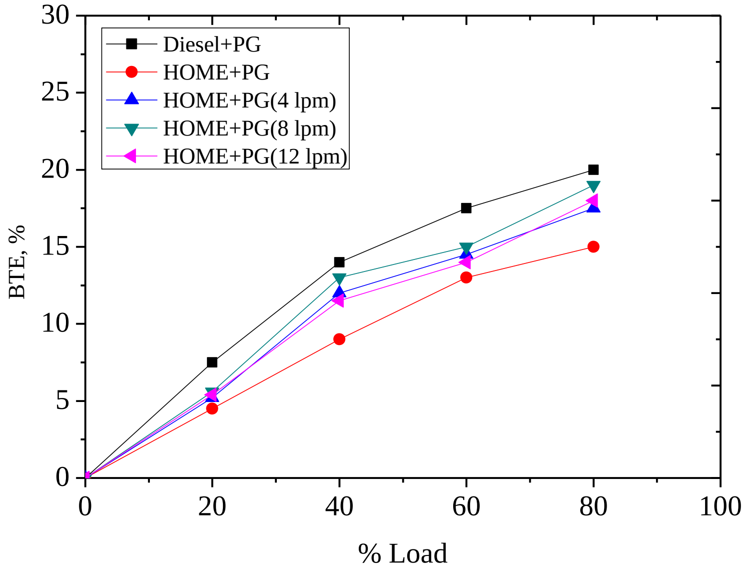


Fig.3 Effect of hydrogen addition on the BTE

3.2 Emission characteristics

Emission characteristics of engine operation at different conditions were presented in the following section.

3.2.1 Smoke opacity

The variation of smoke opacity with load for diesel /HOME -PG-H_2 operation is presented in Figure 4. HOME-PG operation with and without hydrogen addition resulted in higher smoke levels compared to diesel-PG operation. This is because the properties of HOME have a dominating effect during dual-fuel combustion. Heavier molecular structure of the injected HOME caused by the presence of free fatty acids, improper spray pattern and poor soot oxidation leading to incomplete combustion. Poor oxidation caused by reduced oxygen during the combustion of HOME-PG operation is also one of the causes for higher smoke content. Fuel combination being the same, the smoke opacity at a flow rate of 4, 8 and 12 lpm of H2 are found to be 46, 47 and 48 HSU respectively

International Journal of Advance Research in Science and Engineering
Volume No. 14, Issue No. 03, March 2025
www.ijarse.com
IJARSE
ISSN 2319 - 8354

compared to 44 HSU for diesel-PG operation at 80% load. However, the smoke opacity for HOME-PG operation is 33% higher than diesel-PG and 29.4% higher than HOME-PG operation with hydrogen addition at a flow rate of 8 lpm at 80% load. This reduction of smoke levels for HOME-PG operation with hydrogen addition is mainly due to high combustion temperature associated with optimum utilization of available oxygen and the use of carbon-free hydrogen fuel. Therefore, the hydrogen addition for HOME-PG duel fuel engine operation lowers the smoke levels.

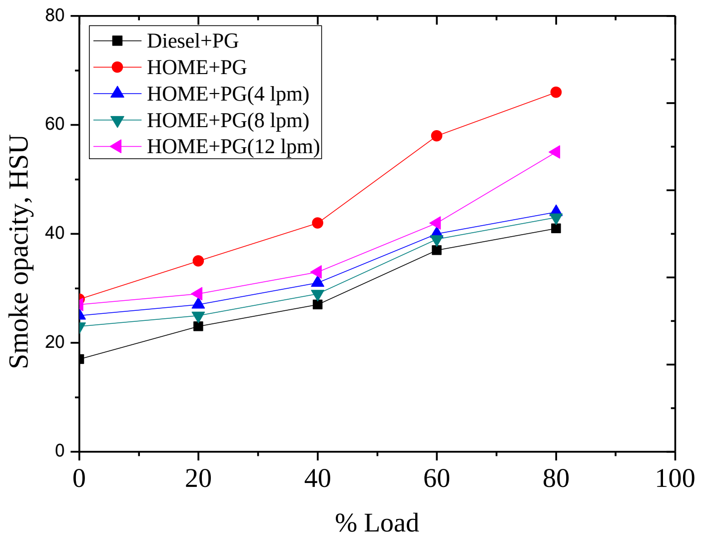


Fig.4 Effect of hydrogen addition on the smoke opacity

3.2.2 HC and CO emissions

HC and CO emissions for diesel/ HOME-PG derived from redgram stalk with and without H_2 addition is shown in Figures 5 and 6. HOME-PG combination has higher HC and CO emissions compared to the diesel-PG combination. This is due to incomplete combustion because of poor atomization caused by the content of higher long-chain fatty acids in HOME, relatively low adiabatic flame temperature of the PG, the low energy content of HOME and PG as well as high viscosity and density of HOME in the presence of the slow-burning PG. Also, poor oxidation of H_2 fuel due to insufficient oxygen for combustion caused by the replacement of air by PG and the presence of CO in the PG leads to incomplete burning of HOME-PG combination. Hence, the lower equivalence ratio is responsible for higher CO emissions during dual-fuel operation. Besides, higher CO content was observed in the exhaust at partial load could be because of too lean mixture for combustion. The presence of higher CO content in the PG and lower combustion temperature are the main causes of such results. For HOME and PG being the same, with an H_2 flow rate of 8 lpm, dual fuel operation resulted in 35.45% and 60% lower CO and HC emissions compared to the operation without H_2 addition at 80% load. This is because of H_2 addition resulted in improved combustion for leaner fuel combinations. Higher combustion temperature and has a higher flame velocity with wider flame leads to burn the fuel combination better. However, at higher flow rates of hydrogen beyond the limit, no positive influence on the combustion process is observed. The HC emission levels of the HOME-PG fueled dual-fuel engine operation with 4, 8 and 12% of hydrogen were 66, 44 and 48 ppm respectively, compared to 40 ppm for the diesel-PG operation. Similarly, CO emission levels of the HOME-PG

IJARSE
ISSN 2319 - 8354

fueled dual-fuel engine operation with 4, 8 and 12% of hydrogen were found to be 0.18, 0.14 and 0.17%, respectively compared to 0.11% for the diesel-PG operation at 80% load.

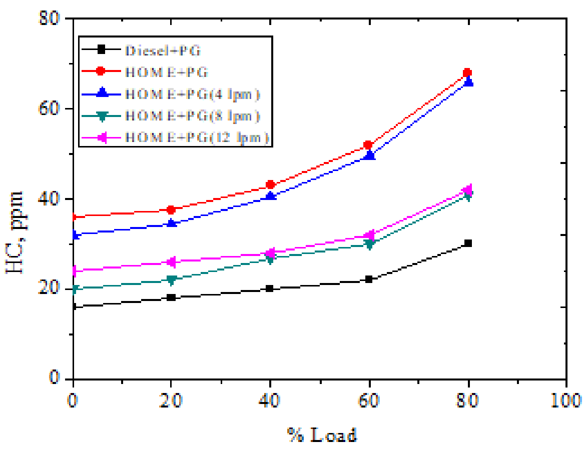


Fig.5 Effect of hydrogen addition on the HC emission

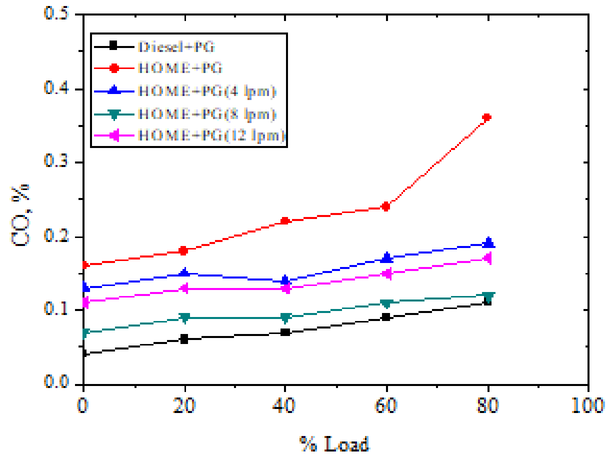


Fig.6 Effect of hydrogen addition on the CO Emission

4. CONCLUSIONS

The HOME-PG dual-fuel engine operation shows that the combustion process is strongly influenced by the H_2 addition. This addition is successful in achieving the goals of the conversion process and a reduction of emissions. The following specific conclusions were drawn:

➢ From the experimental investigations, for HOME-PG operation, it was observed that with 4, 8 and 12 lpm H_2 addition resulted in improved performance compared to the dual-fuel operation without H_2 addition. The H_2 addition to HOME-PG derived from redgram stalk operation resulted in 18.5% increased BTE compared to the without H_2 addition operation. The increase in H_2 addition beyond the limit leads to knocking due to the rapid combustion of H_2.

➢ A remarkable increase in the power output of 4-5% was reported.

➢ Smoke opacity, HC and CO for the HOME-PG with H_2 addition were decreased by 30.1%, 25% and 22% respectively compared to the dual-fuel operation without H_2 addition at 80% load.

➢ Overall it is confirmed that tri-fuel operation using pilot fuel with 8 lpm H_2 addition with PG is revealed as the most appropriate fuel combination for enhanced performance with reduced smoke, HC, CO emissions. This can serve future energy needs for power from engine applications.

REFERENCES

[1] Martins, Florinda; Felgueiras, Carlos; Smitkova, Miroslava; Caetano, Nídia. 2019. "Analysis of Fossil Fuel Energy Consumption and Environmental Impacts in European Countries." *Energies* 12, no. 6: 964.

[2] Kumar, A., Kumar, K., Kaushik, N., Sharma, S., & Mishra, S. (2010). Renewable energy in India: current status and future potentials. Renewable and sustainable energy reviews, 14(8), 2434-2442.

[3] Kumar, A., & Sharma, S. (2011). Potential non-edible oil resources as biodiesel feedstock: an Indian perspective. Renewable and Sustainable Energy Reviews, 15(4), 1791-1800.

[4] Dash, S. K., & Lingfa, P. (2018, June). An overview of biodiesel production and its utilization in diesel engines. In IOP conference series: material science and engineering (Vol. 377, p. 012006).

[5] Malik, A., & Mohapatra, S. K. (2013). Biomass-based gasifiers for internal combustion (IC) engines-A review. Sadhana, 38(3), 461-476.

[6] Bates, R. P., & Dölle, K. (2017). Syngas use in internal combustion engines-A review. Advances in Research, 1-8.

[7] Banapurmath, N. R., Tewari, P. G., & Hosmath, R. S. (2008). Experimental investigations of a four-stroke single cylinder direct injection diesel engine operated on dual fuel mode with producer gas as inducted fuel and Honge oil and its methyl ester (HOME) as injected fuels. Renewable Energy, 33(9), 2007-2018.

[8] Banapurmath, N. R., Yaliwal, V. S., Hosmath, R. S., Indudhar, M. R., Guluwadi, S., & Bidari, S. (2018). Dual fuel engines fueled with three gaseous and biodiesel fuel combinations. Biofuels, 9(1), 75-87.

[9] Wallner T., Miers S.A. (2012) Internal Combustion Engines, Alternative Fuels for. In: Meyers R.A. (eds) Encyclopedia of Sustainability Science and Technology. Springer, New York, NY. https://doi.org/10.1007/978-1-4419-0851-3_865

[10] Ilhak, M. I., Tangoz, S., Akansu, S. O., & Kahraman, N. (2019). Alternative Fuels for Internal Combustion Engines. In The Future of Internal Combustion Engines. IntechOpen.

[11] Roy, M.M., Tomita, E., Kawahara, N., Harada, Y. and Sakane, A., 2009. Effect of fuel injection parameters on engine performance and emissions of a supercharged producer gas-diesel dual fuel engine (No. 2009-01-1848). SAE Technical Paper.

[12] Akkoli, K. M., N. R. Banapurmath, M. M. Shivashimpi, Manzoore Elahi M. Soudagar, Irfan Anjum Badruddin, Mashhour A. Alazwari, V. S. Yaliwal et al. "Effect of injection parameters and producer gas derived from redgram stalk on the performance and emission characteristics of a diesel engine." Alexandria Engineering Journal 60, no. 3 (2021): 3133-3142.

[13] Akkoli, K. M., N. R. Banapurmath, Manzoore Elahi M. Soudagar, T. M. Khan, Maughal Ahmed Ali Baig, M. A. Mujtaba, Nazia Hossain et al. "Effect of Producer Gas from Redgram Stalk and Combustion Chamber Types on the Emission and Performance Characteristics of Diesel Engine." Energies 14, no. 18 (2021): 5879.

[14] Kashipura, Nataraj, N. R. Banapurmath, G. Manavendra, A. M. Nagaraj, V. S. Yaliwal, Vaibhav Kulkarni, and Satish Gokak. "Effect of combustion chamber shapes on the performance of duel fuel engine operated on rice bran oil methyl ester and producer gas." J Pet Environ Biotechnol 6, no. 4 (2015): 1-8.

[15] Akkoli, K. M., P. B. Gangavati, and N. R. Banapurmath. "Effect of Cooling Cleaning System on the Performance and Emission Characteristics of Producer Gas Operated Dual-Fuel CI Engine." International Journal of Applied Engineering Research 14, no. 3 (2019): 687-693.

[16] Akkoli, K. M., P. B. Gangavati, M. R. Ingalagi, and R. K. Chitgopkar. "Assessment and Characterization of Agricultural Residues." Materials Today: Proceedings 5, no. 9 (2018): 17548-17552.

[17] Field, John L., Paul Tanger, Simon J. Shackley, and Stephan M. Haefele. "Agricultural residue gasification for low-cost, low-carbon decentralized power: An empirical case study in Cambodia." Applied Energy 177 (2016): 612-624.

[18] Miqdam Tariq Chaichan, Dina Saadi Muneam Al-Zubaidi, A practical study of using hydrogen in dual e fuel compression ignition engine, Int. J. Mech. Eng. (IIJME) 2 (11) (2014) 1e10. ISSN 2321e6441.

[19] M. Senthil Kumar, A. Ramesh, B. Nagalingam, Use of hydrogen to enhance the performance of a vegetable oil fuelled compression ignition engine, Int. J. Hydrog. Energy 28 (2003) 1143e1154.

[20] N.H. Ravindranath, P. Balachandra, Sustainable bioenergy for India: technical, economic and policy analysis, Energy 34 (2009) 1003e1013.