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# Investigation on Heat Balance, Volumetric Efficiency, and Air-Fuel Ratio of Karanja Oil using Hydrogen Gas in a Dual Fuel Diesel Engine

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**Abstract:- The continuous increase in global energy demand, combined with the dependence on finite fossil fuel resources, the rise in exhaust emissions, and the challenges of climate change, has led to extensive research into alternative fuels. Biodiesel and its blends are considered among the most suitable and practical alternatives for diesel engines. This study examines the performance of a dual-fuel diesel engine using pure diesel and various compositions of biodiesel produced from Karanja oil (BKO) in combination with hydrogen. The physicochemical properties and performance characteristics of biodiesel produced from Karanja oil (BKO), combined with hydrogen as a supplementary fuel, were thoroughly analyzed. Key parameters studied included volumetric efficiency, air-fuel ratio, heat in brake power (HBP), heat in jacket water (HJW), heat carried away by exhaust gases (H Gas), and heat dissipated through radiation (H Rad). The findings indicated that as the proportion of hydrogen and biodiesel increased, the volumetric efficiency of the engine decreased by 5.87%, primarily due to the displacement of air by hydrogen. The air-fuel ratio also decreased significantly, by 81.68%, because of hydrogen's lower density compared to air. Conversely, the heat in brake power (HBP) rose by 99.75%, attributed to the efficient combustion properties of hydrogen within the cylinder. Heat in jacket water (HJW) and heat carried away by exhaust gases (H Gas) decreased by 55.76% and 19.67%, respectively, due to hydrogen's higher thermal conductivity. Meanwhile, the heat dissipated through radiation (H Rad) increased by 66.76% as a result of higher mean gas temperatures when substituting diesel with hydrogen, which increased the fraction of heat lost as radiation.**

***Keywords**:- Diesel, Biodiesel of Karanja Oil, Hydrogen Fuel, and Performance.*

## I. INTRODUCTION

The global demand for energy continues to rise, along with the increasing cost of petroleum and the depletion of fossil fuel reserves. Biodiesel, derived from vegetable oils, has emerged as a promising alternative fuel [1]. It is produced from various vegetable and animal fats and offers several advantages: it is oxygenated, sulfur-free, non-toxic, renewable, and biodegradable. Moreover, biodiesel can be utilized in diesel engines without requiring significant modifications [2]. Traditionally, vehicle fuel has been derived from fossil fuels, but concerns over dwindling fossil fuel reserves and harmful exhaust emissions necessitate the development of environmentally sustainable alternatives. Biodiesel is produced by esterifying plant- and animal-based materials, making it a renewable fuel source [3]. Studies indicate that increasing the blend ratio of biodiesel to diesel enhances brake thermal efficiency under higher loads, although it also leads to higher brake-specific fuel consumption, as demonstrated with Karanja methyl esters [4-6].

The effects of the air-fuel ratio on dual-fuel combustion were investigated under various natural gas substitution ratio (NSR) conditions. Dual-fuel combustion exhibits characteristics of both spark ignition (SI) and compression ignition (CI) engine combustion. The air-fuel ratio plays a critical role in determining the efficiency of dual-fuel engines due to the mixed combustion characteristics. However, despite its importance, the air-fuel ratio has received limited attention in prior research. While some studies have included the air-fuel ratio as an experimental parameter, none have specifically addressed its effects under varying NSR conditions. This study proposes a conceptual design method for large stationary internal combustion engines. The investigation focused on different dual-fuel ratios and their effects on engine performance and emissions, as well as the air-fuel ratio's influence. Additionally, further research aimed to optimize fuel consumption for achieving a target power output while adhering to regulatory requirements. Understanding the impact of dual-fuel ratios on combustion was essential before examining the specific effects of the air-fuel ratio on engine performance and emissions [7].

Alternatively, the engine jacket water can be utilized for preheating. For example, in a recent study, Basinger et al. [8] modified the Change-over Valve (COV) of a Lister engine to absorb heat from the cooling water jacket. This modification allowed the development and installation of a V-shaped plug-type oil preheater. To ensure optimal performance, the oil temperature was maintained at approximately 90°C before injection under all load conditions, as determined by the heat transfer model [8]. The preheating process uses hot jacket water from the engine cooling circuit, which would otherwise

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be wasted, to heat the plant oil. The physical and chemical properties of the fuels can first be evaluated by determining performance metrics and outcomes [9]. A cycle simulation model and a thermodynamically based model were employed to predict the performance of a diesel engine operating on diesel and various blends of diesel and biodiesel. These models account for changes in the thermodynamic state of the working fluid during the engine's intake, combustion, expansion, compression, and exhaust processes. Regarding brake thermal efficiency and brake power, the models evaluate the performance of compression ignition (CI) engines for all fuels considered [10].

Blends of biodiesel increase exhaust gas temperatures as the concentration of biodiesel in the blend rises. Blends of biodiesel produced from waste cooking oil exhibit performance characteristics similar to those of diesel fuel. However, the heating value of waste cooking oil biodiesel is approximately 15% lower than that of conventional diesel fuel [11]. Additionally, biodiesel derived from waste cooking oil results in lower exhaust gas temperatures compared to diesel-biodiesel blends made from waste cooking oil [12–15].

In the present paper, we investigate the variation of Heat balance, Volumetric efficiency, air-fuel ratio, heat in jacket water (HJW), heat carried away by exhaust gas (H Gas), heat in brake power (HBP), and heat carried away by radiation (H Rad) with different composition of diesel, biodiesel, and hydrogen and load varying from low to high.

## II. METHODS AND MATERIALS

The experimental work in dual fuel mode (Fig. 1 (a)-(b)) in a diesel engine was modified using a single-cylinder, four-stroke engine with a power of 3.5 KW @ 1500 rpm, including compression ratio, for the model Kirloskar TV1 engine. The engine was fitted with an eddy current dynamometer, which was configured for loading. The experimental investigation was conducted using a manometer, a fuel tank, a panel box, a fuel measuring device, a digital indicator, and a digital temperature indication. Data was gathered for the engine performance analysis using both MS Excel and IC engine software, and Table 1 lists the engine's technical species. The hydrogen cylinder setup includes a pressure regulator, flashback arrester, rotameter with a one-way non-return valve, and flame arrester. The impact of Karanja oil on biodiesel was examined experimentally in this work while the engine was operating at a constant speed of 1500 rpm and the dynamometer's knob turned in response to changes in engine load, which ranged from 0.2 kg to 18 kg. Piezo signals were also used to send the powering unit/AX-409 for additional analysis, and the engine also prepared a piezo sensor to measure the cylinder pressure.

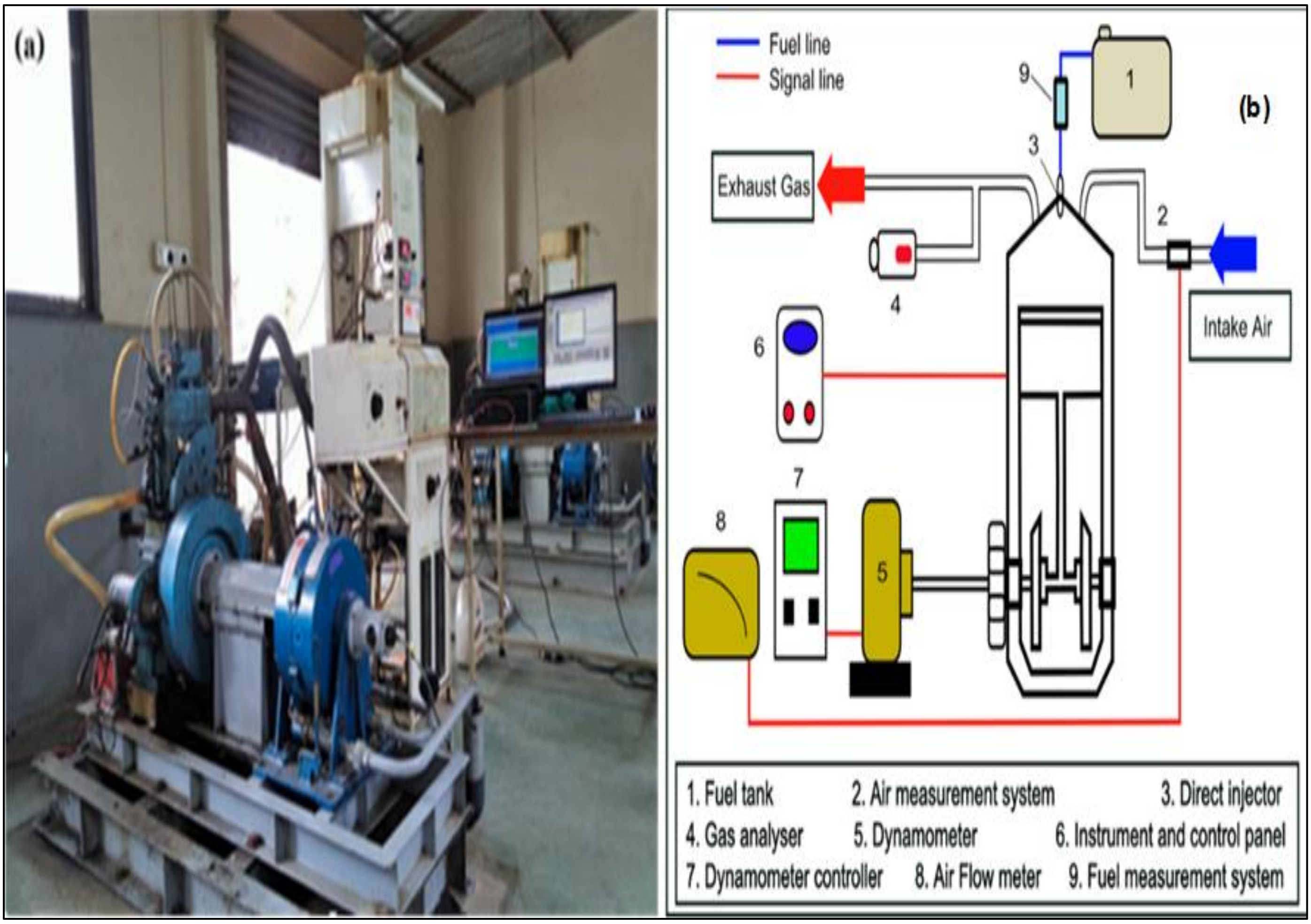

Fig 1: (a) Experimental Photographic View (b) Experimental Set-up Schematic View

Table 1: Scientific Capacity of the Engine

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

Table 2: Properties of Biodiesel (Karanja oil)

| Properties | Unit | Karanja oil |
|---|---|---|
| LCV Calorific Value | Cal\gm | 8828 |
| HCV Calorific Value | Cal\gm | 9414 |
| Flash Point | oC | 68 |
| Dynamic Viscosity @40◦C | cP | 4.7 |
| Kinematic Viscoisty @40◦C | cSt | 5.31 |
| Density at 25◦C | Kg/m3 | 885 |
| Fire point | oC | 74 |

Table 3: Comparison between the Characteristics of Hydrogen and Diesel Fuel

| Properties | Unit | Hydrogen | Diesel |
|---|---|---|---|
| Density At 25◦C | (kg/m3) | 0.09 | 818 |
| Dynamic Viscosity @40◦C | cP | 0.61 | 1.73 |
| Kinematic Viscoisty @40◦C | cSt | 0.64 | 2.09 |
| Fire Point | ◦C | 0.02 | 58 |
| Flash Point | ◦C | 4-7.5 | 51 |
| HCV Calorific Value | (Cal/gm) | 858 | 10463 |
| LCV Calorific Value | (Cal/gm) | 120 | 9877 |

### *A. Physicochemical and Pharmacokinetic Properties*

The effects of the drug have physicochemical and pharmacokinetic properties which are defined by the following four phases: absorption, distribution, metabolism, and excretion (ADME) and have been investigated by Lipinski's rule of five. This rule is also known as Pfizer's rule of five which was used for the screening of large drug molecules [16]. The pongamol and dihydropongamol were used to calculate the drug likeness theoretically. The compound has less than 500Da molecular mass and the lipophilicity (LogP) was observed to be 0.32 and 0.675 which affects absorption. The hydrogen bond donor should be less than or equal to 5 and the hydrogen bond acceptor should be less than or equal to 10 which plays a significant role in affinity inside the body with absorption. However, pongamol contains zero donor and four acceptor bonds of hydrogen, and it has high bioavailability [17].

### *B. Properties of Pongamol and Dihydropongamol*

The purity of pongamol was observed to be 95% in pure form using the HPLC technique and absorption maxima at 350 nm and 235 nm (Fig. 2). The Differential Scanning Colorimetry (DSC) results show a melting point (124.81 °C) with white crystal structure. In HR-MS, the molecular weight (m/z) was observed to be 295.78 $[M+H]^+$. The pongamol contains carbonyl and methoxy group at 1782 $cm^{-1}$ and 3053 $cm^{-1}$ which was observed by IR spectra and also reported enolic form by NMR technique [18].

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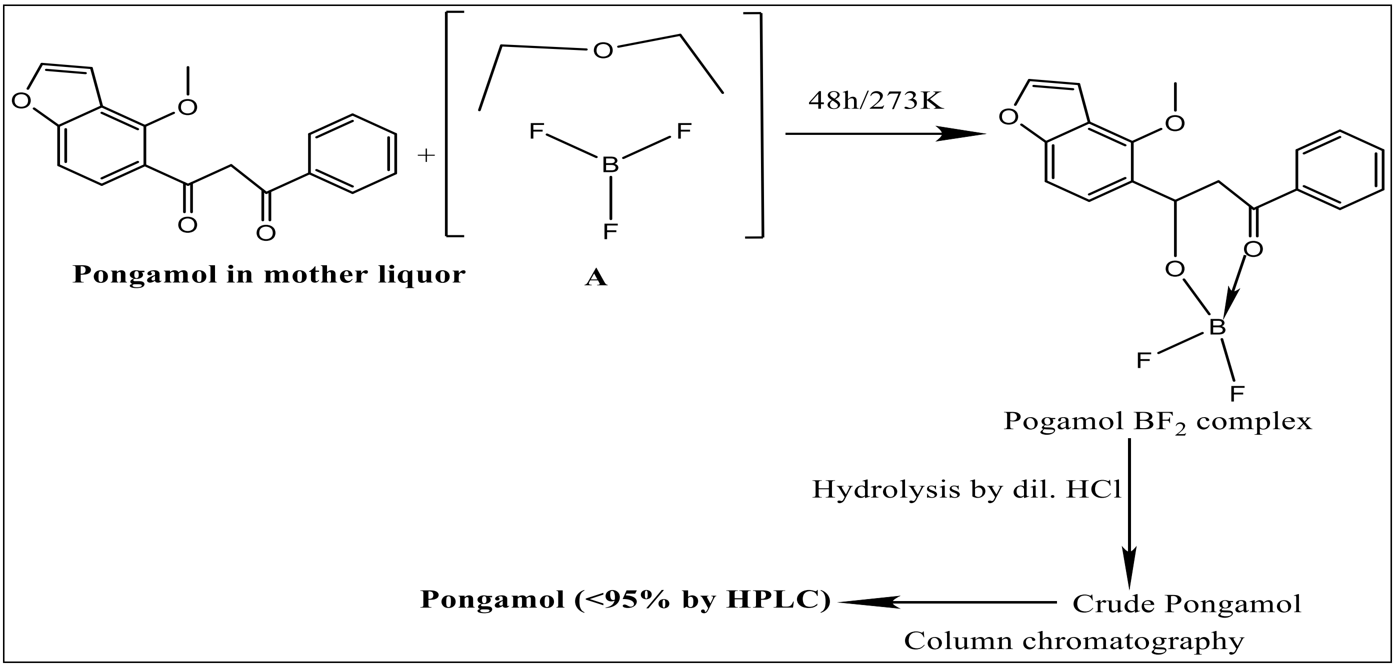


Fig 2: $BF_3$ complex Formation of Pongamol

## III. RESULTS AND DISCUSSION

Table 4: The Values of Performance Parameters with Different Load Conditions

| **D-90%+B-10% + H-7%** | | | | | | |
|---|---|---|---|---|---|---|
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 82.9 | 65.47 | 2.4 | 70.92 | 32.1 | 0 |
| 18 | 81.57 | 48.18 | 13.31 | 42.64 | 21.41 | 22.64 |
| 36 | 80.34 | 31.59 | 17.54 | 31.48 | 16.76 | 34.22 |
| 53 | 79.28 | 25.49 | 22.7 | 30.8 | 16.58 | 29.92 |
| 69 | 79.06 | 19.99 | 22.64 | 28.45 | 16.22 | 32.69 |
| **(b) D-90%+B-10% + H-11%** | | | | | | |
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 83.67 | 54.26 | 1.21 | 28.46 | 12.25 | 58.08 |
| 18 | 81.76 | 48.45 | 15.73 | 32.1 | 14.51 | 37.66 |
| 36 | 79.87 | 33.32 | 20.78 | 32.01 | 14.27 | 32.94 |
| 53 | 78.85 | 25.46 | 21.2 | 34.47 | 15.67 | 28.67 |
| 69 | 78.78 | 21.41 | 24.88 | 34.2 | 17.23 | 23.69 |
| **(c) D-90%+B-10% + H-16%** | | | | | | |
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 80.29 | 82.19 | 2.12 | 101.46 | 41.21 | 0 |
| 18 | 80.82 | 48.09 | 12.9 | 41.73 | 20.46 | 24.92 |
| 36 | 79.49 | 35.27 | 21.19 | 35.39 | 18.01 | 25.41 |
| 53 | 78.33 | 26.47 | 23.89 | 34.38 | 17.13 | 24.59 |
| 69 | 78.33 | 26.47 | 23.89 | 34.38 | 17.13 | 24.59 |
| **(d) D-90%+B-10% + H-20%** | | | | | | |
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 79.88 | 71.65 | 4.78 | 88.71 | 35.74 | 0 |
| 18 | 80.19 | 47.67 | 14.29 | 41.94 | 20.57 | 23.2 |
| 36 | 78.75 | 32.95 | 20.11 | 33.82 | 16.87 | 29.21 |
| 53 | 77.4 | 26.18 | 22.71 | 34.64 | 17.14 | 25.51 |
| 69 | 76.76 | 20.17 | 22.73 | 33.8 | 16.86 | 26.61 |
| **(e) D-90%+B-10% + H-25%** | | | | | | |
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 79.82 | 67.44 | 5.68 | 84.33 | 34.19 | 0 |
| 18 | 79.71 | 49.52 | 16.01 | 42.72 | 20.95 | 20.32 |
| 36 | 78.31 | 31.8 | 19.77 | 32.28 | 16.95 | 31 |

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| | | | | | | |
|---|---|---|---|---|---|---|
| 53 | 77.67 | 25.6 | 21.58 | 33.76 | 16.6 | 28.06 |
| 69 | 76.49 | 20.5 | 24.01 | 34.92 | 17.36 | 23.71 |
| **(f) D-80%+B-20% + H-7%** | | | | | | |
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 80.2 | 71.2 | 5.06 | 90.24 | 34.51 | 0 |
| 18 | 80.01 | 47.26 | 14.88 | 47.29 | 21.12 | 16.71 |
| 36 | 76.98 | 20.98 | 24.23 | 36.54 | 17.82 | 21.41 |
| 53 | 76.98 | 20.98 | 24.23 | 36.54 | 17.82 | 21.41 |
| 69 | 76.98 | 20.98 | 24.23 | 36.54 | 17.82 | 21.41 |
| **(g) D-80%+B-20% + H-11%** | | | | | | |
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 79.75 | 63.19 | 0.06 | 81.89 | 31.18 | 0 |
| 18 | 79.23 | 46.98 | 15.32 | 43.46 | 19.81 | 21.41 |
| 36 | 77.99 | 34.65 | 19.52 | 38.43 | 17.7 | 24.36 |
| 53 | 77.5 | 25.02 | 21.82 | 35.13 | 16.21 | 26.84 |
| 69 | 76.85 | 20.94 | 24.7 | 36.22 | 17.4 | 21.68 |
| **(h) D-80%+B-20% + H-16%** | | | | | | |
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 78.64 | 70.31 | 1.56 | 92.17 | 34.01 | 0 |
| 18 | 79.08 | 51.35 | 17.91 | 47.1 | 21.07 | 13.93 |
| 36 | 78.58 | 42.91 | 24.69 | 45.12 | 20.98 | 9.21 |
| 53 | 76.9 | 25.99 | 23.18 | 36.6 | 16.69 | 23.53 |
| 69 | 75.92 | 21.52 | 25.97 | 37.74 | 17.8 | 18.48 |
| **(i) D-80%+B-20% + H-20%** | | | | | | |
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 78.83 | 70.75 | 2.34 | 92 | 33.98 | 0 |
| 18 | 78.83 | 46.87 | 17.01 | 40.32 | 18.6 | 24.07 |
| 36 | 77.49 | 34.44 | 20.65 | 33.89 | 16.46 | 29.01 |
| 53 | 76.31 | 24.7 | 22.16 | 35.81 | 15.98 | 26.05 |
| 69 | 75.4 | 19.12 | 23.57 | 33.18 | 15.56 | 27.7 |
| **(j) D-80%+B-20% + H-25%** | | | | | | |
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 77.86 | 65.67 | 4.07 | 96.44 | 35.09 | 0 |
| 18 | 79.09 | 49.09 | 14.69 | 43.41 | 19.68 | 22.22 |
| 36 | 77.08 | 33.24 | 20.9 | 36.16 | 16.39 | 26.55 |
| 53 | 76.11 | 23.97 | 22.3 | 33.45 | 15.07 | 29.19 |
| 69 | 75.19 | 20.91 | 26.02 | 38.31 | 17.24 | 18.42 |

Table 5: The Values of Performance Parameters with Different Load Conditions

| **(a) D-70%+B-30% + H-7%** | | | | | | |
|---|---|---|---|---|---|---|
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 80.6 | 94.88 | 6.21 | 144.81 | 49.97 | 0 |
| 18 | 80.95 | 53.96 | 19.36 | 86.66 | 36.39 | 100 |
| 36 | 79.93 | 37.74 | 22.1 | 44.71 | 18.37 | 14.82 |
| 53 | 78.99 | 27.93 | 25.07 | 41.78 | 17.54 | 15.62 |
| 69 | 78.68 | 24.18 | 28.62 | 44.53 | 19.81 | 7.04 |
| **(b) D-70%+B-30% + H-11%** | | | | | | |
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 79.57 | 112.55 | 9.9 | 179.53 | 60.77 | 0 |
| 18 | 80.27 | 56.59 | 17.32 | 60.26 | 23.76 | 0 |
| 36 | 79.54 | 40.07 | 24.6 | 49.18 | 20.24 | 5.97 |
| 53 | 78.55 | 29.2 | 24.68 | 43.66 | 18.31 | 13.35 |
| 69 | 77.62 | 21.94 | 24.93 | 39.91 | 17.96 | 17.19 |
| **(c) D-70%+B-30% + H-16%** | | | | | | |
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 79.95 | 141.26 | 12.61 | 188.98 | 64.86 | 0 |
| 18 | 80.2 | 80.98 | 26.57 | 82.88 | 33.5 | 0 |
| 36 | 78.74 | 46.34 | 26.2 | 55.81 | 23.44 | 0 |
| 53 | 77.67 | 32.21 | 27.84 | 47.4 | 20.25 | 4.52 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 69 | 76.78 | 25.87 | 30.01 | 47.14 | 20.71 | 2.14 |
| **(d) D-70%+B-30% + H-20%** | | | | | | |
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 81.66 | 115.43 | 0.13 | 35.4 | 23.94 | 40.53 |
| 18 | 81.43 | 82.27 | 22.74 | 40.37 | 23.91 | 12.99 |
| 36 | 78.94 | 42.98 | 24.11 | 32.59 | 17.5 | 25.8 |
| 53 | 77.97 | 32.46 | 26.74 | 38.88 | 18.95 | 15.43 |
| 69 | 76.96 | 25.85 | 28.8 | 38.56 | 19.18 | 13.47 |
| **(e) D-70%+B-30% + H-25%** | | | | | | |
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 80.14 | 141.51 | 0.6 | 169.3 | 71.07 | 0 |
| 18 | 80.87 | 81.49 | 21.51 | 64.94 | 33.91 | 0 |
| 36 | 79.24 | 42.96 | 23.2 | 39.02 | 21.2 | 16.58 |
| 53 | 77.69 | 274.55 | 226.89 | 330.68 | 167.52 | 0 |
| 69 | 76.8 | 25.93 | 28.89 | 39.55 | 20.72 | 10.84 |
| **(f) D-60%+B-40% + H-7%** | | | | | | |
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 82.05 | 72.84 | 0.27 | 83.39 | 34.8 | 0 |
| 18 | 80.85 | 44.22 | 12.08 | 39.01 | 18.78 | 30.14 |
| 36 | 80.89 | 31.85 | 17.22 | 32.59 | 16.25 | 33.95 |
| 53 | 78.53 | 21.36 | 23.45 | 32.67 | 17.54 | 26.34 |
| 69 | 78.53 | 21.36 | 23.45 | 32.67 | 17.54 | 26.34 |
| **(g) D-60%+B-40% + H-11%** | | | | | | |
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 80.34 | 81.95 | 0.33 | 119.43 | 48.97 | 0 |
| 18 | 80.7 | 47.88 | 12.65 | 49.26 | 22.2 | 15.89 |
| 36 | 78.96 | 35.03 | 18.91 | 37.2 | 17.9 | 25.99 |
| 53 | 78.65 | 26.57 | 21.69 | 36.87 | 17.74 | 23.7 |
| 69 | 77.23 | 21.88 | 24.24 | 36.76 | 17.9 | 21.11 |
| **(h) D-60%+B-40% + H-16%** | | | | | | |
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 79.45 | 71.04 | 0.27 | 101.32 | 38.91 | 0 |
| 18 | 88.26 | 51.65 | 12.5 | 54.76 | 24 | 8.74 |
| 36 | 79.5 | 35.25 | 19.31 | 38.06 | 18.21 | 24.41 |
| 53 | 78.47 | 26.47 | 21.7 | 34.46 | 16.68 | 27.15 |
| 69 | 77.59 | 20.37 | 22.48 | 33.2 | 16.29 | 28.03 |
| **(i) D-60%+B-40% + H-20%** | | | | | | |
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 79.13 | 70.88 | 0.33 | 102.98 | 39.65 | 0 |
| 18 | 80.42 | 44.1 | 12.34 | 39.34 | 18.52 | 29.8 |
| 36 | 78.93 | 35.08 | 18.66 | 34.51 | 17.03 | 29.81 |
| 53 | 77.26 | 27.43 | 22.54 | 38.26 | 17.45 | 21.76 |
| 69 | 77.26 | 27.43 | 22.54 | 38.26 | 17.45 | 21.76 |
| **(f) D-60%+B-40% + H-25%** | | | | | | |
| **Load (%)** | **Volumetric efficiency (%)** | **Air-fuel ratio** | **HBP (%)** | **HJW (%)** | **H Gas (%)** | **H Rad (%)** |
| 2 | 79.38 | 59.85 | 0.22 | 77.33 | 28.62 | 0 |
| 18 | 79.95 | 45.64 | 12.59 | 41.23 | 18.74 | 27.44 |
| 36 | 79.25 | 34.15 | 18.42 | 32.97 | 16.44 | 32.17 |
| 53 | 77.37 | 25.66 | 21.28 | 30.73 | 15.22 | 32.77 |
| 69 | 76.74 | 20.53 | 22.91 | 32.91 | 15.96 | 28.23 |

In Fig. 3, the smooth diminishment in the fuel composition (D-90% + B-10% + H-7%) of volumetric efficiency was observed to be 4.63% at higher load conditions compared to lower load conditions (Table 4a). However, diminishment in the fuel composition of air-fuel ratio, heat in jacket water (HJW), and heat carried away by exhaust gas (H Gas) was observed to be 69.46%, 59.88%, and 49.47% respectively. Moreover, the enhancement in the fuel composition of heat in brake power (HBP), and heat carried away by radiation (H Rad) were observed to be 89.40%, and 100% respectively at higher load conditions compared to lower load conditions.

In Fig.4, the smooth diminishment in the fuel composition (D-90% + B-10% + H-11%) of volumetric efficiency was observed to be 5.87% at higher load conditions

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compared to lower load conditions (Table 4b). However, diminishment in the fuel composition of air-fuel ratio, and H Rad were observed to be 60.54%, and 59.2% respectively. Moreover, the enhancement in the fuel composition of HBP, HJW, and H Gas was observed to be 95.14%, 16.78%, and 60.54% respectively at higher load conditions compared to lower load conditions.

In Fig. 5, the smooth diminishment in the fuel composition (D-90% + B-10% + H-16%) of volumetric efficiency was observed to be 3.03% at higher load conditions compared to lower load conditions (Table 4c). However, diminishment in the fuel composition of air-fuel ratio, HJW, and H Gas was observed to be 77.42%, 22.18%, and 59.02% respectively. Moreover, the enhancement in the fuel composition HBP, and H Rad were observed to be 91.37%, and 100% respectively at higher load conditions compared to lower load conditions.

In Fig. 6, the smooth diminishment in the fuel composition (D-90% + B-10% + H-20%) of volumetric efficiency was observed to be 3.91% at higher load conditions compared to lower load conditions (Table 4d). However, diminishment in the fuel composition of air-fuel ratio, HJW, and H Gas was observed to be 72.86%, 61.9%, and 52.83% respectively. Moreover, the enhancement in the fuel composition HBP, and H Rad were observed to be 78.98%, and 100% respectively at higher load conditions compared to lower load conditions.

In Fig. 7, the smooth diminishment in the fuel composition (D-90% + B-10% + H-25%) of volumetric efficiency was observed to be 4.17% at higher load conditions compared to lower load conditions (Table 4e). However, diminishment in the fuel composition of air-fuel ratio, HJW, and H Gas was observed to be 69.09%, 59.51%, and 49.22% respectively. Moreover, the enhancement in the fuel composition HBP, and H Rad were observed to be 76.34%, and 100% respectively at higher load conditions compared to lower load conditions.

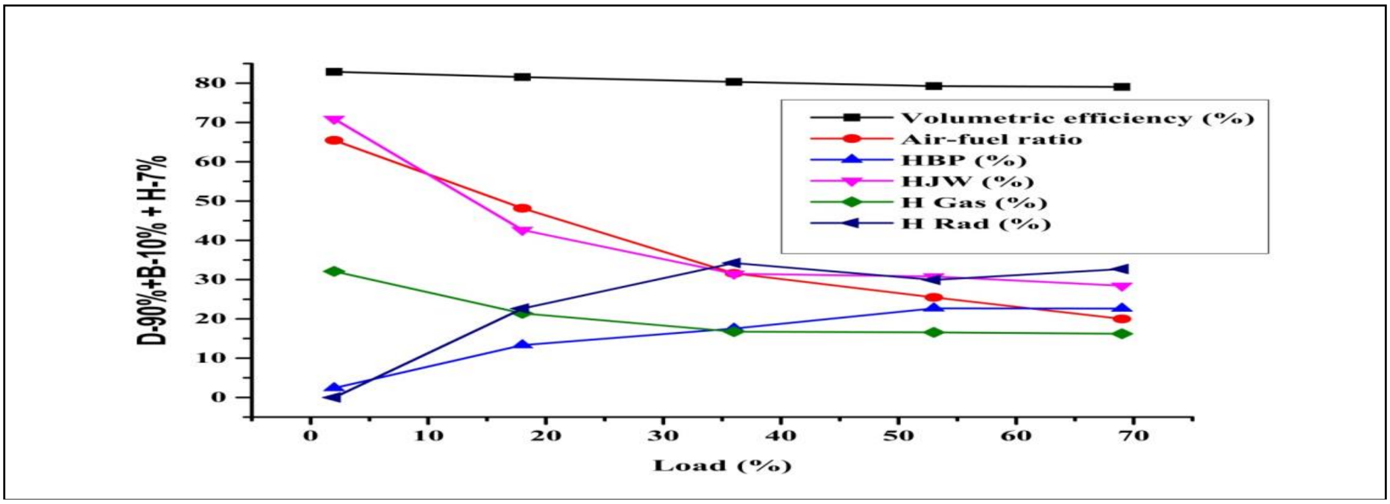


Fig 3: Variation of Different Compositions of Fuel Versus Different Percentages of Load

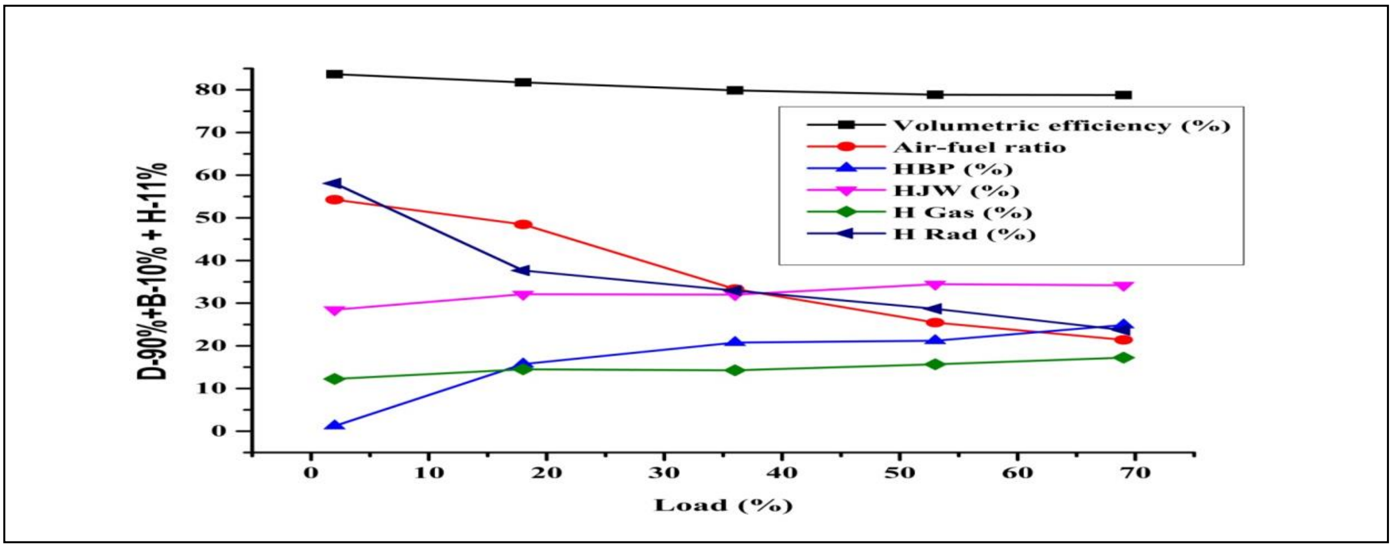


Fig 4: Variation of Different Compositions of Fuel Versus Different Percentages of Load

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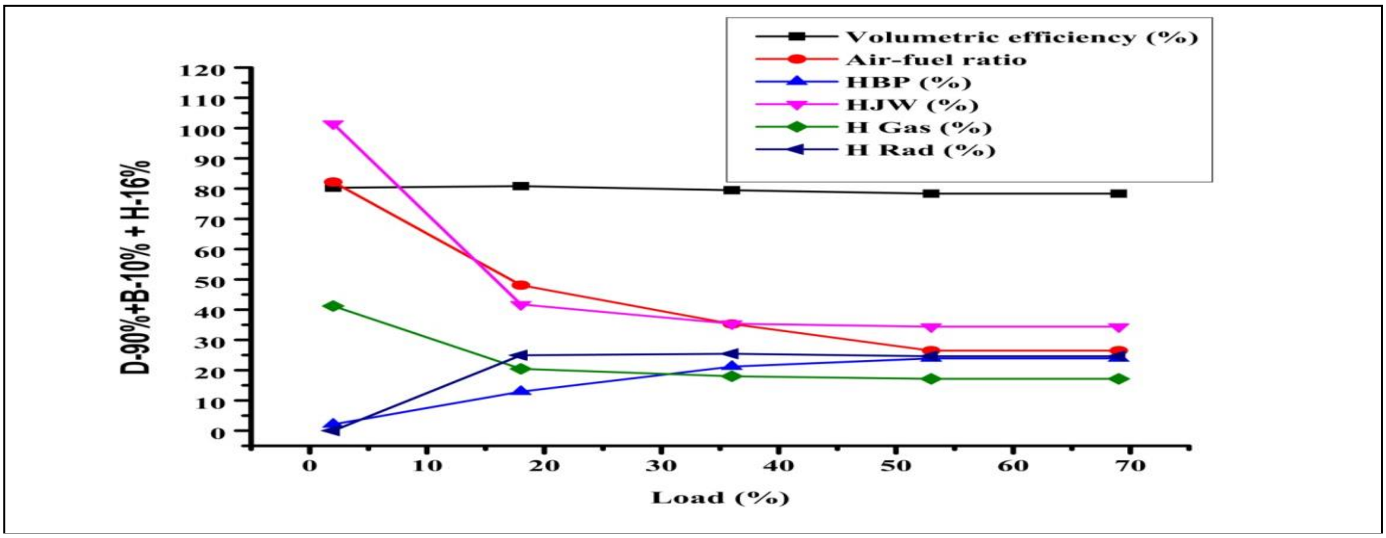

Fig 5: Variation of Different Compositions of Fuel Versus Different Percentages of Load

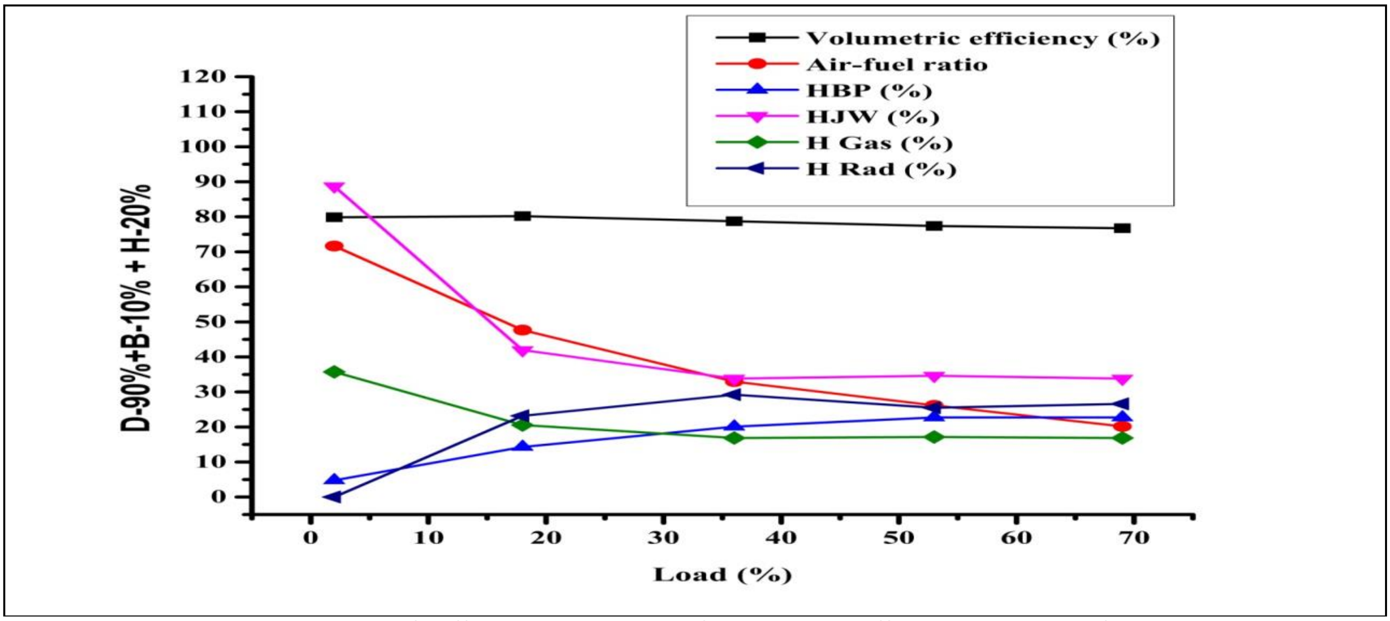

Fig 6: Variation of Different Compositions of Fuel Versus Different Percentages of Load

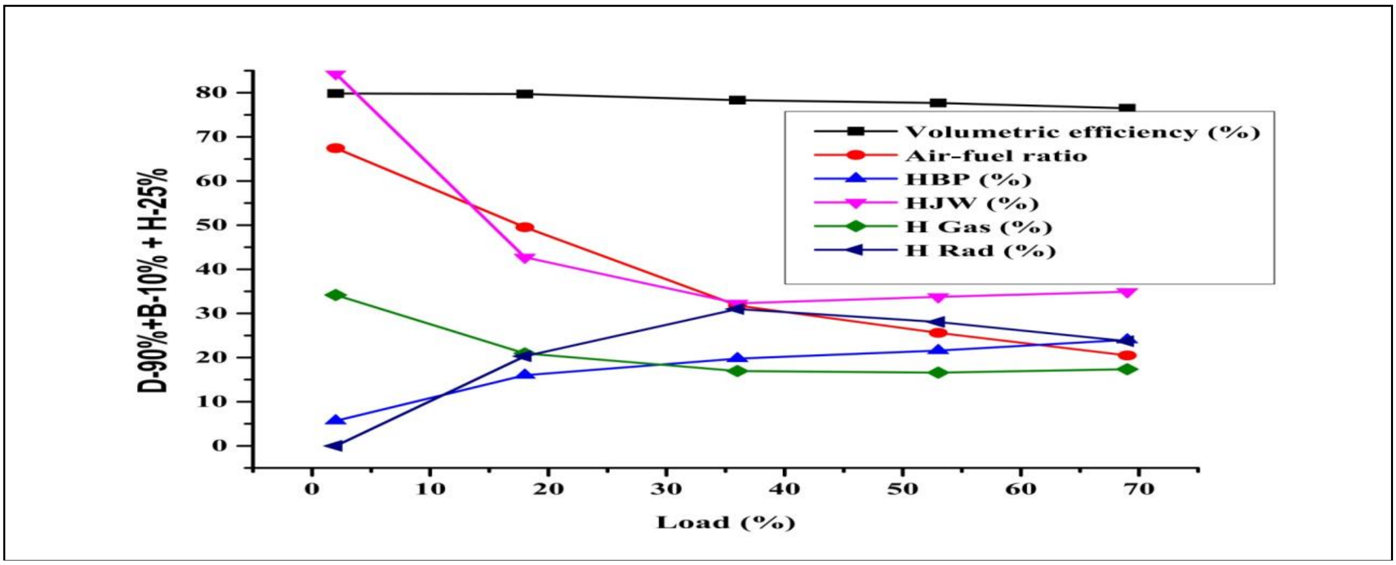

Fig 7: Variation of Different Compositions of Fuel Versus Different Percentages of Load

In Fig. 8, the smooth diminishment in the fuel composition (D-80% + B-20% + H-7%) of volumetric efficiency was observed to be 3.22% at higher load conditions compared to lower load conditions (Table 4f). However, diminishment in the fuel composition of air-fuel ratio, HJW, and H Gas was observed to be 70.53%, 59.51%, and 48.36% respectively. Moreover, the enhancement in the fuel composition HBP, and H Rad were observed to be 79.12%, and 100% respectively at higher load conditions compared to lower load conditions.

In Fig. 9, the smooth diminishment in the fuel composition (D-80% + B-20% + H-11%) of volumetric efficiency was observed to be 3.64% at higher load conditions compared to lower load conditions (Table 4g). However, diminishment in the fuel composition of air-fuel ratio, HJW, and H Gas was observed to be 66.86%, 55.76%, and 44.2% respectively. Moreover, the enhancement in the fuel composition HBP, and H Rad were observed to be 99.75%, and 100% respectively at higher load conditions compared to lower load conditions.

In Fig. 10, the smooth diminishment in the fuel composition (D-80% + B-20% + H-16%) of volumetric efficiency was observed to be 3.46% at higher load conditions compared to lower load conditions (Table 4h). However, diminishment in the fuel composition of air-fuel ratio, HJW, and H Gas was observed to be 26.96%, 59.05%, and 47.66% respectively. Moreover, the enhancement in the fuel composition HBP, and H Rad were observed to be 93.98%, and 100% respectively at higher load conditions compared to lower load conditions.

In Fig. 11, the smooth diminishment in the fuel composition (D-80% + B-20% + H-20%) of volumetric efficiency was observed to be 4.35% at higher load conditions compared to lower load conditions (Table 4i). However, diminishment in the fuel composition of air-fuel ratio, HJW, and H Gas was observed to be 63.93%, 60.27%, and 50.86% respectively. Moreover, the enhancement in the fuel composition HBP, and H Rad were observed to be 90%, and 100% respectively at higher load conditions in comparison to lower load conditions.

In Fig. 12, the smooth diminishment in the fuel composition (D-80% + B-20% + H-25%) of volumetric efficiency was observed to be 3.43% at higher load conditions compared to lower load conditions (Table 4j). However, diminishment in the fuel composition of air-fuel ratio, HJW, and H Gas was observed to be 4.78%, 60.27%, and 50.86% respectively. Moreover, the enhancement in the fuel composition HBP, and H Rad were observed to be 84.35%, and 100% respectively at higher load conditions in comparison to lower load conditions.

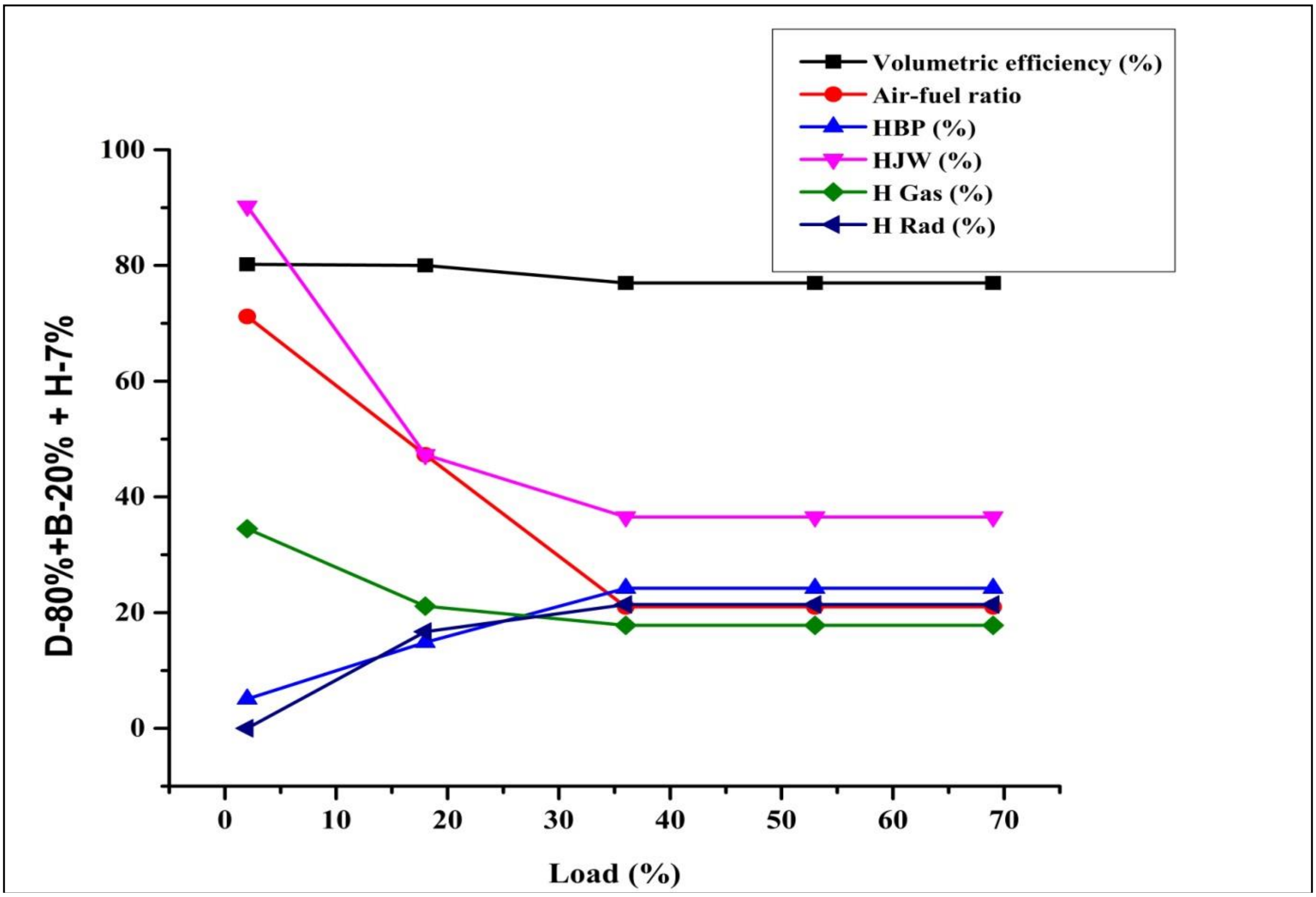

Fig 8: Variation of Different Compositions of Fuel Versus Different Percentages of Load

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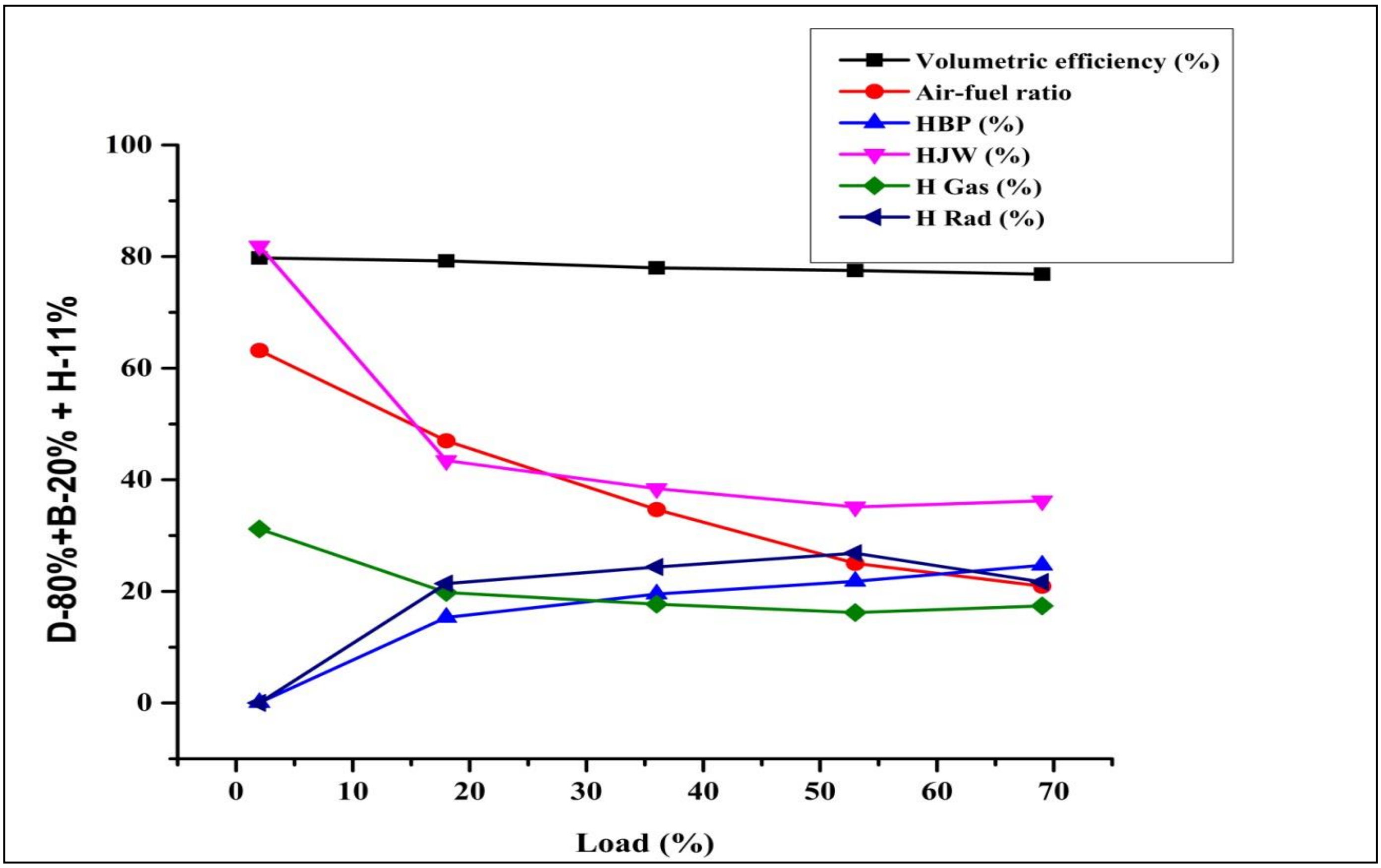


Fig 9: Variation of Different Compositions of Fuel Versus Different Percentages of Load

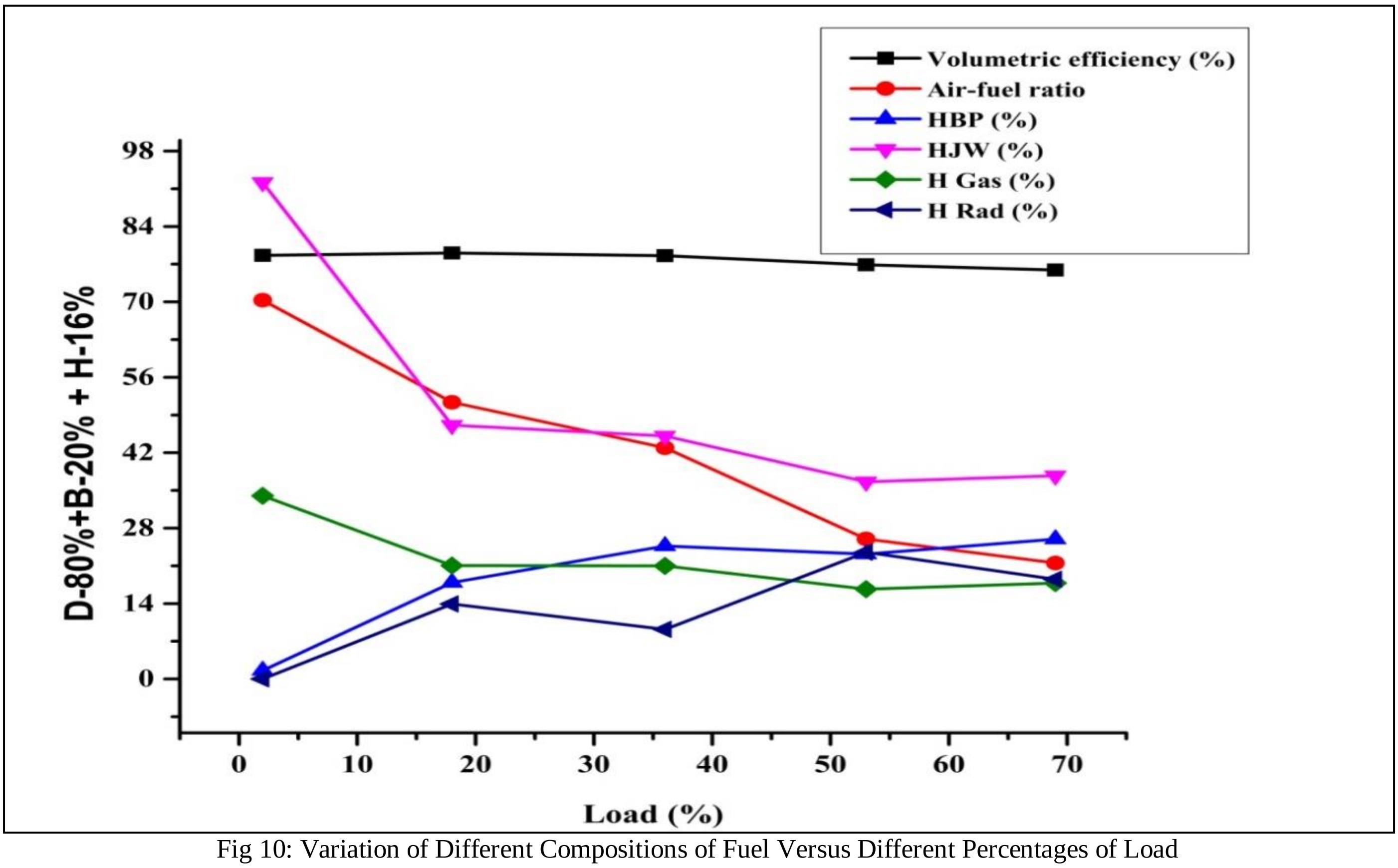


Fig 10: Variation of Different Compositions of Fuel Versus Different Percentages of Load

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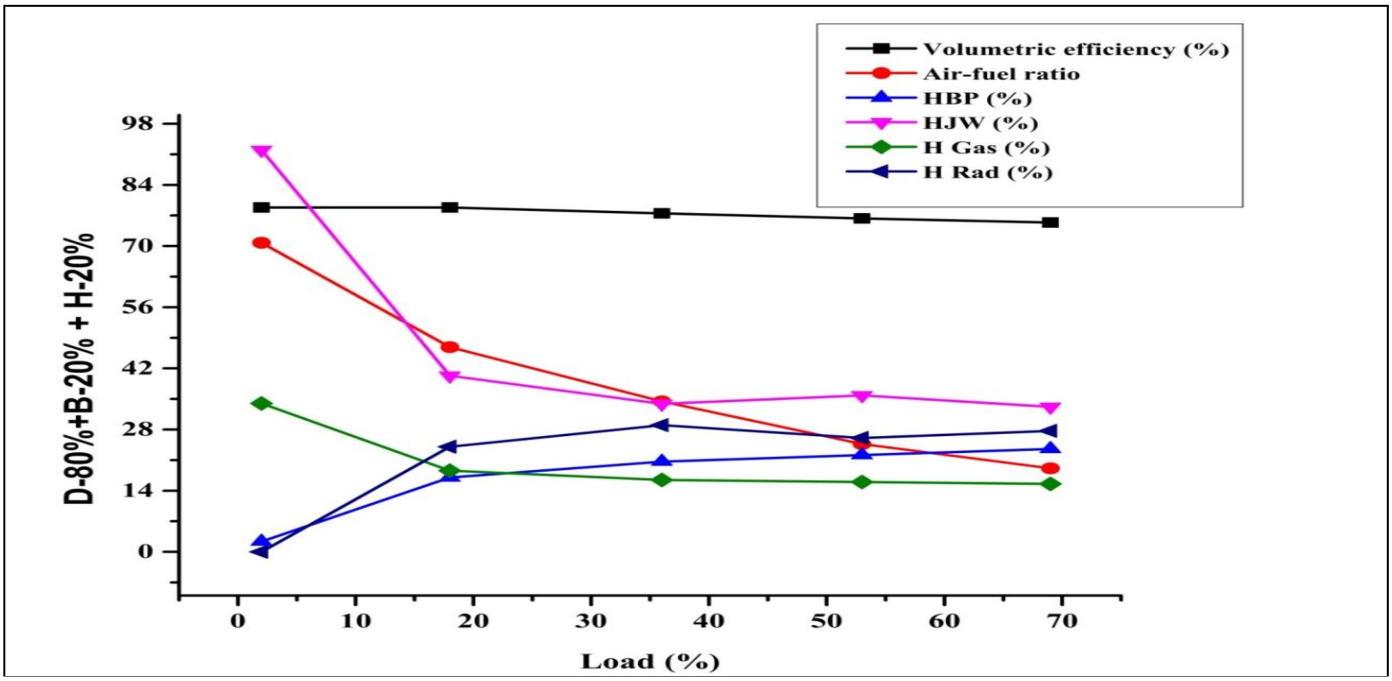


Fig 11: Variation of Different Compositions of Fuel Versus Different Percentages of Load

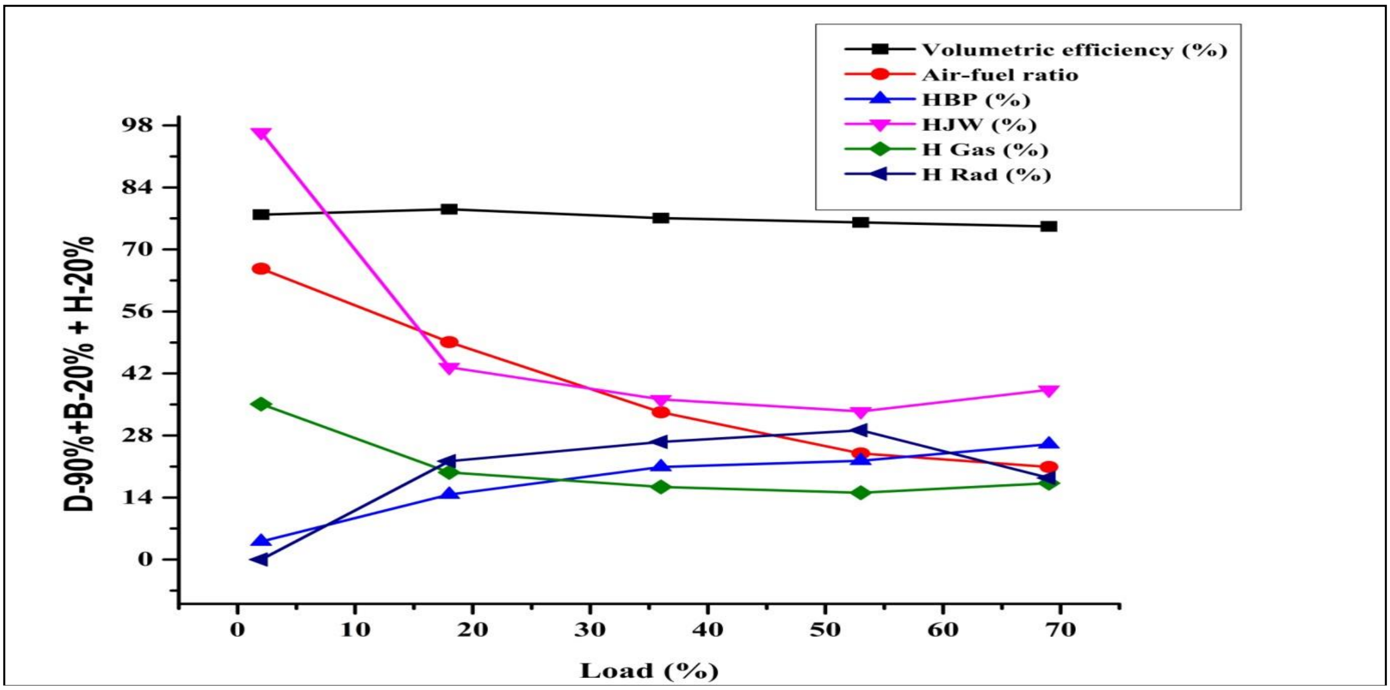


Fig 12: Variation of different compositions of fuel versus different percentages of load.

In Fig. 13, the smooth diminishment in the fuel composition (D-70% + B-30% + H-7%) of volumetric efficiency was observed to be 2.38% at higher load conditions compared to lower load conditions (Table 2a). However, diminishment in the fuel composition of air-fuel ratio, HJW, and H Gas was observed to be 74.52%, 69.25%, and 60.36% respectively. Moreover, the enhancement in the fuel composition HBP, and H Rad were observed to be 78.31%, and 100% respectively at higher load conditions in comparison to lower load conditions.

In Fig. 14, the smooth diminishment in the fuel composition (D-70% + B-30% + H-11%) of volumetric efficiency was observed to be 2.45% at higher load conditions compared to lower load conditions (Table 2b). However, diminishment in the fuel composition of air-fuel ratio, HJW, and H Gas was observed to be 80.51%, 77.77%, and 70.45% respectively. Moreover, the enhancement in the fuel composition HBP, and H Rad were observed to be 61.25%, and 100% respectively at higher load conditions in comparison to lower load conditions.

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In Fig. 15, the smooth diminishment in the fuel composition (D-70% + B-30% + H-16%) of volumetric efficiency was observed to be 3.96% at higher load conditions compared to lower load conditions (Table 2c). However, diminishment in the fuel composition of air-fuel ratio, HJW, and H Gas was observed to be 81.68%, 75.06%, and 68.07% respectively. Moreover, the enhancement in the fuel composition HBP, and H Rad were observed to be 97.8%, and 100% respectively at higher load conditions in comparison to lower load conditions.

In Fig. 16, the smooth diminishment in the fuel composition (D-70% + B-30% + H-20%) of volumetric efficiency was observed to be 5.75% at higher load conditions compared to lower load conditions (Table 2d). However, diminishment in the fuel composition of air-fuel ratio, HJW, and H Gas was observed to be 77.61%, 81.95%, and 19.67% respectively. Moreover, the enhancement in the fuel composition HBP, and H Rad were observed to be 99.54%, and 66.76% respectively at higher load conditions in comparison to lower load conditions.

In Fig. 17, the smooth diminishment in the fuel composition (D-70% + B-30% + H-25%) of volumetric efficiency was observed to be 4.17% at higher load conditions compared to lower load conditions (Table 2e). However, diminishment in the fuel composition of air-fuel ratio, HJW, and H Gas was observed to be 81.68%, 75.63%, and 70.85% respectively. Moreover, the enhancement in the fuel composition HBP, and H Rad were observed to be 97.9%, and 100% respectively at higher load conditions in comparison to lower load conditions.

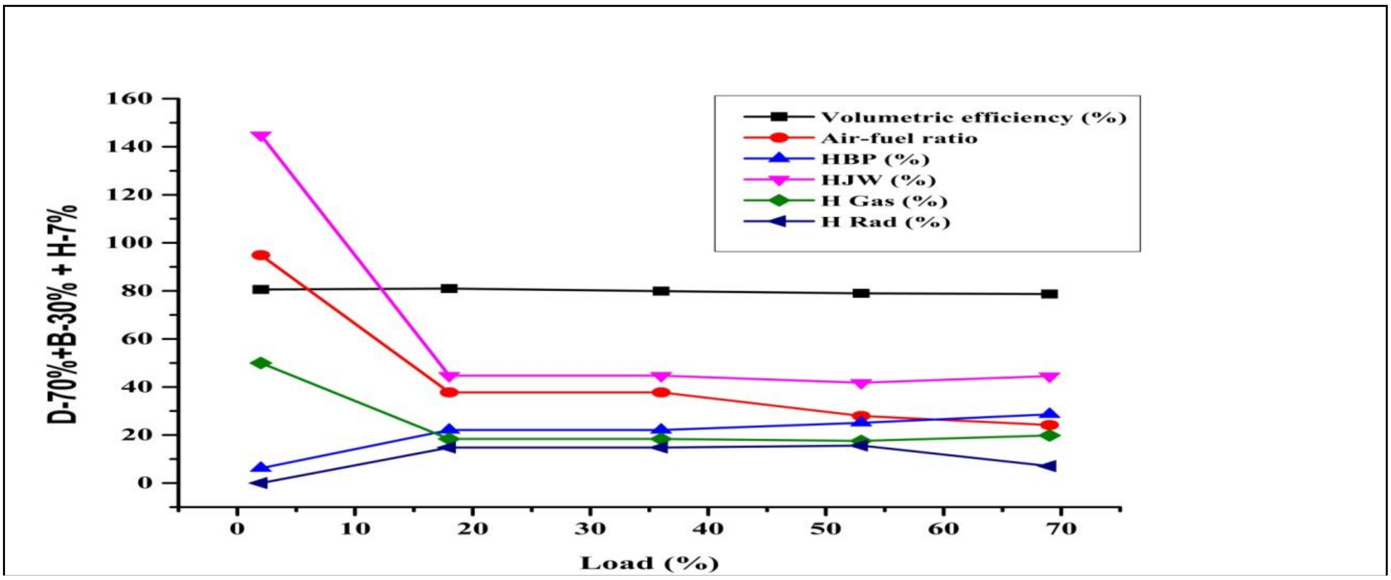

Fig 13: Variation of Different Compositions of Fuel Versus Different Percentages of Load

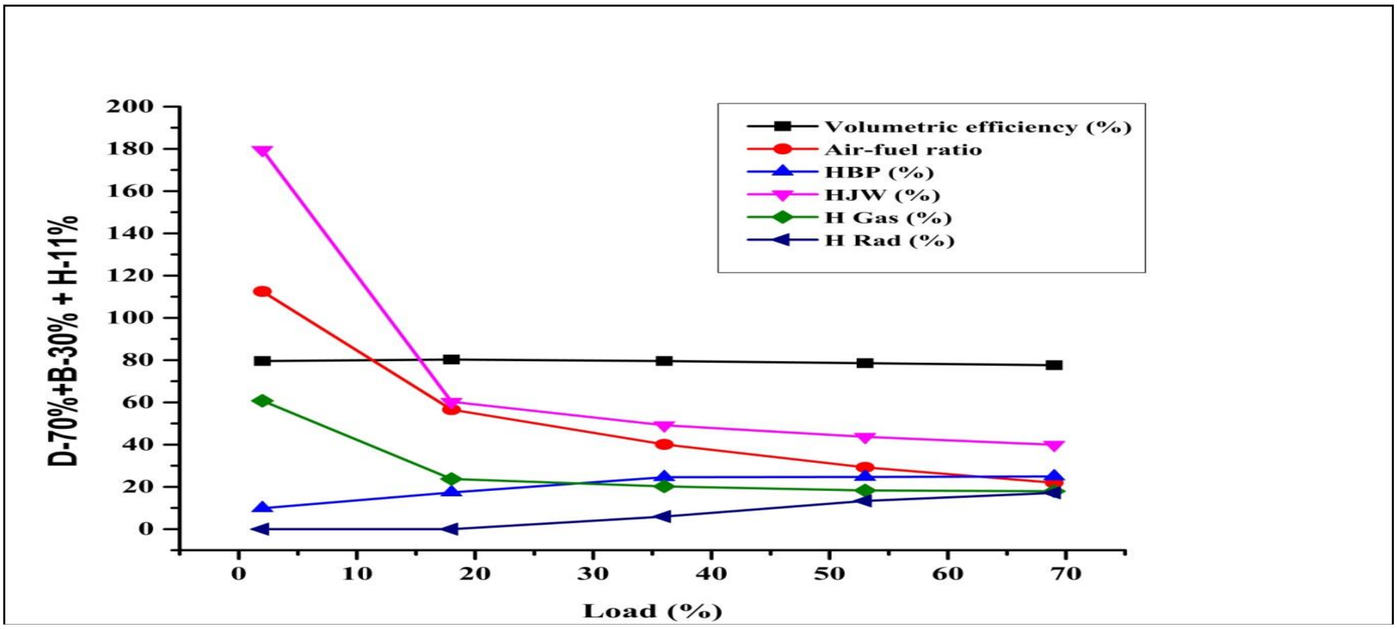

Fig 14: Variation of Different Compositions of Fuel Versus Different Percentages of Load

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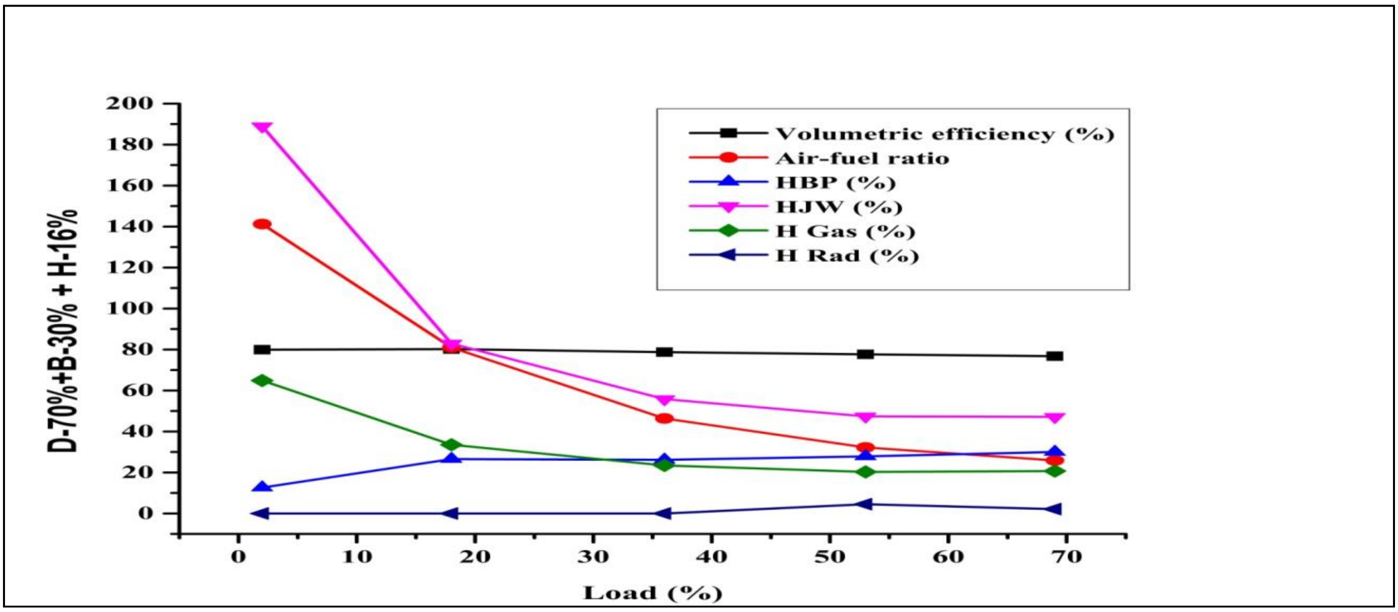


Fig 15: Variation of Different Compositions of Fuel Versus Different Percentages of Load

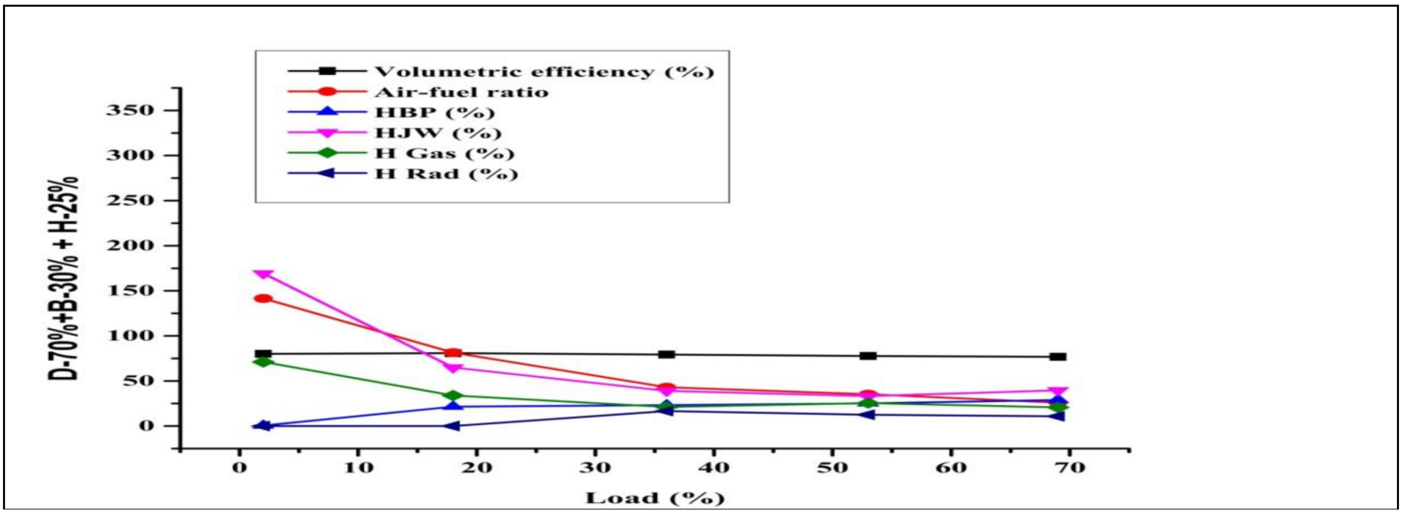


Fig 16: Variation of Different Compositions of Fuel Versus Different Percentages of Load

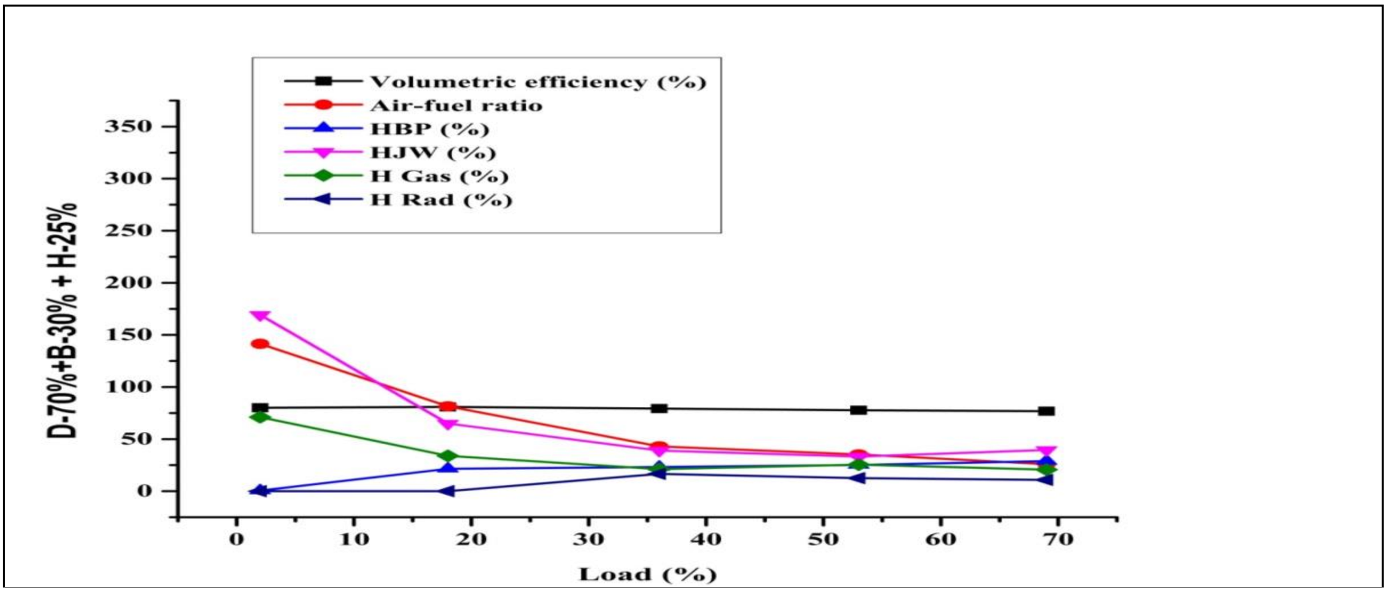


Fig 17: Variation of Different Compositions of Fuel Versus Different Percentages of Load

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In Fig. 18, the smooth diminishment in the fuel composition (D-70% + B-30% + H-7%) of volumetric efficiency was observed to be 4.29% at higher load conditions compared to lower load conditions (Table 2f). However, diminishment in the fuel composition of air-fuel ratio, HJW, and H Gas was observed to be 70.7%, 60.8%, and 49.6% respectively. Moreover, the enhancement in the fuel composition HBP, and H Rad were observed to be 98.8%, and 100% respectively at higher load conditions in comparison to lower load conditions.

In Fig. 19, the smooth diminishment in the fuel composition (D-70% + B-30% + H-11%) of volumetric efficiency was observed to be 3.87% at higher load conditions compared to lower load conditions (Table 2g). However, diminishment in the fuel composition of air-fuel ratio, HJW, and H Gas was observed to be 73.30%, 69.22%, and 63.45% respectively. Moreover, the enhancement in the fuel composition HBP, and H Rad were observed to be 98.63%, and 100% respectively at higher load conditions in comparison to lower load conditions.

In Fig. 20, the smooth diminishment in the fuel composition (D-70% + B-30% + H-16%) of volumetric efficiency was observed to be 2.34% at higher load conditions compared to lower load conditions (Table 2h). However, diminishment in the fuel composition of air-fuel ratio, HJW, and H Gas was observed to be 71.32%, 67.23%, and 58.13% respectively. Moreover, the enhancement in the fuel composition HBP, and H Rad were observed to be 98.80%, and 100% respectively at higher load conditions in comparison to lower load conditions.

In Fig. 21, the smooth diminishment in the fuel composition (D-70% + B-30% + H-20%) of volumetric efficiency was observed to be 2.36% at higher load conditions compared to lower load conditions (Table 2i). However, diminishment in the fuel composition of air-fuel ratio, HJW, and H Gas was observed to be 61.30%, 62.85%, and 55.99% respectively. Moreover, the enhancement in the fuel composition HBP, and H Rad were observed to be 98.54%, and 100% respectively at higher load conditions in comparison to lower load conditions.

In Fig. 22, the smooth diminishment in the fuel composition (D-70% + B-30% + H-25%) of volumetric efficiency was observed to be 3.32% at higher load conditions compared to lower load conditions (Table 2j). However, diminishment in the fuel composition of air-fuel ratio, HJW, and H Gas was observed to be 65.69%, 57.44%, and 42.24% respectively. Moreover, the enhancement in the fuel composition HBP, and H Rad were observed to be 99.04%, and 100% respectively at higher load conditions in comparison to lower load conditions.

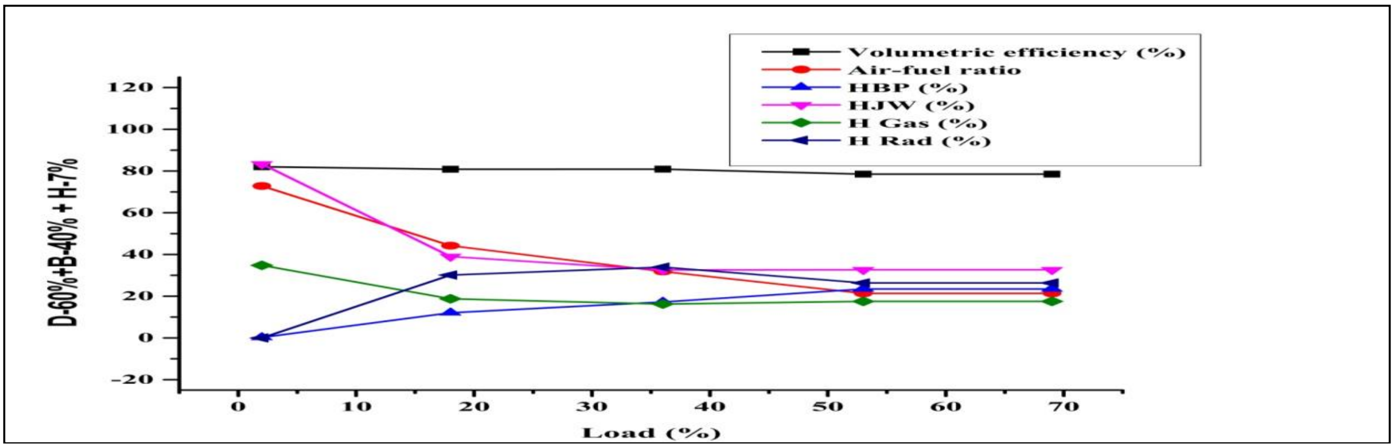

Fig 18: Variation of Different Compositions of Fuel Versus Different Percentages of Load

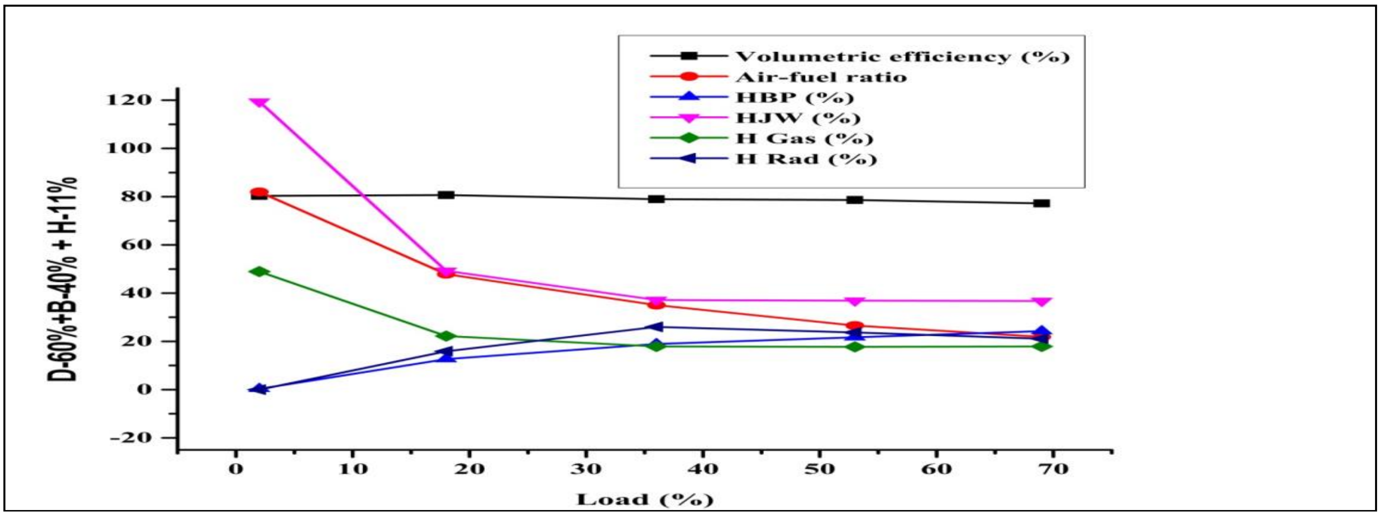

Fig 19: Variation of Different Compositions of Fuel Versus Different Percentages of Load

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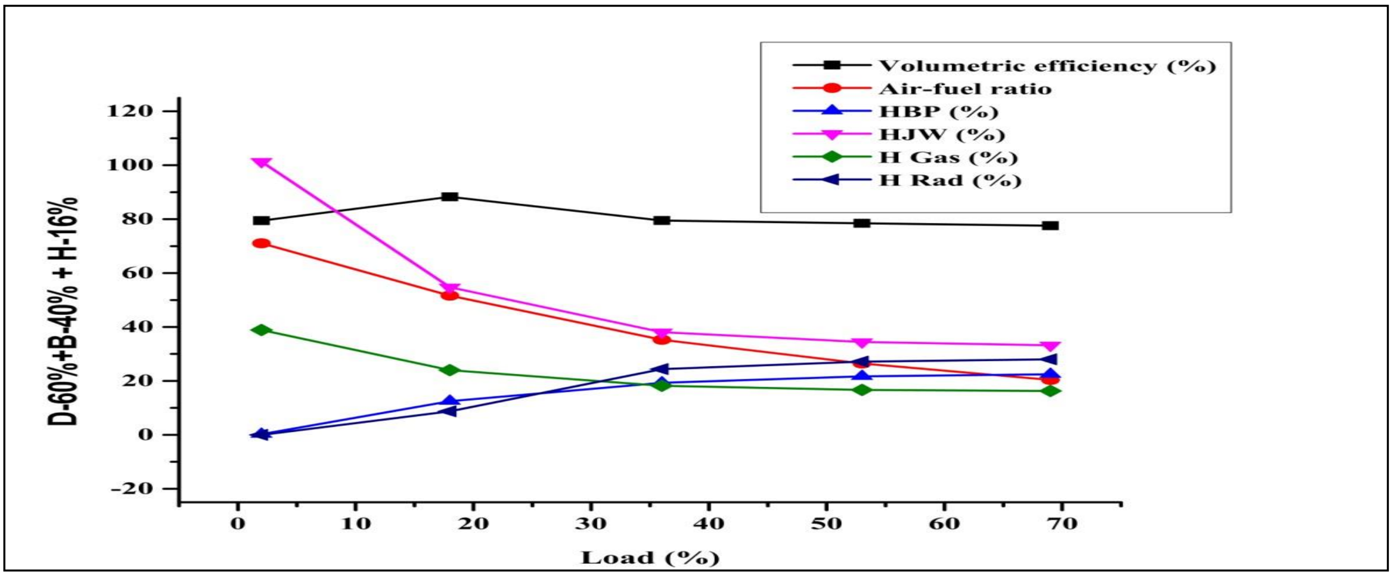

Fig 20: Variation of Different Compositions of Fuel Versus Different Percentages of Load

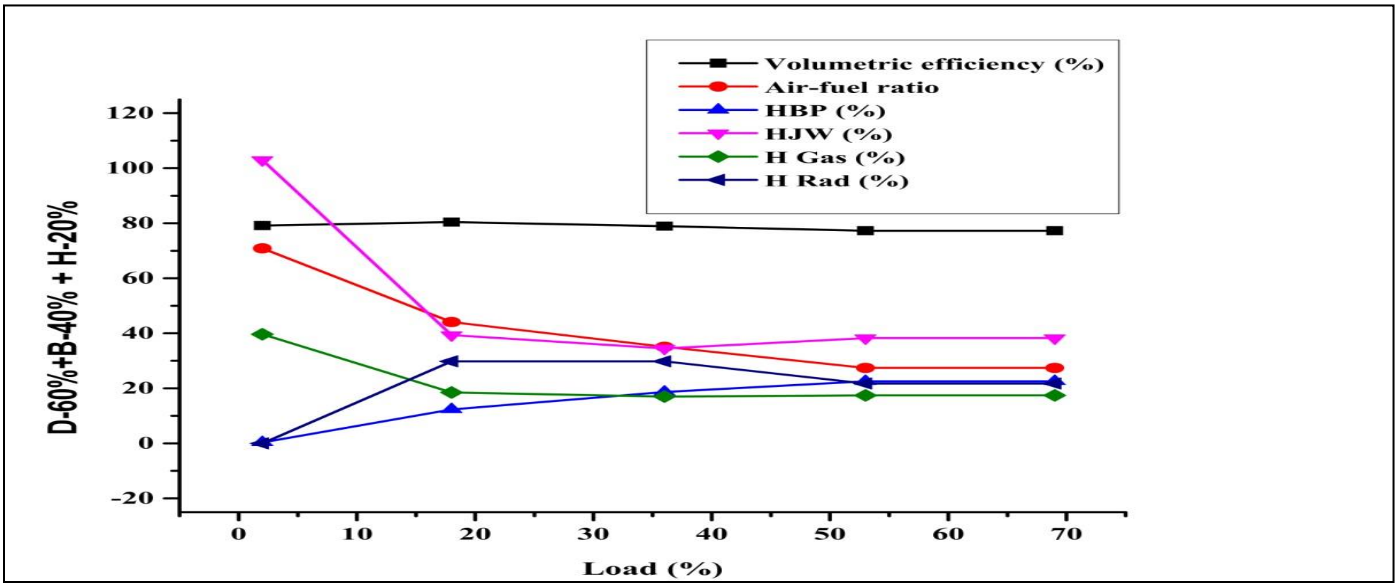

Fig 21: Variation of Different Compositions of Fuel Versus Different Percentages of Load

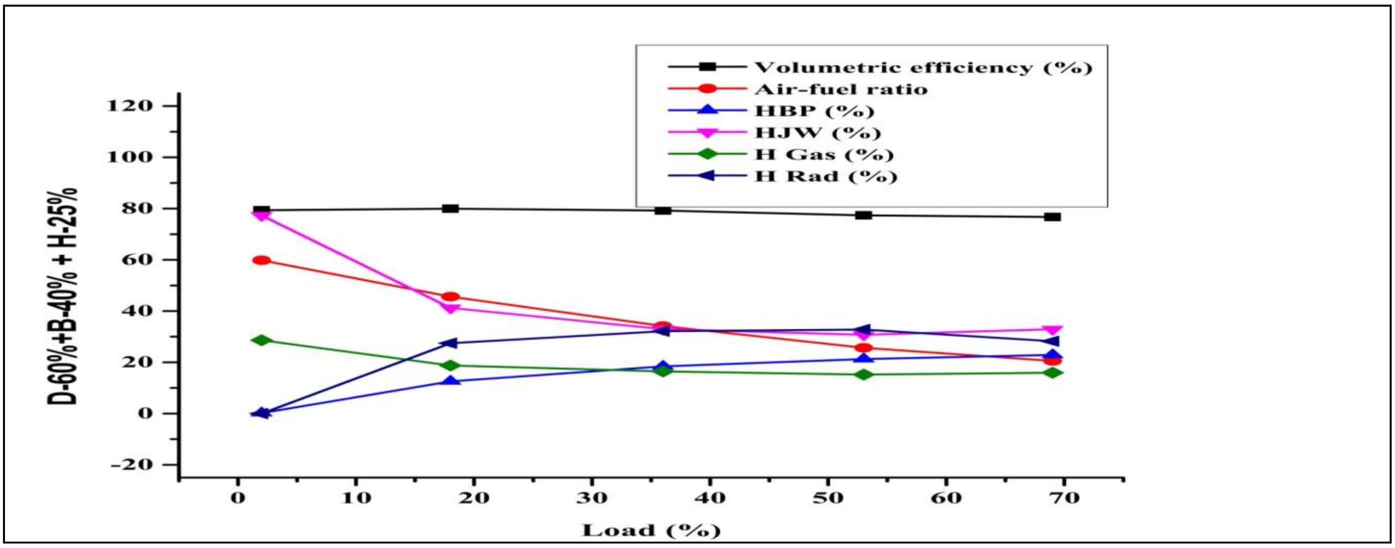

Fig 22: Variation of Different Compositions of Fuel Versus Different Percentages of Load

With increasing in the hydrogen percentages from 7% to 25% with a fixed proportion of 90% diesel, and 10% BKO, and also with increasing both BKO from 10% to 40% and hydrogen from 7% to 25%, the volumetric efficiency of the engine decreases at higher load condition as compared to lower load condition. With the increase in BKO and hydrogen substitution, it displaces the air by hydrogen due to lower density as compared to air; this may be the reason for the decreased volumetric efficiency of the engine with an increase in hydrogen percentage. In the case of the air-fuel ratio, it also decreases due to light density as compared to air, the use of air decreases as compared to diesel-hydrogen. So, the air-fuel ratio decreases with an increase in percentages of BKO and percentages of hydrogen substitution at higher load conditions as compared to lower load conditions [19].

However, in the case of heat in brake power (HBP), it increases due to the gaseous nature of hydrogen combustion inside the cylinder core smoothly [20]. Now, in the case of heat in jacket water (HJW), and heat carried away by exhaust gas (H Gas), it decreases due to the higher thermal conduction of percentages of BKO and percentages of hydrogen fuel substitution as compared to air in diesel [21-22]. Since the fraction of heat as compared to air in diesel fuel operation, decreases in HJW and H Gas. In the case of heat carried away by radiation (H Rad) increases due to higher mean gas temperature in case of substitution of diesel fuel with hydrogen fuel, it increases the fraction of heat in radiation at higher load conditions as compared to lower load conditions [23].

## IV. CONCLUSIONS

In this paper, the experiments were carried out with neat diesel and different compositions of BKO (10%, 20%, 30%, and 40%) and hydrogen (7%, 11%, 16%, 20%, and 25%) on a dual fuel diesel engine. The variation of volumetric efficiency, air-fuel ratio, heat in brake power (HBP), heat in jacket water (HJW), heat carried away by exhaust gas (H Gas), and heat carried away by radiation (H Rad) of the engine are experimentally investigated. The following conclusions are drawn:

The diminishment in the volumetric efficiency was observed to be 5.87% at higher load conditions compared to lower load conditions with fuel composition (D-90% + B-10% + H-11%). The diminishment in the air-fuel ratio was observed to be 81.68% at higher load conditions compared to lower load conditions with fuel composition (D-70% + B-30% + H-16%). The enhancement in HBP was observed to be 99.75% at higher load conditions in comparison to lower load conditions with fuel composition (D-80% + B-20% + H-11%). The diminishment in HJW was observed to be 55.76% at higher load conditions compared to lower load conditions with fuel composition (D-80% + B-20% + H-11%). The diminishment in H-Gas was observed to be 19.67% at higher load conditions compared to lower load conditions with fuel composition (D-70% + B-30% + H-20%). The enhancement in H-Rad was observed to be 66.76% at higher load conditions compared to lower load conditions with fuel composition (D-70% + B-30% + H-20%).

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