ISSN No:-2456-2165

Effect on the Emissions, Combustion, and Performance Characteristics of Karanja Oil Biodiesel and Di- tert Butyl Peroxide Assisted Using Hydrogen as a Secondary Fuel in a Diesel Engine

Satish Saw[1*]; Sunil Mahto[2]; Ashish Kumar Saha[2]; Navin Chandra[1]
[1]University Department of Physics, VBU, Hazaribagh, Jharkhand, India
[2]University Department of Chemistry, VBU, Hazaribagh, Jharkhand, India

Corresponding Author:- Satish Saw[1*]

Abstract:- The world faces major problems due to the growing need for fuel in daily life. Biodiesel is a desirable alternative fuel source that lowers engine emissions. In this paper, the effect on the emissions, combustion, and performance characteristics of Karanja oil biodiesel has been studied at a higher load (69%) in comparison to pure diesel fuel. The enhancement in the brake thermal efficiency (BTE) was observed to be 12.7% by the addition of 5% di- tert butyl peroxide (DTBP), 40% biodiesel of Karanja oil (BKO), and 16% hydrogen. The diminishment in nitrogen oxide (NO_x) emission was observed to be 14.38% with 5% DTBP, 40% BKO, and 7% hydrogen. Similarly, the diminishment in carbon monoxide (CO) emission was observed to be 5.01% by adding 3% DTBP, 30% BKO, and 25% hydrogen. The reduction in carbon dioxide (CO2) emission was 39.19% by adding 5% DTBP, 40% BKO, and 25% hydrogen as a secondary fuel. The diminishment in unburnt hydrocarbon (HC) emission has also been found. Finally, the diminishment in the net heat release rate (NHRR) and mean gas temperature (MGT) by the addition of biodiesel of Karanja oil (10%-40%) with or without hydrogen fuel in a diesel engine.

***Keywords:-** Karanja oil, Di-tert butyl peroxide, Hydrogen fuel, Emission, Combustion, and Performance*

I. INTRODUCTION

The worldwide energy consumption has increased up to 53% as predicted by the International Energy Agency (IEA) [1-2]. Air fuel consumption has risen from 86.1 million barrels to 110.6 million per day as predicted by Energy Information Administration (EIA) projections [3-4]. Biodiesel is more eco-friendly than fossil fuels because of the less production of smoke and carbon dioxide that is responsible for global warming [5]. The US Environmental Protection Agency (EPA) shows that pure biodiesel enhanced NOx 10% more in comparison to diesel [4, 6]. This result may be a serious problem for market adoption.

In comparison to other conventional fuels, biodiesel is a carbon-containing substance, renewable, and offers superior environmental benefits resulting in lower emissions of carbon monoxide (CO), and aromatic hydrocarbons (HC) along with particulate matter (PM) [1, 3–8]. Fuel efficiency declines as a result reduction in the heating value of biodiesel as well as power output produced during combustion [3, 11]. Dual fuel combustion with hydrogen assisted is investigated as a potential remedy to improve the lower power issue that biodiesel combustion faces and improve the process of biodiesel emission and combustion production. When it comes to combustion and emissions, hydrogen is far better than other liquid or gaseous fuels. For instance, burning hydrogen does not release any hazardous emissions like HC, CO, or sulfur oxides since hydrogen does not contain a carbon atom.

In general, biodiesel in CI engines permits less carbon monoxide (CO), smoke, and hydrocarbon (HC) while increasing the emissions of NO_x since biodiesel contains more oxygen molecules [7-17]. To reduce dependency on fossil fuels, and environmental and health effects, developing countries utilize biodiesel [18]. Biodiesel can be made with edible and non-edible waste and recycles vegetable oils and animal fats through the transesterification method [19]. Biodiesel has a lot of demerits such as high molecular weight, high viscosity, high Power-point, and low volatility in comparison to pure diesel. These deficiencies are caused decrement in atomization as well as partial combustion [20-21]. In comparison to pure diesel, Karanja (Pongamia) biodiesel produces higher emissions of NO_x. Devan et al. show the increment in brake thermal efficiency when biodiesel is mixed with pure diesel but at higher load conditions, pure biodiesel emits more smoke [22]. Some combined study analyzes the emissions and performance for the combustion of biodiesel with the diminishment of NO_x emissions [23-24].

In the present study, the enhancement in the BTE was observed by the addition of different proportions of BKO, and DTBP using hydrogen as a secondary fuel in a diesel engine. Now, variation of emissions of various gases such as NO_x, HC, CO_2, and CO with a proportion of BKO, and

DTBP using hydrogen as a secondary fuel in a diesel engine, the reduction was observed. The diminishment in the net heat release rate (NHRR) and mean gas temperature (MGT) were observed by the addition of different proportions of biodiesel with or without hydrogen substitution.

II. EXPERIMENTAL PROCESS

A single cylinder four strokes having a power of 3.5 KW @ 1500 rpm including compression ratio for the model Kirloskar TV1 was used to modify an experimental work in dual fuel mode (Fig. 1 (a)) in a diesel engine. Eddy current type dynamometer was connected to the engine had set up for loading purposes. The scientific capacity of the engine has been listed in Table 1.

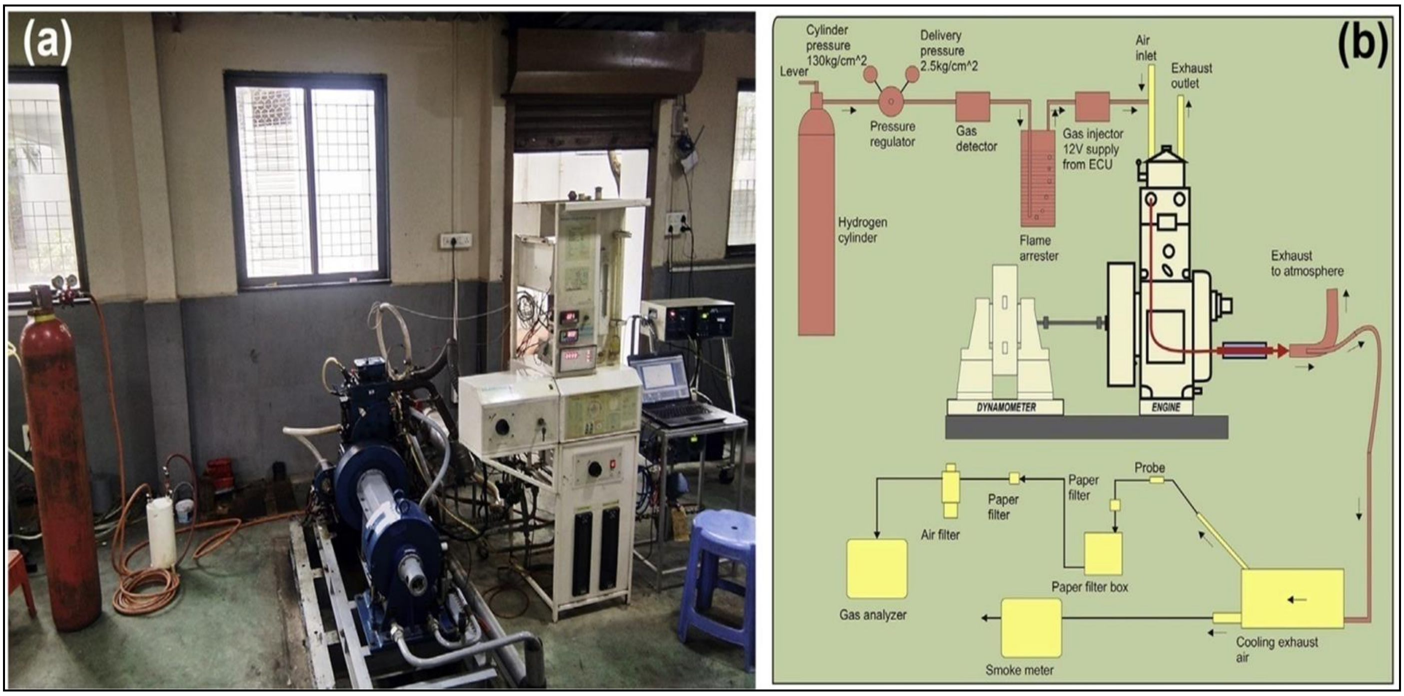

Fig 1 (a)-Photographic view of the Experiment set-up and (b)-Schematic view of the experimental set-up [25].

Table 1 Scientific capacity of the engine [26].

S. No.	Factors	Measurements	Units
1	Make and model	Model Kirloskar, TV1	-
2	Engine type	Single cylinder four-strokes, CI engine, etc.,	-
3	No. of cylinder	1	-
4	Bore × stroke	87.50 × 110	Mm × mm
5	Rated speed	1500	RPM
6	Swept volume	661.45	cc
7	Compression ratio	18	-
8	Injection pressure	224.11	bar
9	Rated power	3.5	KW
10	Inlet temperature	300	K
11	Injection timing before top center (BTDC)	19	°C
12	Inlet pressure	1.03	bar

Table 2 Properties of Biodiesel of Karanja Oil (B100)

Properties	Unit	Biodiesel of Karanja oil
Fire point	°C	74
Density at 25°C	kg/m^3	885
Kinematic viscosity @40°C	cSt	5.31
Dynamic Viscosity @40°C	cP	4.7
Flash Point	°C	68
HCV Calorific Value	Cal\gm	9414
LCV Calorific Value	Cal\gm	8828

Table 3 The Experimental Investigation of the Test Template at High Load (69%).

Case No.	Primary Fuel	Biodiesel of Karanaja oil (BKO)	DTBP (Additive)	Secondary Fuel
1	Pure Diesel	-	-	-
2	Pure Diesel	BKO	-	-
3	Pure Diesel	-	DTBP (Additive)	H_2 fuel
4	Pure Diesel	-	-	H_2 fuel
5	Pure Diesel	BKO	-	H_2 fuel
6	Pure Diesel	-	DTBP (Additive)	H_2 fuel
7	Pure Diesel	BKO	DTBP (Additive)	H_2 fuel

III. METHODS AND MATERIALS

For the experiment, a dual-fuel diesel engine running on hydrogen as a secondary fuel utilized biodiesel made from Karanja oil with di-tert butyl peroxide added as an additive. The features of biodiesel of Karanja oil (BKO) are summarized in Table 2 and the experimental investigations of the test template at high load (69%) are listed in Table 3. An organic compound known as an additive (DTBP) consists of a peroxide group that is directly bonded to two tert-butyl groups. This is one of the most stable organic peroxides available. The chemical formula for di-tert butyl peroxide (DTBP) is $C_8H_{18}O_2$ [27].

- *Mechanisms of NO_x:*

The standard name for NO and NO_2 is denoted by the formula NO_x which is nitrogen oxide. It's critical to realize the kinetics of NO_x-like reactions to decrease NO_x emissions [28]. The two main mechanisms to produce NO_x in biodiesel combustion chemistry are prompt and thermal among others [28]. When ordinary petroleum along with bio-based fuels burn conventionally for generation of NO_x as a primary source is air or molecular nitrogen. The primary sources of nitrogen for NO_x during conventional burning of ordinary petroleum and bio-based fuels. The production of general mechanisms for NO_x are outlined below and drawn from several literature sources [11, 23, 29-33].

- *Zeldovich Mechanism*

Nitrogen and oxygen combine via several chemical steps at 1700 K temperature and undergo NO_x formation using the Zeldovich mechanism [23]. Now, an increase in the temperature leads to an enhancement in the reaction rate of formation. Equations (1) - (3) mentioned below talk about the fundamental kinetic for the formation of NO_x thermally and the total amount of NO_x is considered to be a transcendent donor.

$$N_2 + O \rightarrow NO + N \quad (1)$$

$$N + O_2 \rightarrow NO + O \quad (2)$$

$$N + OH \rightarrow NO + H \quad (3)$$

To proceed with rate limiting equation (1), required high temperature and high activation energy (314 KJ/mole). The oxygen and nitrogen concentration and time duration also affect to creation of thermal NO [27]. Hu and Huang [34] provide theoretical evidence that temperature and reactant concentration are the two main determinants of NO_x production.

- *Prompt or Fenimore Mechanism*

Fenimore was the first to discover the formation of NO_x through a second mechanism named prompt NO_x. There is strong evidence that in certain combustion situations such as low temperatures, fuel concentrations, and brief residence times, quick NO_x can develop in considerable amounts [33, 35]. When nitrogen reacts with hydrocarbons in the combustion chamber forms nitrogen species like HCN and also prompts NO_x [36]. The prompt NO_x must be taken into account when estimating the total NO_x, according to Miller and Bowman's [37] study on the modeling and mechanism of nitrogen combustion chemistry. This finding was also supported in recent work by Ren and Li [38].

The prompt NO_x is formed through the mechanism of the following reactions (4) to (8).

$$CH + N_2 \leftrightarrow HCN + N \quad (4)$$

$$CH_2 + N_2 \leftrightarrow HCN + NH \quad (5)$$

$$N + O_2 \leftrightarrow NO + O \quad (6)$$

$$HCN + OH \leftrightarrow CN + H_2O \quad (7)$$

$$CN + O_2 \leftrightarrow NO + CO \quad (8)$$

Here, CH and CH_2 contribute to the formation of prompt NO_x (Eqs. (4), and (5)) and are proportional to the carbon atoms in unit volume. The concentration of hydrocarbon radicals rises with an increment in the equivalency ratio that increases the amount of HCN. When the equivalency ratio rises, prompt NO_x generation rises until it peaks and then falls due to a lack of oxygen.

IV. RESULT AND DISCUSSION

- *Brake Thermal Efficiency (BTE)*

The brake thermal efficiency of fuel is a measurement of chemical energy that is converted to mechanical work (power) [39]. In Fig. 2, the sharp enhancement in the BTE by adding 30% biodiesel of Karanja oil (BKO) in case 2 and 30% BKO and 25% H_2 as a secondary fuel (case 5) at 69% load condition in comparison to pure diesel. However, the enhancement in BTE by adding BKO above 40% rather than decreased by adding BKO above 40% and 25% H_2 as a secondary fuel in comparison to pure diesel at 69% load condition. Moreover, the sharp decrease in the BTE was observed to be 4.8% using 7% H_2 as a secondary fuel in diesel engines in contrast to pure diesel (case 4), the reason may be lower calorific value and high viscosity [40-41]. Finally, gradual enhancement in BTE was observed by the addition of H_2 as a secondary fuel from 11% to 25%.

Now, in Fig. 3, the regular enhancement in BTE by adding DTBP as an additive (case 3) from 1% to 5% in contrast to pure diesel at 69% load condition and also, the enhancement in BTE by adding 1% DTBP and 25% H_2 as an additive (case 6) due to larger oxygen content, lower viscosity as well as density of the fuel and also increase in cetane number **[42],** however, almost constant in the BTE by adding DTBP from 3% to 5% and 25% H_2 as a secondary fuel at 69% load condition.

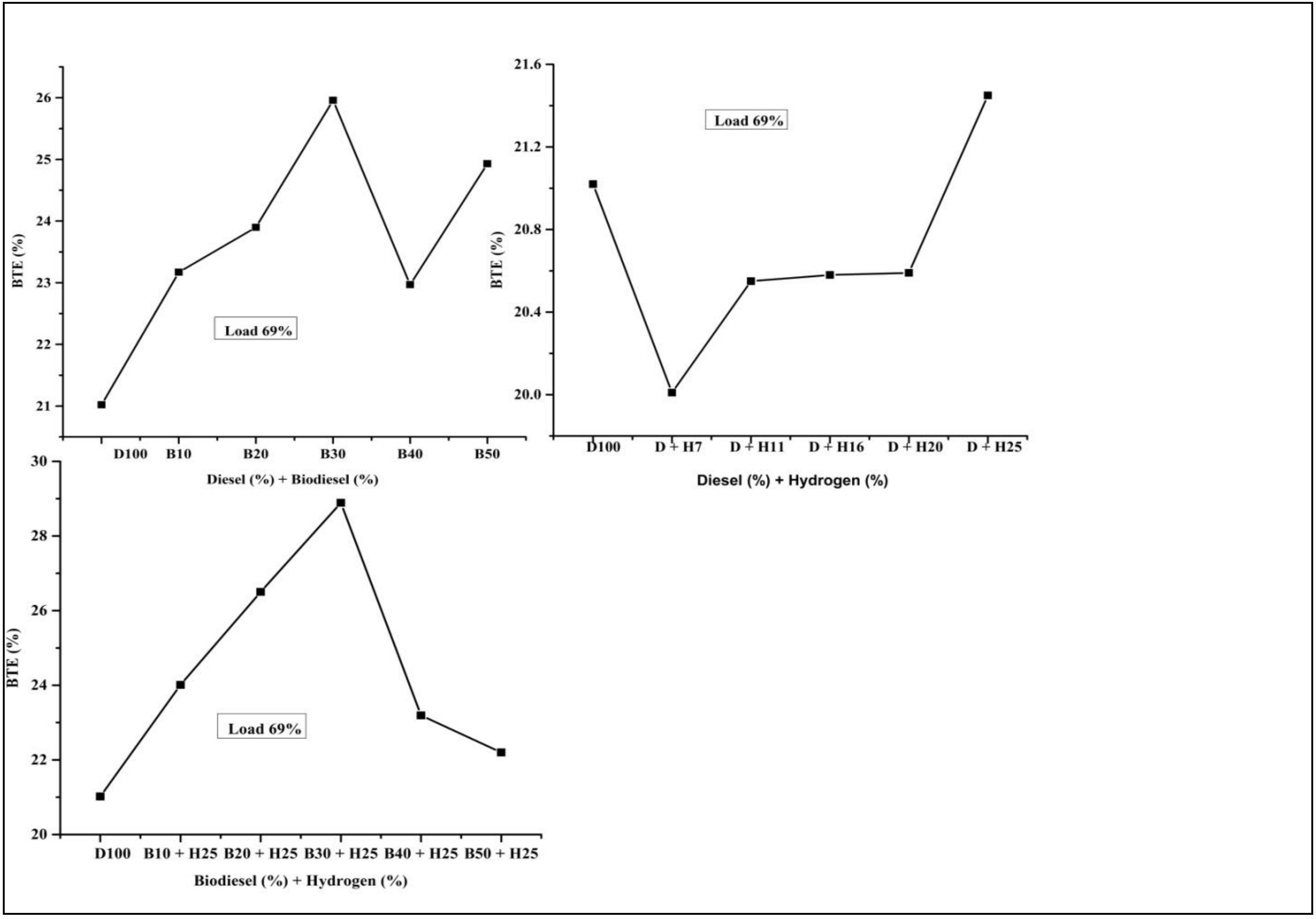

Fig 2 Variation of Brake Thermal Efficiency (BTE) versus Different Percentages of BKO as well as Hydrogen.

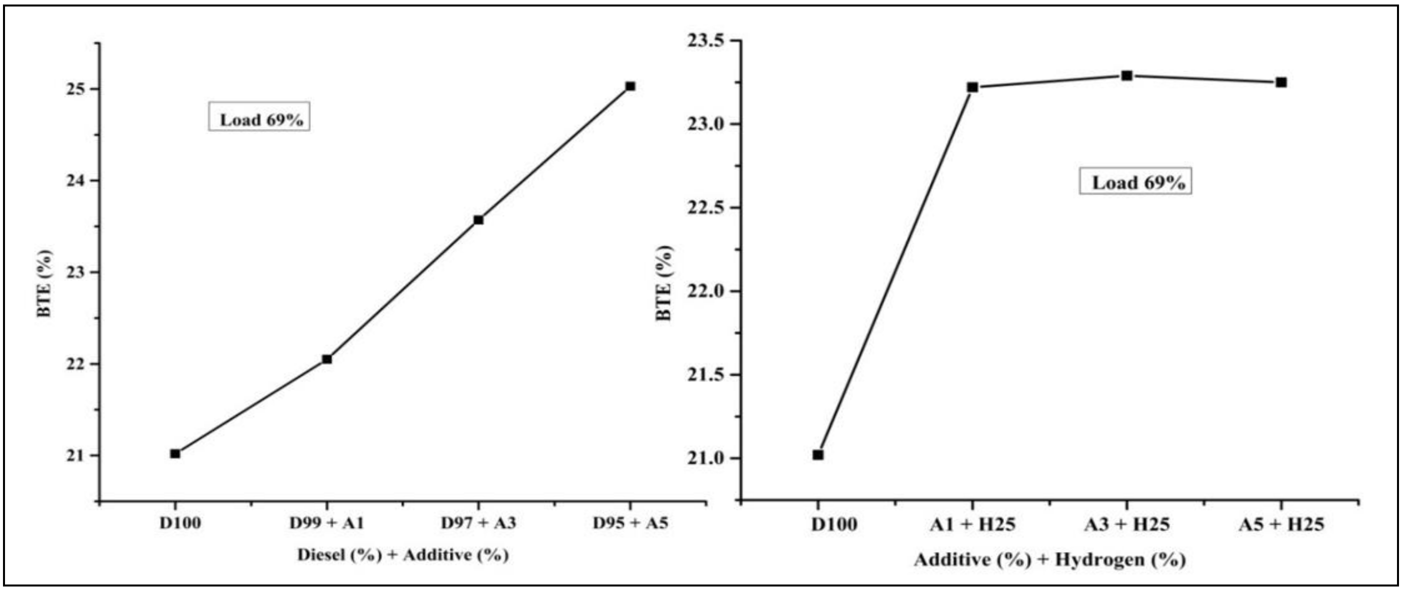

Fig 3 Variation of Brake Thermal Efficiency (BTE) Versus Different Percentages of DTBP with Hydrogen.

In Fig. 4 (case 7), the enhancement in the BTE was observed to be 4.28% by the addition of 1% DTBP, 20% BKO, and 7% hydrogen, 6.3% by the addition of 3% DTBP, 30% BKO, and 11% hydrogen and 12.7% by the addition of 5% DTBP, 40% BKO and 16% hydrogen respectively at 69% load condition. However, the gradual diminishment in BTE by the addition of 1% DTBP, 20% BKO, and hydrogen from 7% to 25%, 3% DTBP, 30% BKO, and hydrogen from 11% to 16% and 5% DTBP, 40% BKO, and hydrogen from 16% to 25% at 69% load condition.

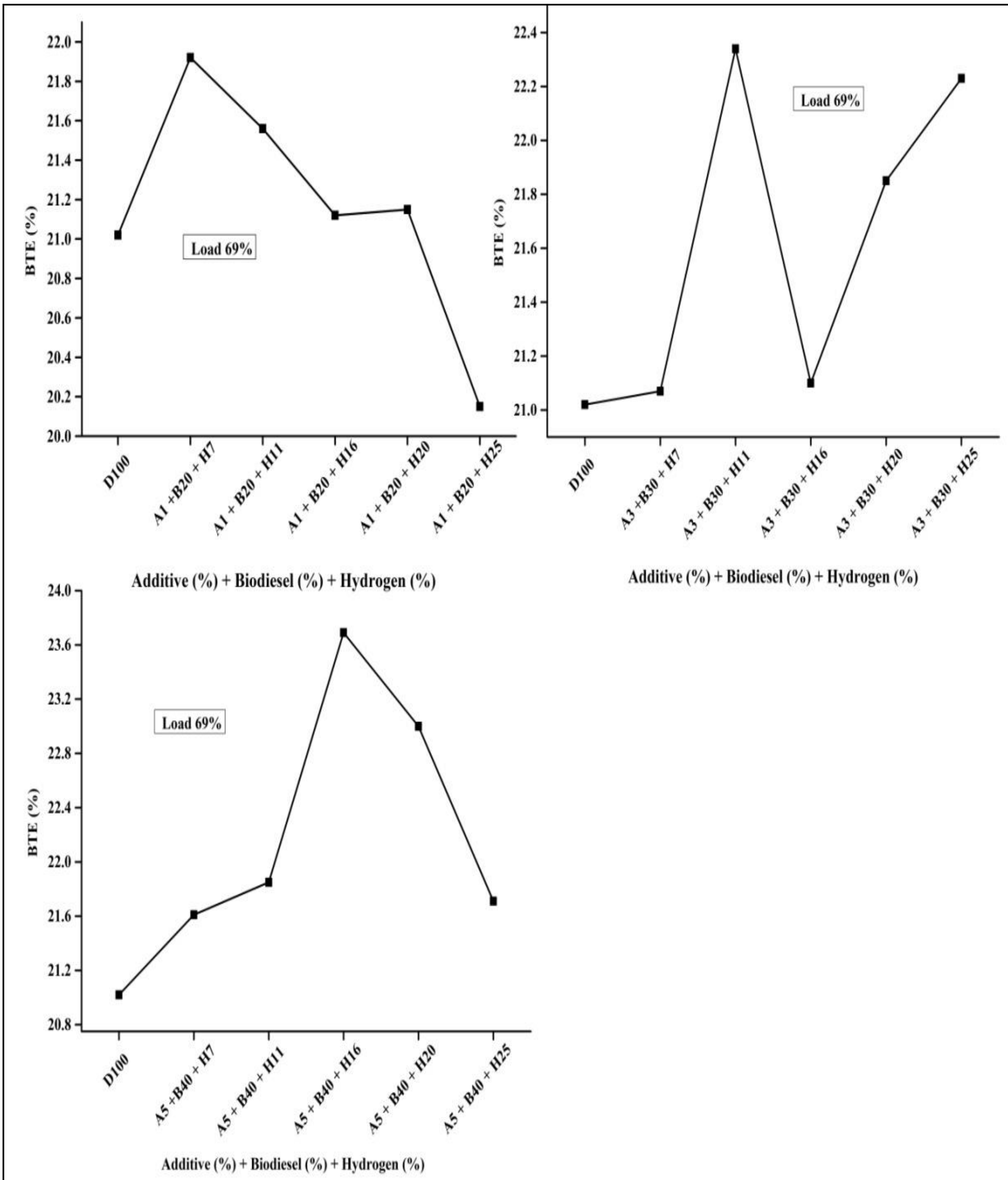

Fig 4 Variation of Brake Thermal Efficiency (BTE) Versus Different Percentages of DTBP, BKO, and Hydrogen.

➤ *Emissions of Various Gases in Diesel Engine*

Now, in Fig. 5, the regular diminishment in NO_x emission was observed by the addition of BKO (case 2) from 10% to 50% and also addition of BKO from 1% to 10% with 25% H_2 as a secondary fuel (case 5) in contrast to pure diesel at 69% load condition, however, the gradual enhancement in NO_x emission by the addition of BKO from 10% to 50% with 25% H_2 as a secondary fuel (case 5) at 69% load condition. Finally, an irregular trend was observed in NO_x emission by the addition of H_2 as a secondary fuel from 7% to 25% in diesel engines at 69% load condition.

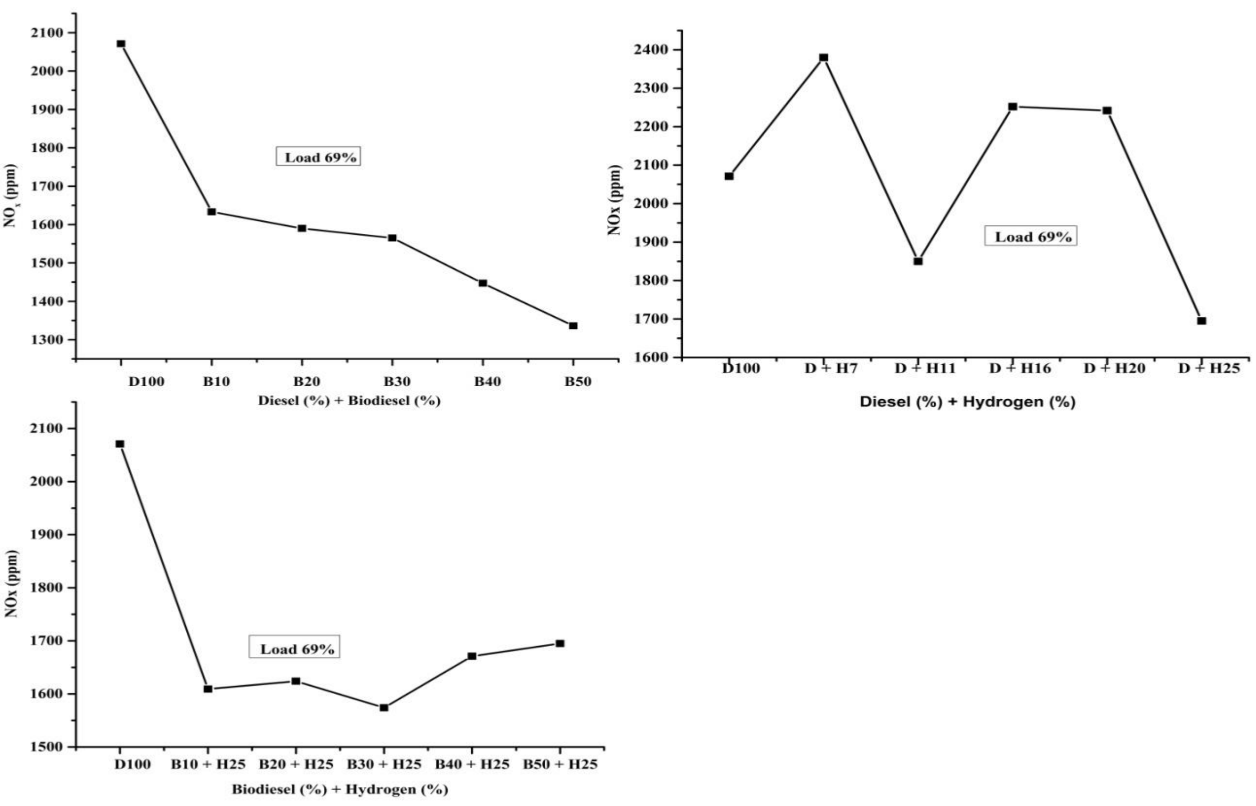

Fig 5 Variation of NO_x (ppm) Emission Versus Different Percentages of BKO as well as Hydrogen.

In Fig. 6, the regular enhancement in NO_x emission by the addition of DTBP as an additive (case 3) from 1% to 5% in contrast to pure diesel at 69% load condition and also, the enhancement in the NO_x by the addition of DTBP up to 1% and 25% H_2 as a secondary fuel (case 6). However, the gradual diminishment in NO_x emission by the addition of DTBP from 1% to 5% and 25% H_2 as a secondary fuel at 69% loads condition. Now, in Fig. 7 (case 7), the gradual diminishment in the NO_x emission was observed to be 16.85% by the addition of 1% DTBP, 20% BKO and 11% hydrogen, 12.50% by addition of 3% DTBP, 30% BKO, and 11% hydrogen and 14.38% by the addition of 5% DTBP, 40% BKO and 7% hydrogen respectively at 69% load condition. Further shows the gradual diminishment in the NO_x emission by the addition of 1% DTBP, 20% BKO, and hydrogen from 20% to 25%, 3% DTBP, 30% BKO, and hydrogen from 16% to 25%, and 5% DTBP, 40% BKO, and hydrogen from 20% to 25% at 69% load condition due to increase in the temperature of the combustion chamber and the phenomenon of NO_x formation completely dependent on temperature [43-44].

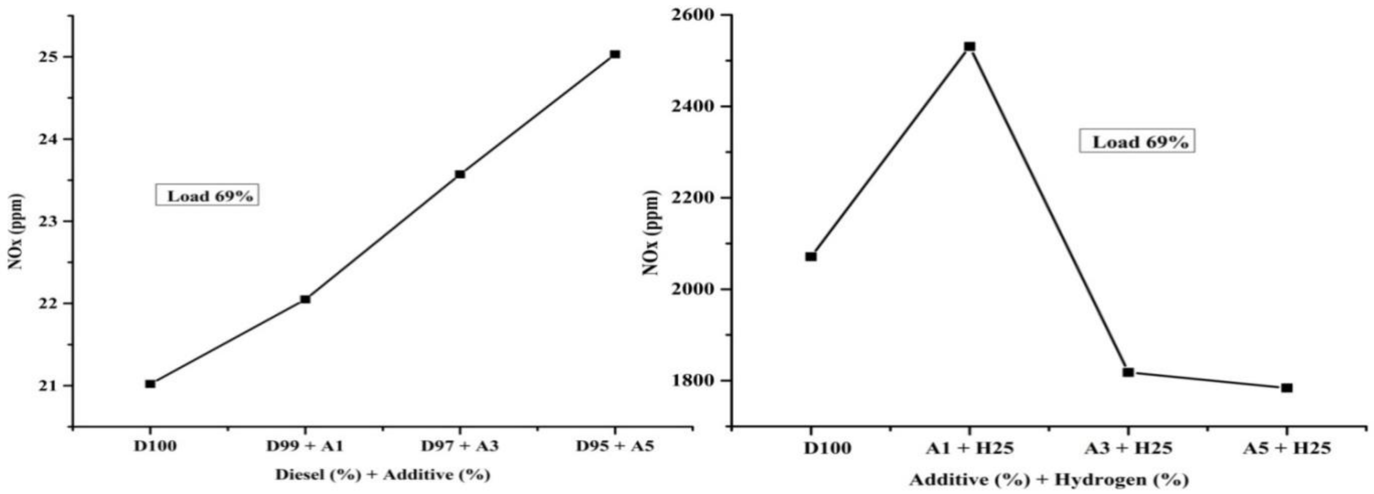

Fig 6 Variation of NO_x (ppm) Emission Versus Different Percentages of DTBP with Hydrogen.

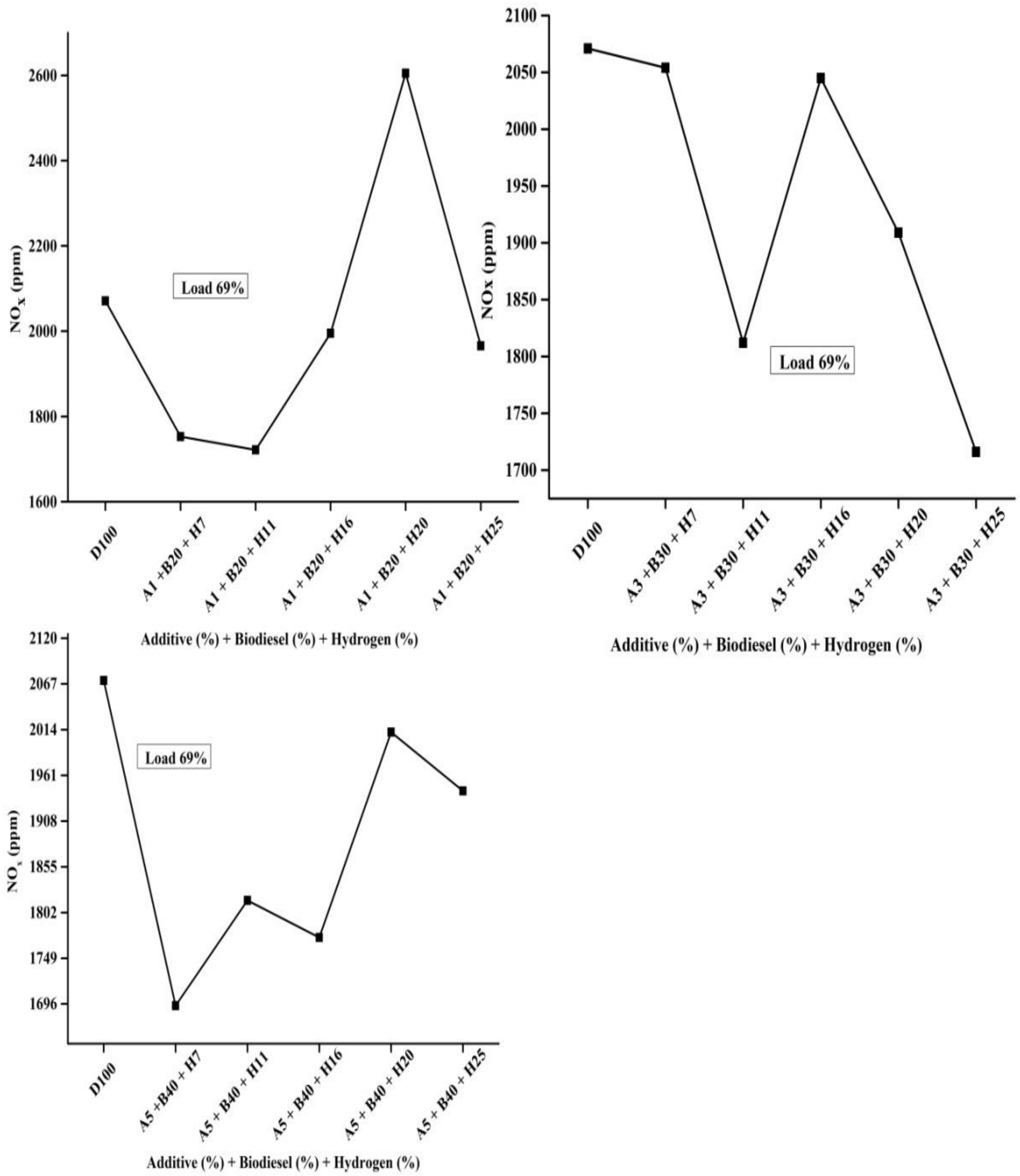

Fig 7 Variation of NO_x (ppm) Emission Versus Different Percentages of DTBP, BKO, and Hydrogen.

Now, in Fig. 8, the sharp diminishment in CO emission was observed by the addition of 10% BKO (case 2) and also the addition of 10% BKO with 25% H_2 as a secondary fuel (case 5) in contrast to pure diesel at 69% load condition, further, the gradual enhancement in CO emission by the addition of BKO from 20% to 50% and also by the addition of BKO from 20% to 50% with 25% H_2 as a secondary fuel (case 5) at 69% load condition. Finally, the gradual diminishment in CO emission was observed by the addition of hydrogen from 7% to 25% (case 2) in diesel engines at 69% load condition due to an increase in the percentage of hydrogen, the degree of burning increases which causes lowering of CO emission. Also, at a high degree of burning, temperature increases which causes dissociation of CO.

In Fig. 9, the gradual diminishment in CO emission by the addition of DTBP as an additive (case 3) from 1% to 5% and also, the enhancement in NO_x by the addition of 1% DTBP and 25% H_2 as a secondary fuel (case 6) in contrast to pure diesel at 69% load condition respectively.

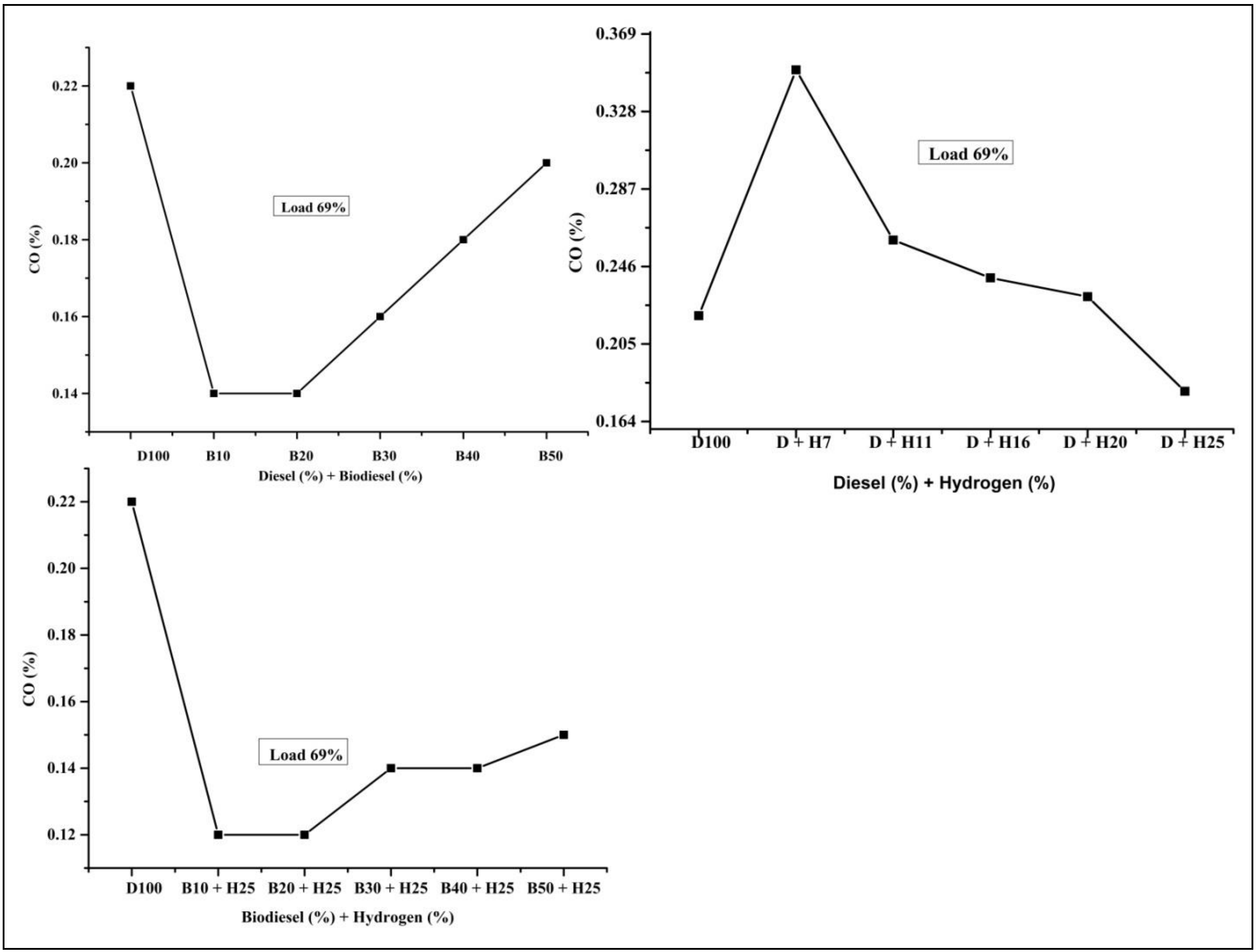

Fig 8 Variation of CO (%) Emission Versus Different Percentages of BKO as well as Hydrogen.

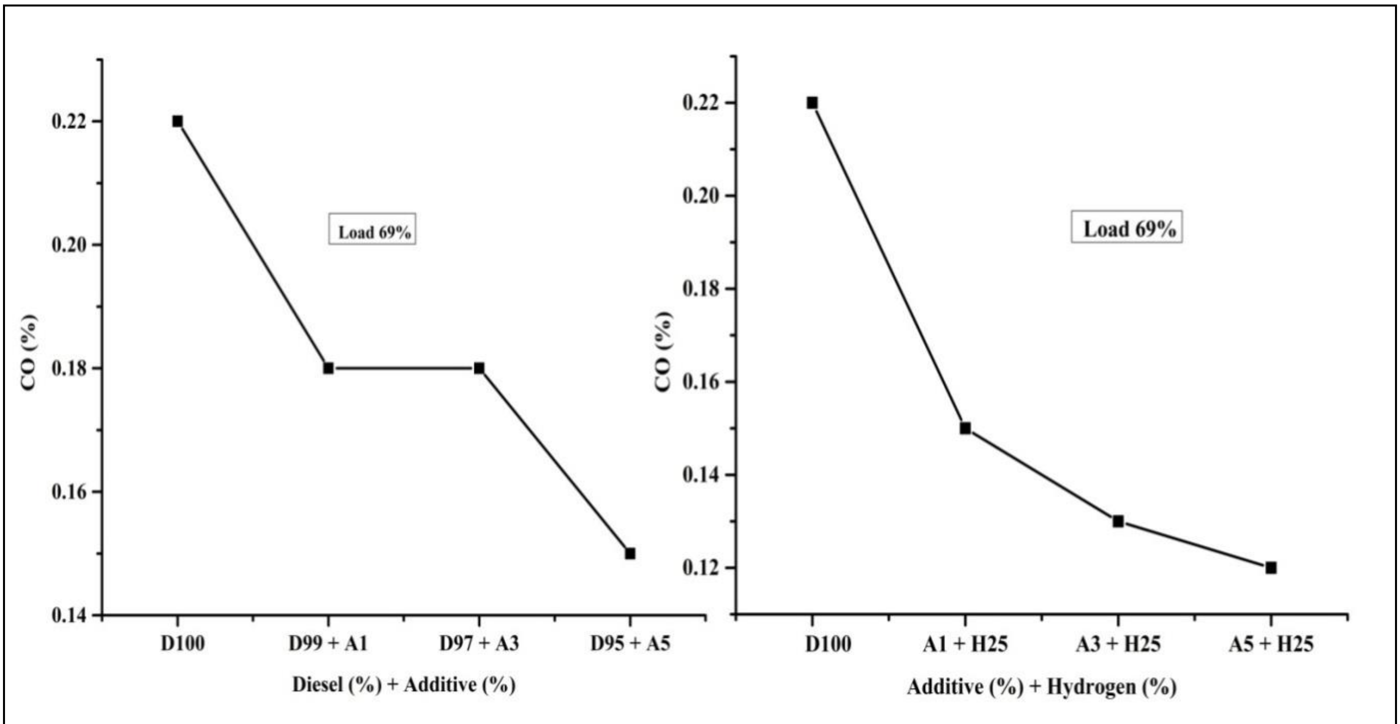

Fig 9 Variation of CO (%) Emission Versus Different Percentages of DTBP with Hydrogen.

Now, in Fig. 10 (case 7), the gradual diminishment in the CO emission was observed to be 18.18% by the addition of 1% DTBP, 20% BKO, and 25% hydrogen, 5.01% by the addition of 3% DTBP, 30% BKO and 25% hydrogen, however, 7.01% enhancement in the CO emission by the addition of 5% DTBP, 40% BKO, and 25% hydrogen as a secondary fuel respectively at 69% load condition in comparison to pure diesel condition.

The reaction of hydrocarbon undergoes radical mechanism for the CO [45] formation as follows:

$RH \rightarrow R \rightarrow RO_2 \rightarrow RCHO \rightarrow RCO \rightarrow CO$

Where R is a radical of hydrocarbon, the reaction of CO combustion which is oxidized into CO_2 has a slower rate by the given reaction.

$CO + OH \rightarrow CO_2 + H$

Due to incomplete CO_2 conversion containing low oxygen in the rich fuel-air mixture, and burnt gases undergo rapid combustion to produce carbon monoxide [46].

Now, in Fig. 11, the diminishment in CO_2 emission was observed to be 18.92%, 41.89%, and 36.48% by the addition of 50% BKO (case 2), 25% H_2 as a secondary fuel (case 4) and 50% BKO with 25% H_2 as a secondary fuel (case 5) in contrast to pure diesel at 69% load condition. However, the gradual enhancement in CO_2 emission was observed by the addition of BKO from 10% to 50% (case 2) and BKO from 10% to 50% with 25% H_2 as a secondary fuel (case 5) rather than diminishment in CO_2 emission was observed by the addition of H_2 as a secondary fuel (case 4) from 16% to 25%. In Fig. 12, the abrupt enhancement in CO_2 emission was observed by the addition of DTBP as an additive (case 3) from 1% to 3% rather than the diminishment in CO_2 emission was observed by the addition of DTBP as an additive (case 6) from 1% to 3% with 25 % H_2 as a secondary fuel (case 4) at 69% load condition.

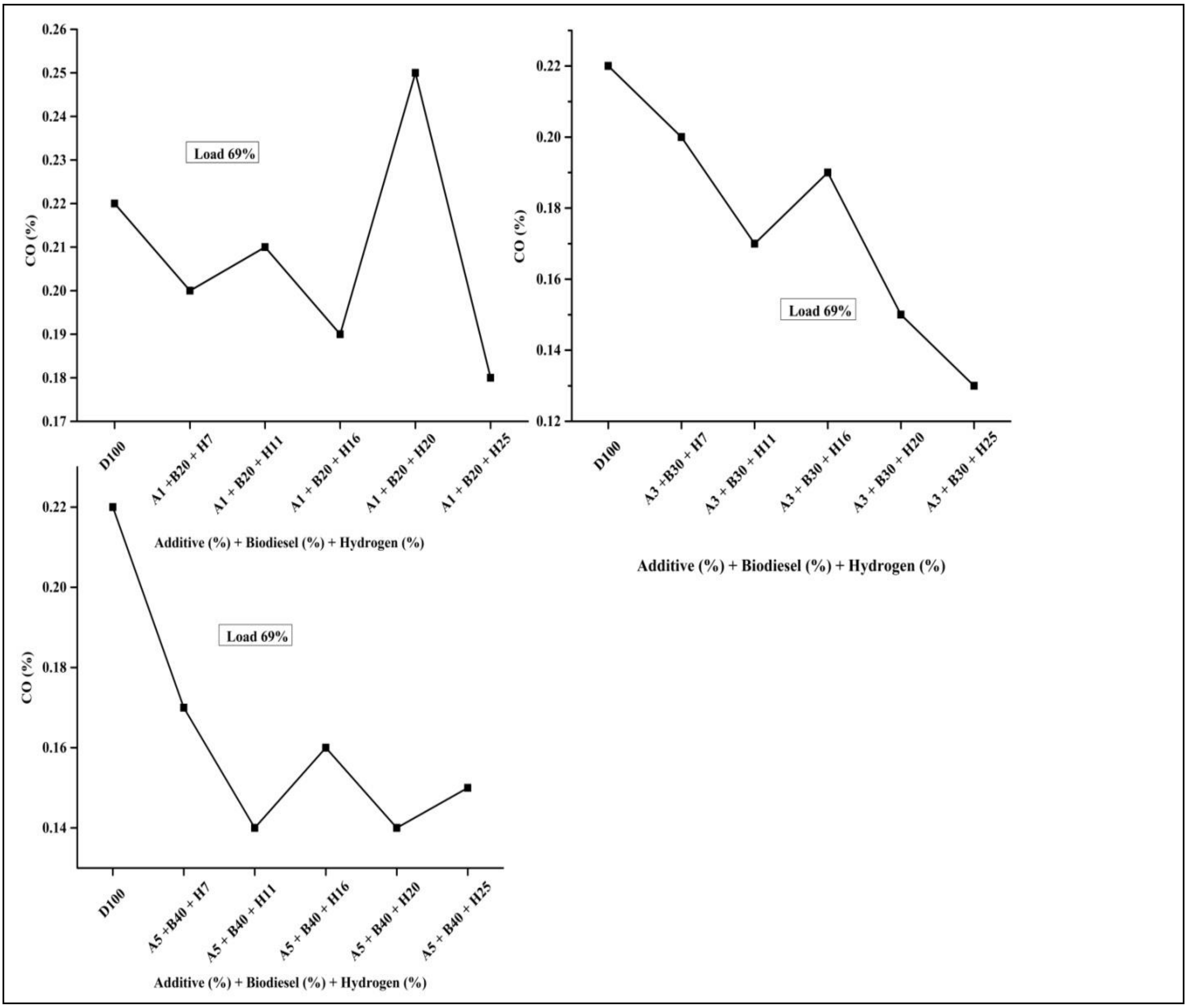

Fig 10 Variation of CO (%) Emission Versus Different Percentages of DTBP, BKO, and Hydrogen.

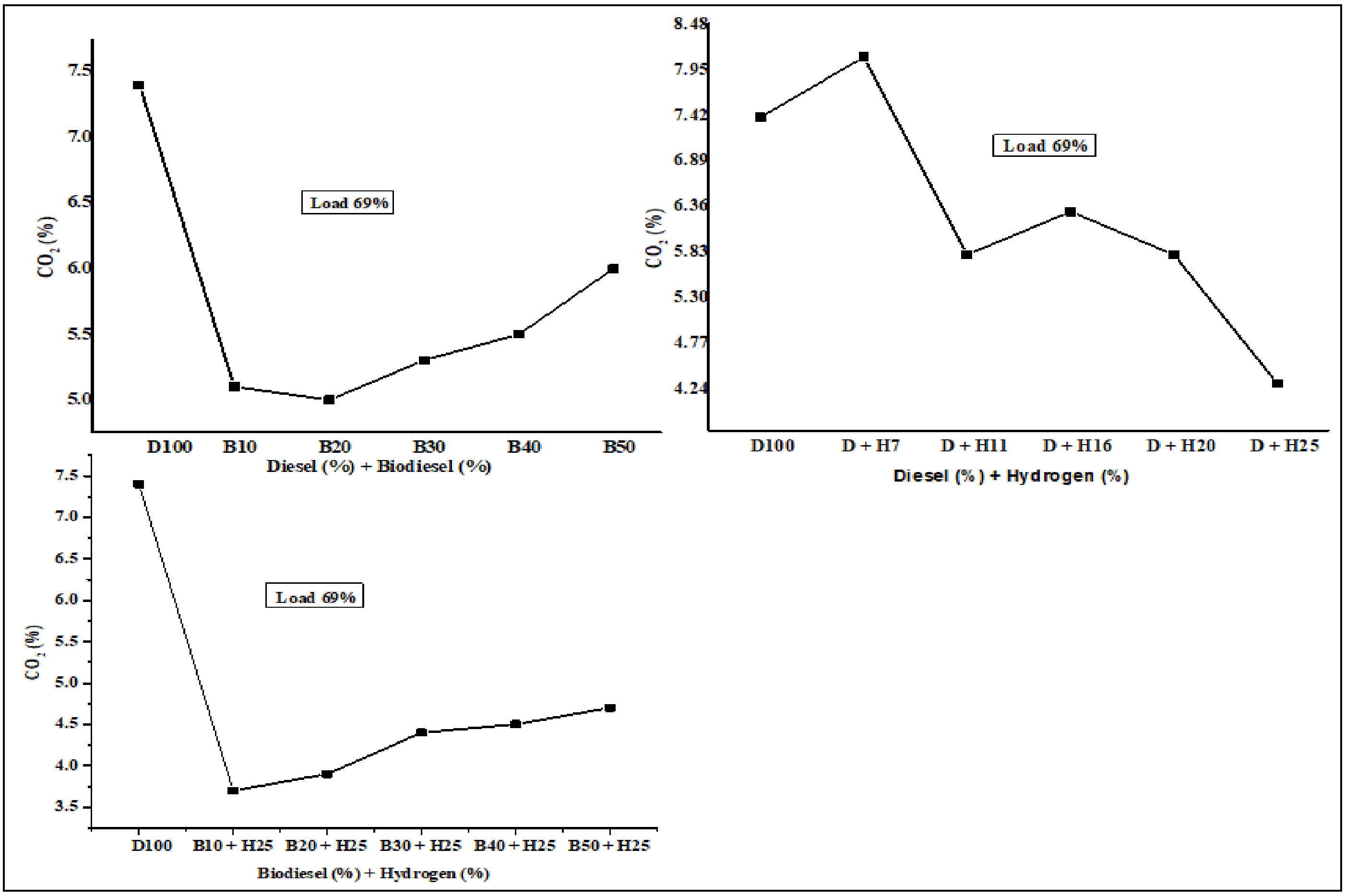

Fig 11 Variation of CO_2 (%) emission versus different percentages of BKO as well as hydrogen.

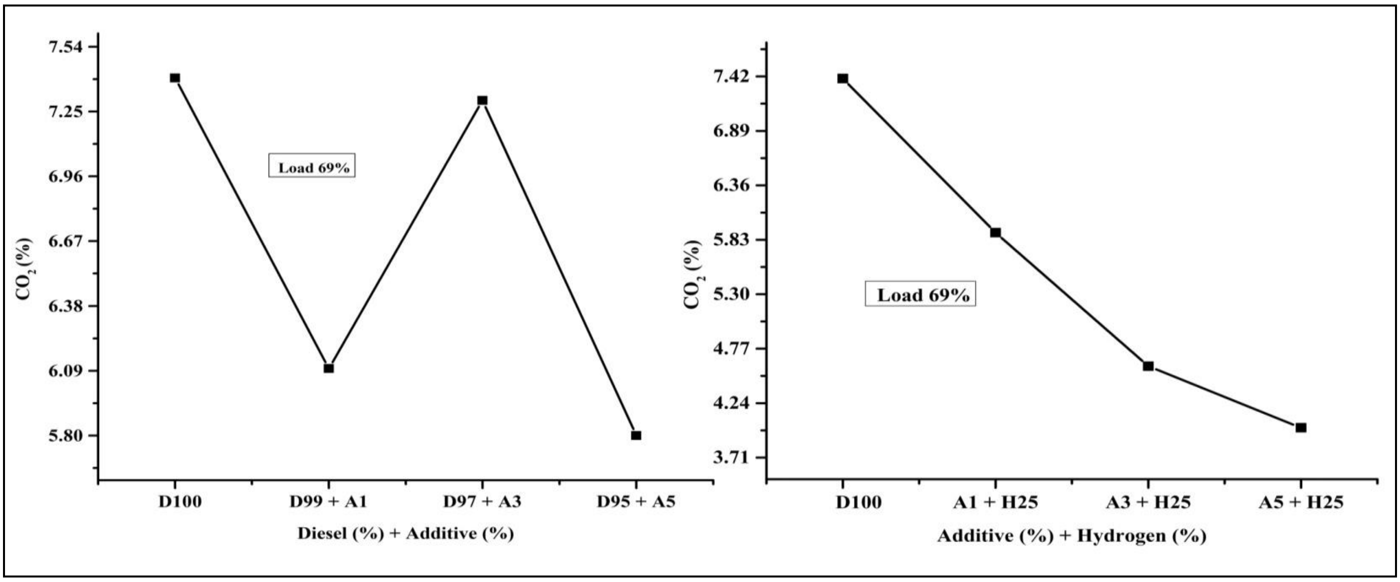

Fig 12 Variation of CO_2 (%) Emission Versus Different Percentages of DTBP with Hydrogen.

Now, in Fig. 13 (case 7), the diminishment in the CO_2 emission was observed to be 32.43% by the addition of 1% DTBP, 20% BKO, and 25% hydrogen, 44.59% by the addition of 3% DTBP, 30% BKO and 25% hydrogen and 39.19% by the addition of 5% DTBP, 40% BKO and 25% hydrogen as a secondary fuel respectively at 69% load condition in comparison to pure diesel condition. However, gradual enhancement by the addition of 1% DTBP, 20% BKO, and hydrogen (case 7) from 11% to 20% and 3% DTBP, 30% BKO and hydrogen from 11% to 16%. It may be concluded that by the addition of DTBP, biodiesel of Karanja and hydrogen mixed with pure diesel in different proportions contain larger oxygen amounts resulting in a decrease in the ignition delay as well as the viscosity of fuel. Also at the injection time of the fuel, temperature, and pressure increase leads to a decrease in the emission of CO_2 in the diesel engine when hydrogen is used as a secondary fuel.

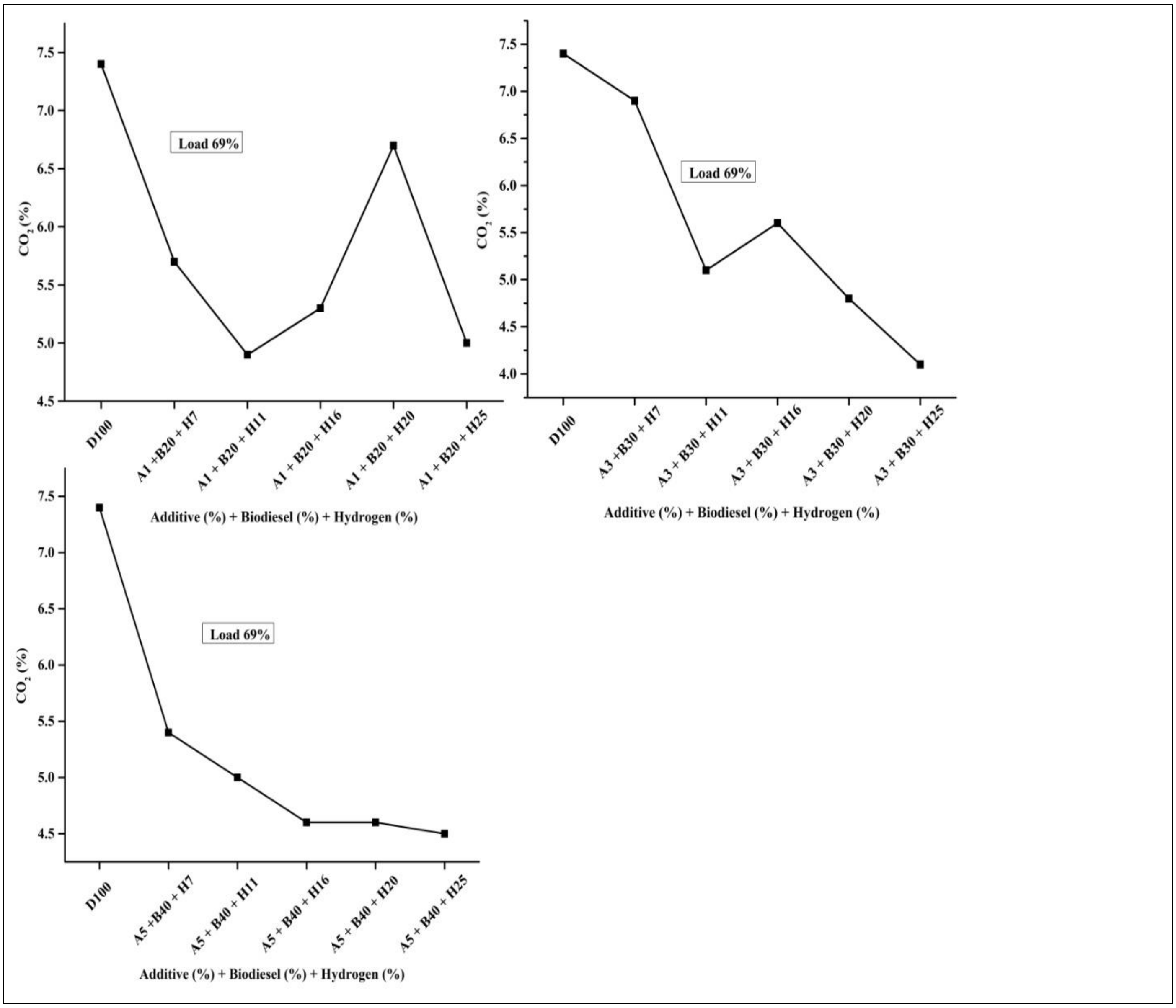

Fig 13 Variation of CO$_2$ (%) Emission Versus Different Percentages of DTBP, BKO, and Hydrogen.

Now, in Fig. 14, the diminishment in HC emission was observed to be 40%, and 48% by the addition of 10% BKO (case 2), and BKO from 10% to 50% with 25% H$_2$ as a secondary fuel (case 5) in contrast to pure diesel rather than enhancement in HC emission by the addition of 7% H$_2$ as a secondary fuel in a diesel engine as compared to pure diesel fuel at 69% load condition and further diminished by the addition of H$_2$ as a secondary fuel from 7% to 25%. In Fig. 15, the diminishment in HC emission was observed by the addition of DTBP as an additive from 1% to 3% with 25 % H$_2$ as a secondary fuel (case 6) or without the addition of H$_2$ as a secondary fuel (case 6).

Now, in Fig. 16 (case 7), the diminishment in the HC emission was observed by the addition of 1% DTBP, 20% BKO, and hydrogen as a secondary fuel from 7% to 16%, by the addition of 3% DTBP, 30% BKO, and hydrogen from 11% to 25%, and also by the addition of 5% DTBP, 40% BKO, and hydrogen from 7% to 25% respectively at 69% load condition in comparison to pure diesel. However, the sharp enhancement in the HC emission was observed by the addition of 1% DTBP, 20% BKO, and hydrogen (case 7) from 15% to 20% due to the addition of DTBP, biodiesel of Karanja, and hydrogen mixed with pure diesel in different proportion contain larger oxygen amount result decrease in the ignition delay as well as the viscosity of the fuel. Also, at the injection time of the fuel, temperature, and pressure increase leads to a decrease in the emission of HC in the diesel engine when hydrogen is used as a secondary fuel.

Further, the addition of hydrogen in dual-fuel diesel engines with or without DTBP as an additive and biodiesel of Karanja oil (BKO) lead to the reduction of HC emission. The homogeneity of the air-fuel blend gives complete combustion with a high rate of diffusivity and high hydrogen energy content in contrast to hydrocarbon fuel [14].

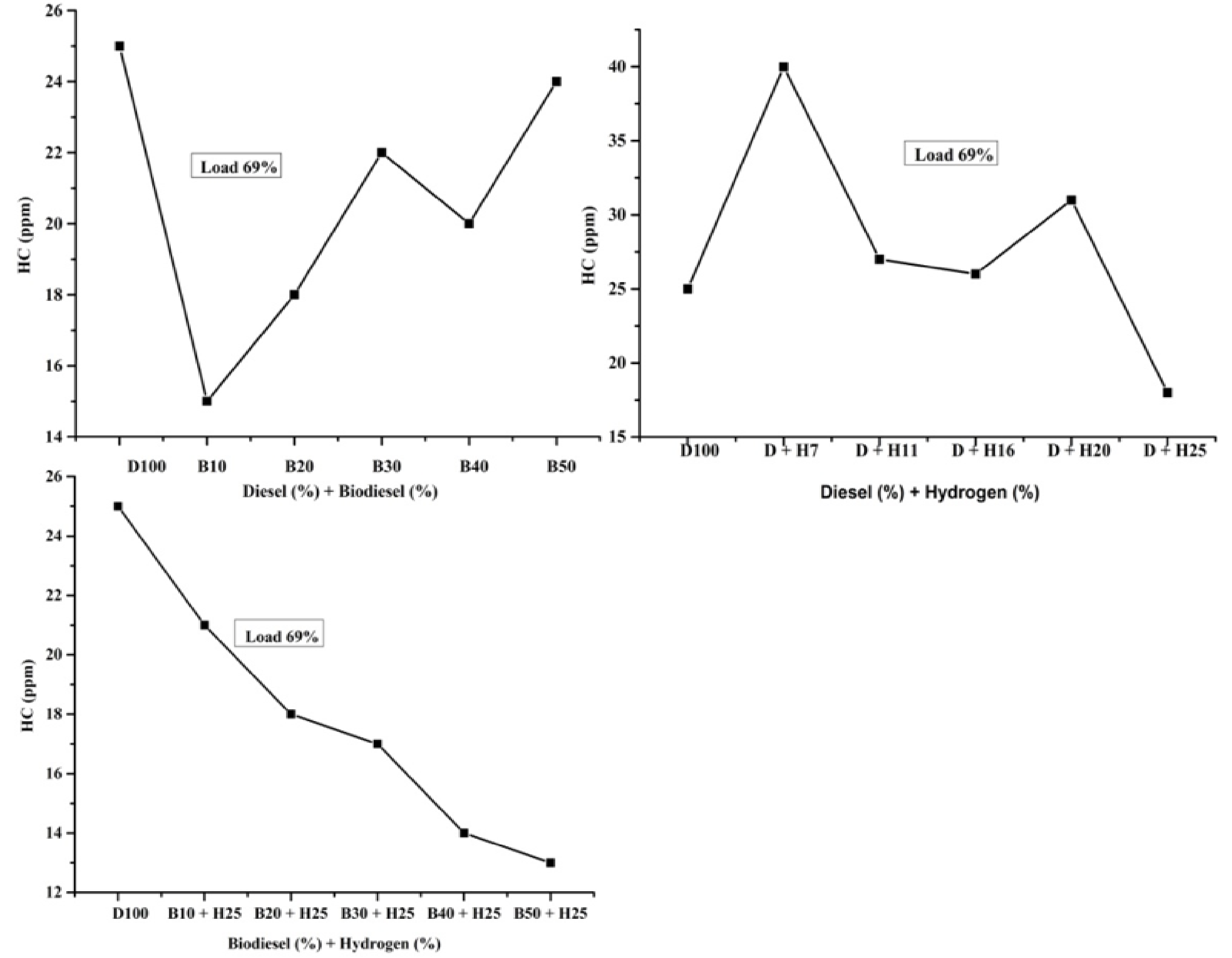

Fig 14 Variation of HC (ppm) Emission Versus Different Percentages of BKO as well as Hydrogen.

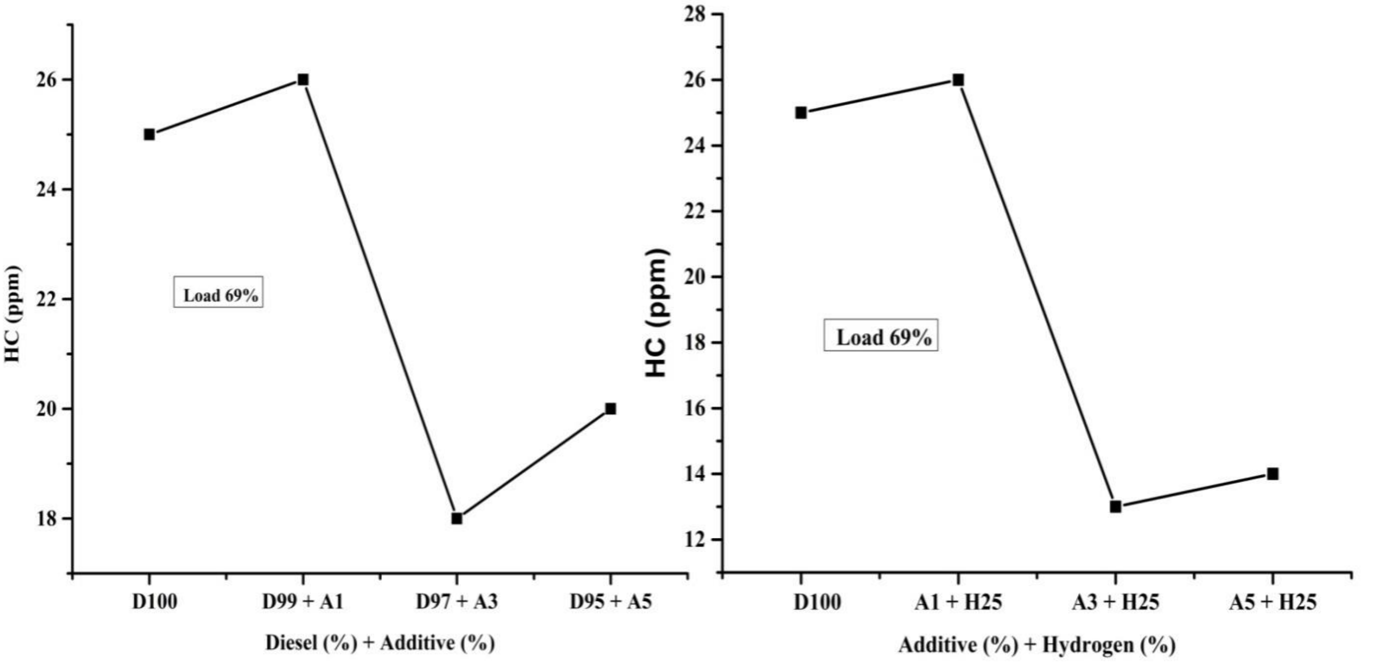

Fig 15 Variation of HC (ppm) Emission Versus Different Percentages of DTBP with Hydrogen.

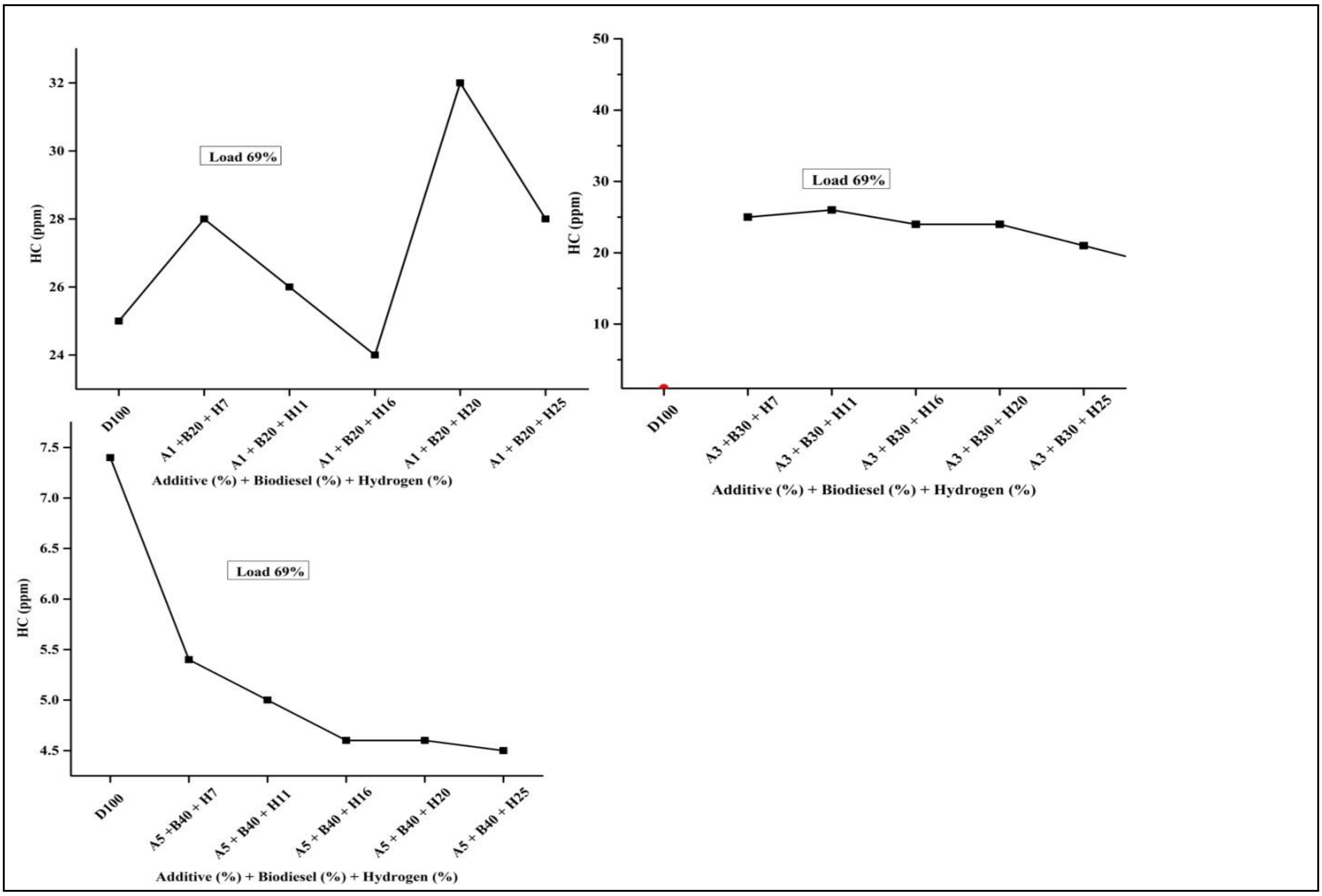

Fig 16 Variation of HC (ppm) Emission Versus Different Percentages of DTBP, BKO, and Hydrogen.

Fig. 17 shows the variation of net heat release rate (NHRR) versus Crank angle. At 69% load, the diminishment in the net heat release rate (NHRR) was observed by the addition of biodiesel of Karanja oil (BKO) from 10% to 40% with diesel fuel in comparison to pure diesel fuel. It is observed that when 30% BKO blended with pure diesel has the highest NHRR. This is due to the higher ignition delay. Now, Fig. 18 shows the variation of net heat release rate (NHRR) versus Crank angle. At 69% load, the diminishment in the net heat release rate (NHRR) by the addition of biodiesel of Karanja oil (BKO) from 10% to 40% and 25% hydrogen as a secondary fuel with diesel fuel in comparison to pure diesel fuel. It is observed that 30% BKO and 25% hydrogen as a secondary fuel blended with pure diesel have the highest NHRR. This is due to the higher ignition delay.

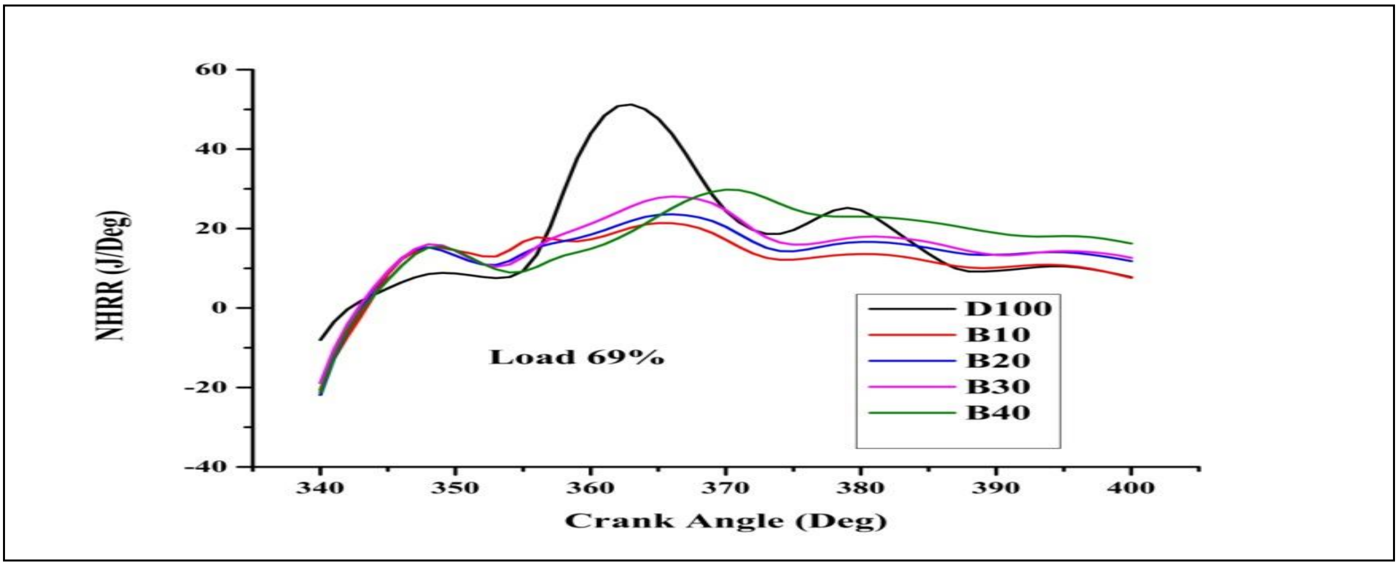

Fig 17 Variation of Net Heat Release Rate (NHRR) Versus Crank angle with Different Percentages of Biodiesel.

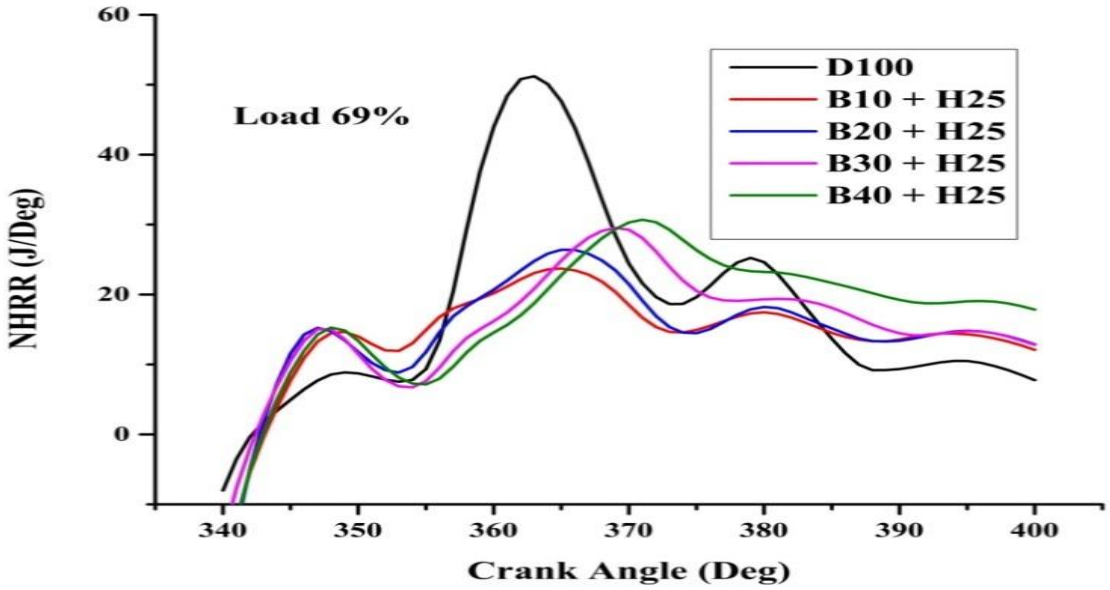

Fig 18 Variation of Net Heat Release Rate (NHRR) Versus Crank angle with Different Percentages of Biodiesel using H_2 as a Secondary Fuel.

Fig. 19 shows the variation of mean gas temperature (MGT) with Crank angle. At 69% load, the diminishment in the mean gas temperature (MGT) was observed by the addition of biodiesel of Karanja oil (BKO) from 10% to 40% with diesel fuel in comparison to pure diesel fuel. It is observed that when 30% BKO blended with pure diesel has the highest MGT. This is due to the lower heating value of mixed diesel fuel resulting in the reduction in the net heat release and accordingly diminishes the mean gas temperature.

Now, Fig. 20 shows the variation of mean gas temperature (MGT) with Crank angle. At 69% load, the diminishment in the mean gas temperature (MGT) by the addition of biodiesel of Karanja oil (BKO) from 10% to 40% and 25% hydrogen as a secondary fuel with diesel fuel in comparison to pure diesel fuel. It is observed that when 20% BKO and 25% hydrogen as a secondary fuel blended with pure diesel has the highest MGT. This is due to the lower heating value of mixed diesel fuel results in the reduction in the net heat release and accordingly diminishes the mean gas temperature.

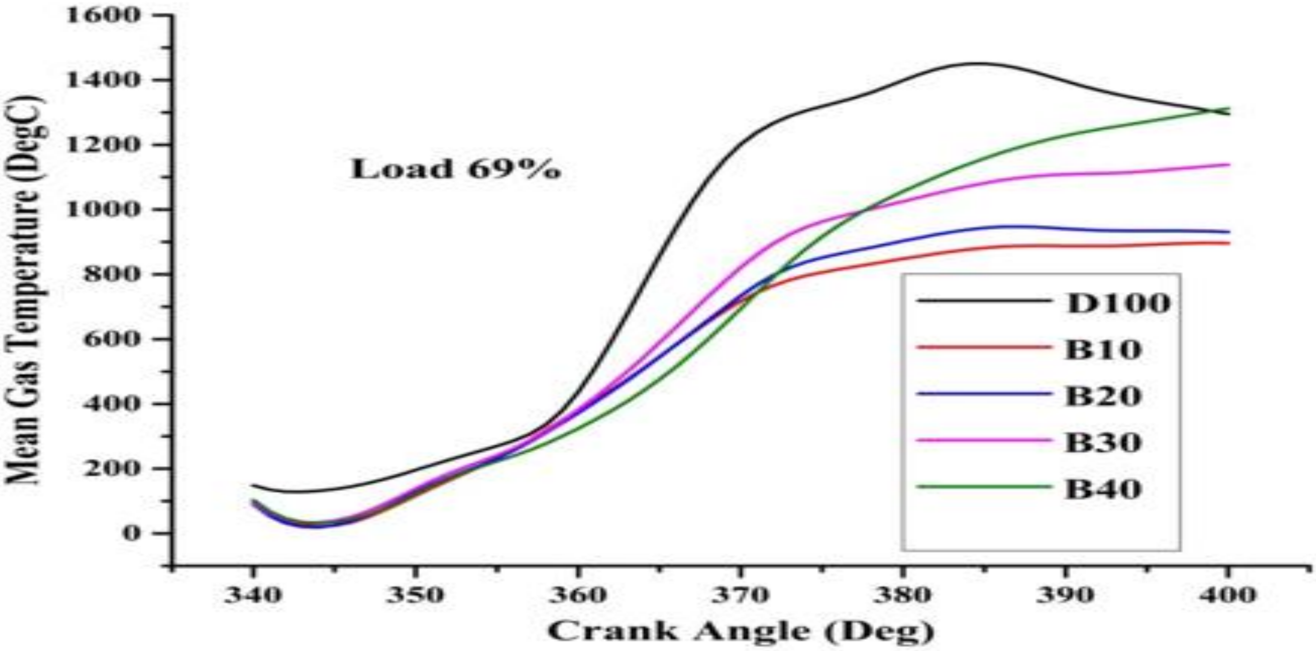

Fig 19 Variation of mean Gas Temperature (MGT) versus Crank angle with Different Percentages of Biodiesel.

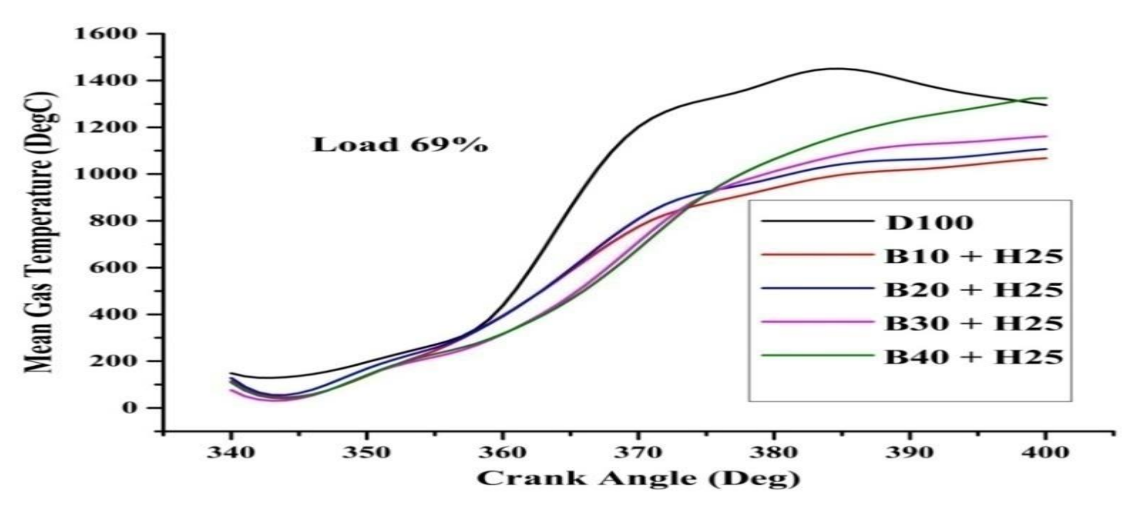

Fig 20 Variation of mean Gas Temperature (MGT) versus Crank angle with Different Percentages of Biodiesel using H_2 as a Secondary Fuel.

V. CONCLUSION

To analyze the performance, emissions and combustion characteristics of Karanja oil biodiesel (10%, 20%, 30%, and 40%) and di- tert butyl peroxide (1%, 3%, and 5%) with hydrogen (7%, 11%, 16%, 20%, and 25%) assisted in a diesel engine at higher load (69%) condition. The following conclusion has been drawn:

- The enhancement in the BTE by the addition of BKO (20%-40%), DTBP as an additive (1%-5%) using hydrogen (7%-16%) as a secondary fuel.
- The diminishment in NO_x emission by the addition of BKO from 10% to 50% and BKO from 1% to 10% with 25% H_2 as a secondary fuel at 69% load. Also, by the addition of 5% DTBP, 40% BKO, and 7% hydrogen.
- The diminishment in CO emission by the addition of BKO (10%-30%), DTBP as additive (1%-3%) using hydrogen (25%) as a secondary fuel.
- The diminishment in CO_2 emission and HC emission by the addition of BKO (30%-40%), DTBP as additive (3%-5%) using hydrogen (7%-25%) as a secondary fuel.
- The diminishment in the net heat release rate (NHRR) and mean gas temperature (MGT) by the addition of biodiesel of Karanja oil (10%-40%) with or without hydrogen fuel in a diesel engine.

The use of Karanja oil (20%-40%) and DTBP as an additive (3%-5%) using hydrogen (25%) as a secondary fuel in a diesel engine plays one of the most important roles in the decline the emission, and combustion along with enhancement in the performance. Therefore, we can conclude that the biodiesel of Karanja oil can be used as a fuel in the future.

ACKNOWLEDGEMENTS

Satish Saw would like to acknowledge UGC India and Sunil Mahto to CSIR-HRDG for providing financial support as a fellowship.

REFERENCES

[1]. Ong HC, Mahlia TMI, Masjuki HH. A review of energy scenario and sustainable energy in Malaysia. Renewable and Sustainable Energy Reviews 2011;15:639–47.

[2]. Mofijur M, Masjuki HH, Kalam MA, Hazrat MA, Liaquat AM, Shahabuddin M, et al. Prospects of biodiesel from Jatropha in Malaysia. Renewable and Sustainable Energy Reviews 2012;16:5007–20.

[3]. United States Energy Information Administration (EIA), Alternatives to traditional transportation fuels. Washington, D.C. 2008.

[4]. Cecrle E, Depcik C, Duncan A, Guo J, Mangus M, Peltier E, et al. Investigation of the effects of biodiesel feedstock on the performance and emissions of a single-cylinder diesel engine. Energy & Fuels 2012;26:2331–41.

[5]. Ahmad Abbaszaadeh, Barat Ghobadian, Mohammad Reza Omidkhah, Gholamhassan Najafi, Current biodiesel production technologies: A comparative review, Energy Conversion and Management, 63, 2012, 138-148, https://doi.org/10.1016/j.enconman.2012.02.027.

[6]. (EPA) USEPA. A comprehensive analysis of biodiesel impacts on exhaust emissions. 2002.

[7]. Jayed M, Masjuki H, Saidur R, Kalam M, Jahirul M. Environmental aspects and challenges of oilseed produced biodiesel in Southeast Asia. Renewable and Sustainable Energy Reviews 2009;13:2452–62.

[8]. Murugesan A, Umarani C, Chinnusamy TR, Krishnan M, Subramanian R, Neduzchezhain N. Production and analysis of bio-diesel from non-edible oils —a review. Renewable and Sustainable Energy Reviews 2009;13:825–34.

[9]. Patil PD, Deng S. Optimization of biodiesel production from edible and nonedible vegetable oils. Fuel 2009;88:1302–6.

[10]. Basha SA, Gopal KR, Jebaraj S. A review on biodiesel production, combustion, emissions and performance. Renewable and Sustainable Energy Reviews 2009; 13:1628–34.
[11]. Sun J, Caton JA, Jacobs TJ. Oxides of nitrogen emissions from biodiesel-fuelled diesel engines. Progress in Energy and Combustion Science 2010;36:677–95.
[12]. Szulczyk KR, McCarl BA. Market penetration of biodiesel. Renewable and Sustainable Energy Reviews 2010;14:2426–33.
[13]. Qi D, Chen H, Geng L, Bian Y. Experimental studies on the combustion characteristics and performance of a direct injection engine fueled with biodiesel/diesel blends. Energy Conversion and Management 2010;51: 2985–92.
[14]. Chauhan BS, Kumar N, Cho HM. A study on the performance and emission of a diesel engine fueled with Jatropha biodiesel oil and its blends. Energy 2011.
[15]. Xue J, Grift TE, Hansen AC. Effect of biodiesel on engine performances and emissions. Renewable and Sustainable Energy Reviews 2011;15:1098–116.
[16]. Fazal MA, ASMA Haseeb, Masjuki HH. Biodiesel feasibility study: an evaluation of material compatibility; performance; emission and engine durability. Renewable and Sustainable Energy Reviews 2011;15:1314–24.
[17]. Janaun J, Ellis N. Perspectives on biodiesel as a sustainable fuel. Renewable and Sustainable Energy Reviews 2010;14:1312–20
[18]. Liaquat AM, Kalam MA, Masjuki HH, Jayed MH. Potential emissions reduction in the road transport sector using biofuel in developing countries. Atmospheric Environment 2010;44:3869–77.
[19]. Europia (European Petroleum Industry Association), White Paper on EU Refining. Wood Mackenzie, Cambridge, UK; 2010.
[20]. S. Kent Hoekman, Amber Broch, Curtis Robbins, Eric Ceniceros, Mani Natarajan, Review of biodiesel composition, properties, and specifications, Renewable and Sustainable Energy Reviews, 16, 1, 2012, 143-169, https://doi.org/10.1016/j.rser.2011.07.143.
[21]. S. Sivalakshmi, T. Balusamy, Effect of biodiesel and its blends with diethyl ether on the combustion, performance, and emissions from a diesel engine, Fuel, 106, 2013, 106-110. https://doi.org/10.1016/j.fuel.2012.12.033.
[22]. P.K. Devan, N.V. Mahalakshmi, Performance, emission and combustion characteristics of poon oil and its diesel blends in a DI diesel engine, Fuel, Volume 88, Issue 5, 2009, 861-867. https://doi.org/10.1016/j.fuel.2008.11.005.
[23]. Hoekman SK, Robbins C. Review of the effects of biodiesel on NOx emissions. Fuel Processing Technology 2012;96:237–49.
[24]. Rajasekar E, Murugesan A, Subramanian R, Nedunchezhian N. Review of NOx reduction technologies in CI engines fuelled with oxygenated biomass fuels. Renewable and Sustainable Energy Reviews 2010;14:2113–21.
[25]. Rizwanul Fattah IM, Masjuki HH, Liaquat AM, Ramli R, Kalam MA, Riazuddin VN. Impact of various biodiesel fuels obtained from edible and non-edible oils on engine exhaust gas and noise emissions. Renewable and Sustainable Energy Reviews 2013;18:552–67.
[26]. Chandra Bhushan Kumar, D.B. Lata, Dhaneshwar Mahto, Effect of addition of di-tert butyl peroxide (DTBP) on performance and exhaust emissions of a dual fuel diesel engine with hydrogen as a secondary fuel, International Journal of Hydrogen Energy, 46, 14, 2021, 9595-9612, https://doi.org/10.1016/j.ijhydene.2020.12.129.
[27]. Yilmaz IT, Demir A, Gumus M. Effects of hydrogen enrichment on combustion characteristics of a CI engine. Int J Hydrogen Energy 2017; 42(15):10536-46.
[28]. Varatharajan K, Cheralathan M, Velraj R. Mitigation of NOx emissions from jatropha biodiesel fuelled DI diesel engine using antioxidant additives. Fuel 2011; 90:2721–5.
[29]. Varatharajan K, Cheralathan M. Influence of fuel properties and composition on NOx emissions from biodiesel powered diesel engines: a review. Renewable and Sustainable Energy Reviews 2012;16:3702–10.
[30]. Ban-Weiss GA, Chen J, Buchholz BA, Dibble RW. A numerical investigation into the anomalous slight NOx increase when burning biodiesel; a new (old) theory. Fuel processing technology 2007;88:659–67.
[31]. McCormick R, Alvarez J, Graboski M. NOx solutions for biodiesel. NREL, NREL/ SR-510-31465 2003.
[32]. Bowman CT. Kinetics of pollutant formation and destruction in combustion. Progress in Energy and Combustion Science 1975;1:33–45.
[33]. Fenimore C. Formation of nitric oxide in premixed hydrocarbon flames. Elsevier; 373–80.
[34]. Hu B, Huang Y. Theoretical analysis of lowest limits of NOx formation of methane-air mixtures. Power and Energy Engineering Conference (APPEEC) 2011:1–6 Asia-Pacific. Wuhan2011.
[35]. Fluent I. Prompt NOx formation. 2001-11-29.
[36]. Fernando S, Hall C, Jha S. NOx reduction from biodiesel fuels. Energy & Fuels 2006;20:376–82.
[37]. Miller JA, Bowman CT. Mechanism and modeling of nitrogen chemistry in combustion. Progress in Energy and Combustion Science 1989;15: 287–338.
[38]. Ren Y, Li X. Numerical simulation of the soot and NOx formations in a biodiesel-fuelled engine. SAE Technical Paper 2011:01–1385.

[39]. Dhamodaran G., Krishnam R., Pochareddy Y. K., Ganeshram A. K., Pyarelal H. M., Sivasubramanian H. "A comparative study of combustion, emission, and performance characteristics of rice-bran, neem, and cottonseed oil biodiesel with varying degrees of unsaturation", Fuel, Vol. 187, 2017, pp 296- 305.
[40]. N. Shrivastava, S.N. Varma, and M. Pandey, "Experimental study on the production of the Karanja oil methyl ester and its effect on a diesel engine," Int. journal of Renewable Energy and Development, Vol. 1 (3), pp. 115-122, 2012.
[41]. F.K. Forson, E.K. Oduro, and E.H. Donkoh, "Performance of Jatropha oil in a diesel engine," Renewable Energy, Vol. 29, pp. 1135- 1145, 2004.
[42]. Lata DB, Misra A. Analysis of ignition delay period of a dual fuel diesel engine with hydrogen and LPG as a secondary fuel. Int J Hydrogen Energy 2011;36(5):3746e56.
[43]. Rajak U, Nashine P, Verma TN. Assessment of diesel engine performance using spirulina microalgae biodiesel. Energy 2019;166:1025–36.
[44]. Singh TS, Verma TN. Impact of tri-fuel on compression ignition engine emissions: blends of waste frying oil–alcohol–diesel. Methanol and the alternate fuel economy. Springer; 2019. p. 135–56.
[45]. Sher, Eran. Handbook of air pollution from internal combustion engines pollutant formation and control. [Chapter 9], p.no-226-320.
[46]. Saravanan N, Nagarajan G. Performance and emission studies on port injection of hydrogen with varied flow rates with Diesel as an ignition source. Appl Energy 2010;87:2218-29. https://doi.org/10.1016/ j.apenergy.2010.01.014.