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# Effects of Ethanol Fumigation on the Performance and Emissions of Diesel Engines

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This study aimed to develop an electronic fuel injection system for utilizing ethanol as a fumigant in a single-cylinder, four-stroke, water-cooled diesel engine. The engine's emissions and performance were evaluated through experiments to determine the impact of ethanol fumigation. The main objective was to identify the optimal amount of ethanol that could reduce emissions while enhancing performance using a simple fumigation process. The tests were conducted at constant engine speeds and loads, with diesel fuel and ethanol flow rates ranging from 0.2737 to 0.958 kg h$^{-1}$. The findings indicated that the most effective percentage of ethanol was 0.8767, resulting in the best outcomes. Additionally, the emissions of CO, HC, and NOx remained constant after reaching 21.69% thermal efficiency, indicating the optimal level of fumigation. To better understand the engine behavior observed, the theoretical aspects of diesel engine combustion were combined with the distinct physical and chemical properties of ethanol compared to those of diesel fuel.

**Keywords:** Fumigation, Diesel engines, Ethanol, Carbon monoxide, Oxides of nitrogen

## INTRODUCTION

India, like many other developing countries, relies on internal combustion engines, both gasoline and diesel, for transportation [1]. Internal combustion engine vehicles have recently come under fire for a variety of issues they have caused. The emissions produced during the combustion process are the most important of these issues [2]. The pollutants from diesel vehicles are particulate matter (PM), smoke density, oxides of nitrogen (NOx), sulphur oxides (SOx), carbon dioxide (CO$_2$), and hydrocarbons (HC). Most of these pollutants are emitted from exhaust gases. Diesel engines have low HC and CO emissions because they operate at a high air-to-fuel ratio [3]. They emit significantly more PMs than gasoline-powered automobiles. However, for heavy-duty vehicles, CO, HC, and NOx in the exhaust also vary with driving modes, engine speed, and load [4-6].

A diesel engine's main source of air pollution is combustion by-products that are released through the exhaust pipe. While both the fuel tank and crankcase breathers contribute, 65 to 85% of the pollutants created by the engine are attributed to the exhaust [7]. In addition to the particles, unburned hydrocarbons (HC), nitrogen oxides (NOx), carbon dioxide (CO$_2$), carbon monoxide (CO), and traces of alcohols, aldehydes, ketones, phenols, acids, esters, ethers, epoxides, peroxides, and other oxygenates, engine exhaust contains additional substances as well. Carbonaceous soot particles collect and condense hydrocarbons on their surfaces, forming particulates in diesel exhaust [8]. The

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soluble organic fraction refers to the hydrocarbon portion of the particles (SOF). The name stems from the fact that in the analysis of a particulate sample, a solvent is employed to separate the organic fraction from the carbonaceous core. The way a particle sample is obtained can have an impact on the amount of SOF it contains [9]. The time between creation and collection, as well as the temperatures in the collecting system, affect how much hydrocarbons adsorb and condense onto particle surfaces [10]. Unburned paraffin, olefin, and aromatic fuel components make up the majority of the insoluble fraction, whereas unburned gasoline, engine oil, and paraffin are all sources of hydrocarbons that make up the SOF.

NOx emissions from diesel engines are equivalent to those from spark-ignition engines. 20 grammes per kilogramme of fuel, or 500 to 1000 ppm, are the norm for concentrations. 10 to 30% of NOx emissions come from NO, and the remaining portion comes from $NO_2$. Although NO is the most often created species in the cylinder, the bulk of NO is converted to $NO_2$ in the atmosphere. In the burned-gas areas of the cylinder, an endothermic reaction produces NO. The temperature has a big impact on the production of NO. Nitrogen oxide formation is considerably increased by the higher flame temperatures associated with early or fast burning [11]. Therefore, the time of the injection and the rate of combustion have an impact on the amount of NOx in the diesel exhaust. The cooling that occurs during the expansion stroke freezes the reaction, resulting in concentrations that are substantially greater than the equilibrium concentrations for the temperature of the exhaust.

The obvious sign of the combustion process in the engine is the exhaust smoke, which is produced as a result of incomplete combustion. There are three types of smoke produced by diesel engines. Blue, white, and black smoke are quantified using the visible method of analysis [12]. Smoke measurements can be divided into two categories. Methods of comparison and obscuration. The density of the smoke as it emerges from the exhaust is used to calculate smoke emissions. Depending on the engine being regulated as well as the jurisdiction, there are several hydrocarbon regulations. In some cases, "non-methane hydrocarbons," and in others, "total hydrocarbons," are subject to regulation. Technology made to meet a non-methane hydrocarbon criterion may not be appropriate for other uses (meeting a total hydrocarbon standard). Although methane is not dangerous, it is harder to degrade in a catalytic converter; therefore, a "non-methane hydrocarbon" criterion can be viewed as a more forgiving standard [13]. Because methane is a greenhouse gas, there is a growing interest in finding ways to reduce its emissions. Sulphur oxides are emitted by motor vehicles when they burn fuel with a high sulphur content. Though alcohols have been utilised as a fuel for internal combustion engines since their inception, little attention has been paid to their usage in compression ignition engines due to the following issues [14].

- ➢ By proportion and volume, more alcohol fuel is required than diesel.
- ➢ Because large amounts of alcohol do not combine with diesel fuel, diesel-alcohol mixes are not possible. In addition, in the presence of trace amounts of water, the blends are unstable and separate.
- ➢ Alcohol has a quite low acetone number, but diesel engines prefer fuels with a high acetone number (45-55), which auto-ignite quickly and have a short ignition delay.
- ➢ Diesel fuel is used to maintain the lubrication of diesel engines. Alcoholic fuels don't have gasoline's lubricating qualities.
- ➢ Alcohols' weak auto-ignition capacity results in significant knock because of the fast burning of vaporised alcohol, combustion quenching brought on by the high latent heat of vaporisation, and subsequent charge cooling.

Although it is hard to replace diesel fuel totally with alcohol, there has been an increase in interest in using alcohols, especially lower alcohols (methanol and ethanol), in different proportions and ways as a dual fuel in diesel engines recently. According to further literature surveys, there is not enough knowledge about how alcohols affect particulate matter and smoke emissions from diesel engines, and there is not much information about how alcohols interact with diesel fuel. We have used ethanol percentages as a fraction of the diesel energy intake at full load because a comparison of these two techniques needed a starting point. These percentages must be delivered to the engine in order to maintain constant total fuel energy based on diesel fuel operation at full load. To do this, a quick and effective fumigation technique might be created.

Alcohol can be introduced into an engine *via* the fumigation technique by being carbureted, vaporized, or injected into the intake air stream. In ethanol fumigation, the diesel fuel is pumped directly into the cylinder like in a conventional diesel engine, while the ethanol is combined with the intake air by injection or vaporization of the alcohol. Many researchers have looked into a variety of methods, such as dual injection and alcohol-diesel liquid blends, to employ alternative fuels in diesel engines to reduce the consumption of petroleum and pollutants, and the fumigation method is just one of them.

## EXPERIMENTAL APPARATUS AND TEST PROCEDURE

Fumigation is a technique for introducing alcohol into an engine by carburetting, vaporising, or injecting it into the intake air stream. The experimental schematic arrangement is shown in Fig. 1. A carburettor, vaporizer, or injector, as well as a separate fuel tank, pipes, and controls, are essential. To avoid flame quenching and misfiring, alcohol delivery must be lowered at low loads. Alcohol delivery must also be lowered at high loads to avoid pre-ignition and engine knock. Up to 50% of the power can be generated from the alcohol in the mid-load range. To meet such a requirement, widely available straight diesel fuel operation becomes more difficult, requiring fumigation, which is desired if diesel fuel sources are unstable. Major fraction and minor fraction fumigation are two types of fumigation. The term "major fraction" refers to the use of more than 50% of fuel injection. These performance improvements and reduced target emissions can be identified when a small proportion of fumigation is under 50% of fuel injection. To suit alcohol fumigation, a single-cylinder Kirloskar AV-1 engine, a four-stroke, water-cooled diesel engine with 3.7 KW power, 80mm bore, 110mm stroke, and 1500 rpm speed, has been adapted. The engine is coupled to an electrical swing-field dynamometer. From the previous report [15], the properties of diesel, ethanol, and methanol have been shown in Table 1.

## CHEMICAL AND DEVICES

Ethanol fumigation involves injecting ethanol into the intake air system of a diesel engine. This is achieved through

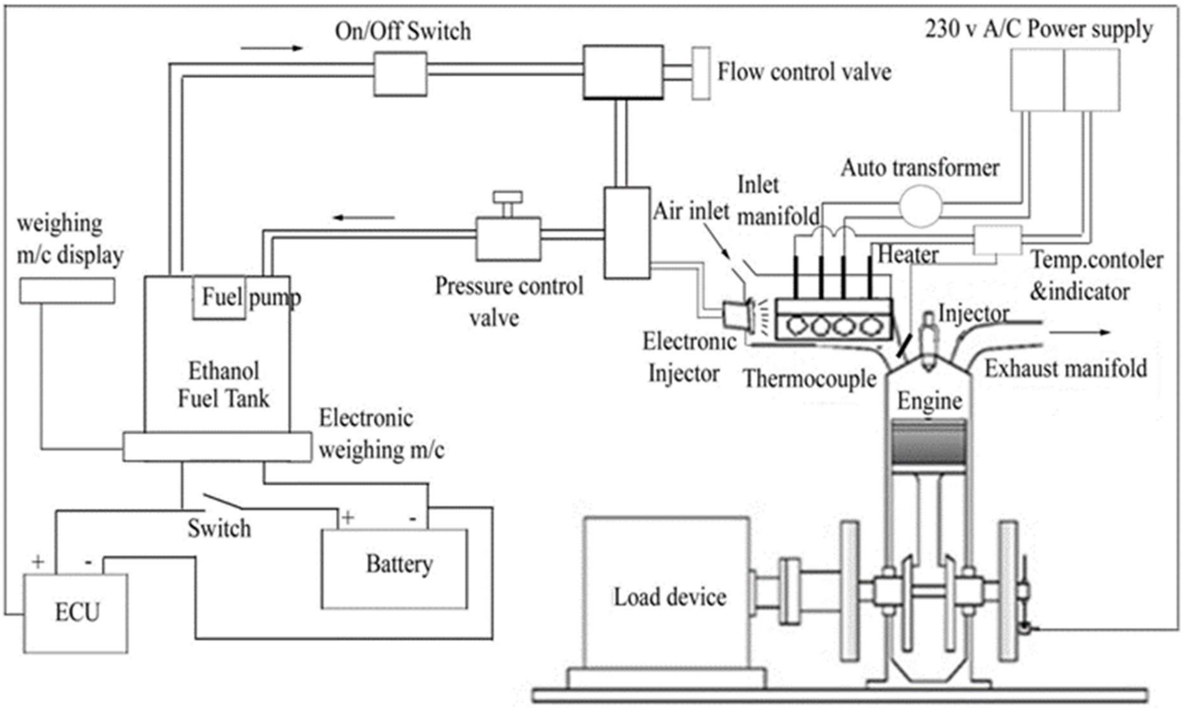

**Fig. 1.** Experimental schematic arrangement.

**Table 1.** Properties of Diesel, Ethanol, and Methanol

| *Parameters | Diesel | Ethanol | Methanol |
|---|---|---|---|
| Density at 20 °C (× $10^3$ kg $m^{-3}$) | 0.829, liquid | 0.789, liquid | 0.792, liquid |
| Boiling point (°C) | 180-360 | 78.4 | 64.7 |
| Pour point (°C) | -1 to 3 | -117.3 | -97.6 |
| Mole weight | 190-220 | 46.07 | 32.04 |
| Flashpoint (°C) | 65-88 | 13-14 | 11-12 |
| Heat content (MJ $kg^{-1}$) | 3.35 | 1.20 | 22.56 |
| Cetane number | 45-50 | 5-8 | 55-60 |
| Appearance | Mild brown liquid | Colourless liquid | Colourless liquid |
| Other names | Petrodiesel, diesel oil | Ethyl alcohol, grain alcohol, hydroxy ethane, ethyl hydrate | Wood spirit, Methyl alcohol, Hydroxy methane, Wood alcohol. |
| Specific gravity | 0.835 | 0.787 | 0.791 |
| Calorific value | 41000 kJ $kg^{-1}$ | 30000 kJ $kg^{-1}$ | 23000 kJ $kg^{-1}$ |

*Taken from Ref. [15].

an electronic fuel injection system, which is fabricated to use ethanol as a fumigant. The system comprises various components, including an ethanol tank, a pump, an injector, a filter, a pressure regulator, and an electronic control unit (ECU). The ethanol tank stores the fuel and supplies it to the pump, which pressurizes the fuel to the desired level. The fuel is then filtered to remove any impurities before being injected into the intake air system through the injector. The pressure regulator maintains a constant pressure in the fuel line, while the ECU controls the fuel injection timing and duration. The chemical properties of ethanol make it an ideal fuel for fumigation in diesel engines. Ethanol has a higher oxygen content than diesel fuel, which leads to better combustion and reduced emissions of harmful gases such as NOx, CO, and HC. Additionally, ethanol has a higher octane rating than diesel fuel, which improves engine performance by reducing knocking and increasing power output.

## EXPERIMENTAL PROCEDURE

1. Fabrication of an electronic fuel injection system for use as a fumigant in a single-cylinder, four-stroke water-cooled diesel engine.
2. The diesel fuel and ethanol flow rates for the experiment are being prepared. Flow rates range from 0.2737 to 0.958 kg $h^{-1}$.
3. Engine instrumentation contains sensors to measure performance metrics such as power output, torque, and fuel consumption, as well as CO, HC, NOx, and smoke emissions.
4. Engine testing at constant speeds and loads using diesel fuel and various ethanol flow rates fed *via* the electronic fuel injection system.
5. Data gathering and analysis of engine performance and emissions at each step of fumigation.
6. The results of each fumigation step are compared to determine the appropriate amount of ethanol that delivers the highest engine performance and the lowest emissions.
7. Theoretical features of diesel engine combustion and the physical and chemical characteristics of ethanol in comparison to diesel fuel are used to interpret observed engine behaviour.

The performance and emission tests are to be carried out using this experimental setup. Initially, the engine runs using sole fuel at a constant speed of 1500 rpm, for nearly 15 min to attain the steady state conditions at no load. The cooling water flow is to be maintained constant and the following observations are to be made as shown in Fig. 2 and Fig. 3.

- Time for 10 cc of fuel consumption using a stopwatch.
- Through the use of electronic weighing equipment, determine the amount of ethanol flow rate.
- The exhaust gas temperature.
- Smoke density using the AVL (Standard Brand) smoke meter at the exhaust
- The concentrations of $CO_2$, CO, HC, $O_2$, and $NO_x$ in engine emissions are to be measured directly using an AVL di-gas analyzer

After completing the experiments with sole fuel, the experiment will be repeated with ethanol as fumigated fuel. The flow rates of ethanol fumigation inside the cylinder will be varied, and for each flow rate, the reading will be taken for different loads from Fig. 4. The engine is loaded using an eddy current dynamometer. When the driving shaft rotates, the rotor also rotates, creating a constant change in flux density at all points on the stator. Hence, eddy current is included in the stator. These eddy currents oppose the rotation of the rotor. With the help of the brake arm and balance system, the moment of resistance is measured. This is used to determine the torque and, thereby, the shaft power. The diesel is supplied from the diesel tank. The secondary fuel, ethanol, is supplied from the separate tank to the electronic fuel injector, which is placed on the inlet air manifold. The burettes are connected to measure the flow rates of diesel and ethanol. The electronic fuel injector is placed in the air intake manifold. The ethanol from the injector and fresh air gets mixed, and the mixture is supplied to the cylinder. The control unit gets the signal from the sensor, the signal is conditioned, and it is given to the injector. The ethanol flow and period of injection are controlled by the ECU. The ECU has two rotating switches. One switch is controlled by the quantity of ethanol flow rate, and another switch is controlled by the period of injection. An oscilloscope is used to control the time of the injector. As long as power is given to the injector's solenoid coil, the electronic fuel injector is generally closed and releases pressurised fuel. The pulse width, or duration, of this action is related to the amount of fuel emitted. An electromagnet operates a plunger that opens the valve when the injector is turned on, allowing the pressurised gasoline to spray out through a tiny nozzle. The nozzle's purpose is to atomize the fuel into as thin a mist as possible, allowing it to burn easily.

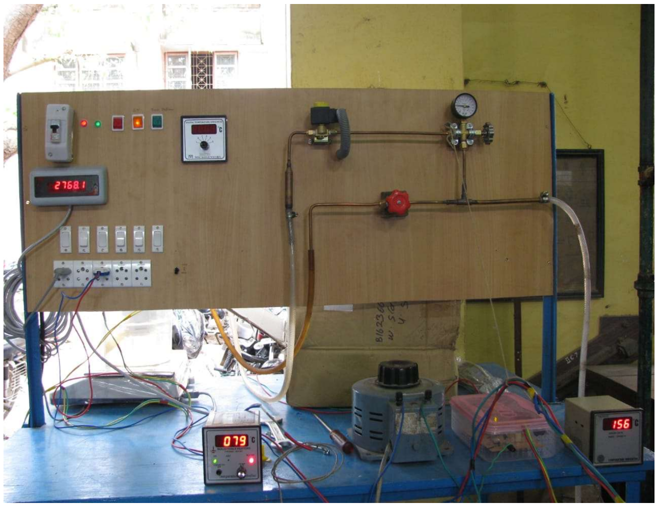

**Fig. 2.** Experimental setup.

**Fig. 3.** Engine test setup.

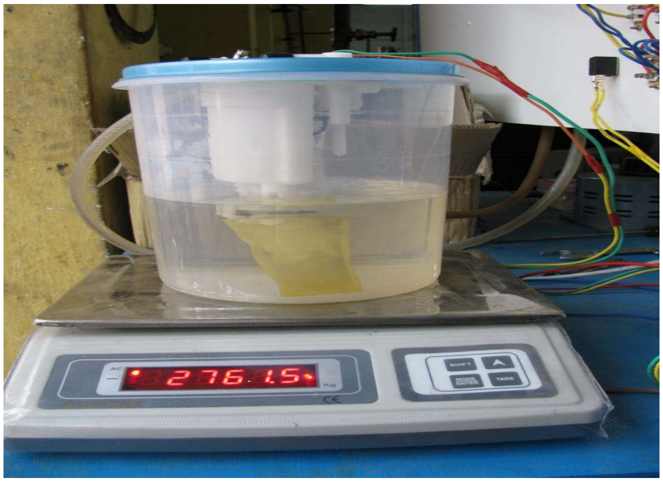

**Fig. 4.** Fuel flow measurement setup.

The length of time the fuel injection is open determines the amount of fuel provided to the engine. The temperature control unit is used to sense the thermocouple temperature. The thermocouple was fixed after heating the coil before the intake cylinder.

## RESULTS AND DISCUSSION

The injection pressure is varied by the pressure gauge. The quantity of ethanol flow rate controlled by the switch rotates one full revolution. The diesel injection period is 15° before TDC to 25° after TDC, and the alcohol injection period is 10° before TDC to 25° after TDC. The thermocouple calibrated the temperature of the mixture before the intake cylinder and after the heating coil. The temperature coil is controlled by the temperature control unit, and it can act as a temperature indicator. An electronic fuel injection system is fabricated to fumigate ethanol into the intake air charge of a single-cylinder, four-stroke, water-cooled diesel engine, coupled with an eddy current dynamometer for experimental work [16]. The various results are calculated with diesel as fuel: 0.2737 kg $h^{-1}$ flow rate of ethanol fumigation, 0.4593 kg $h^{-1}$ flow rate of ethanol fumigation, 0.5743 kg $h^{-1}$ flow rate of ethanol fumigation, 0.8769 kg $h^{-1}$ flow rate of ethanol fumigation, and 0.958 kg $h^{-1}$ flow rate of ethanol fumigation are tabulated with standard temperature and injection pressure at 1000 C, 2 bar, and 1500 rpm, as shown in Fig. 5 and Table 2.

Figure 6 and Table 3 depict the relationship between emissions and brake thermal efficiency at a 0.2737 kg $h^{-1}$ flow rate of ethanol fumigation. The plotted graph shows that the percentages of $CO_2$, $NO_X$, and HC increase as the brake thermal efficiency increases. The amount of CO generated decreases as thermal efficiency improves. When comparing emissions, it is discovered that CO emissions are higher at lower levels of thermal efficiency. $CO_2$ emissions, on the other hand, are lower. The explanation for this may be attributed to full combustion, which increases the supply of oxygen molecules. The breakdown of $N_2$ molecules into N, which interacts with available oxygen to form nitrogen oxides, can be the cause of NOx pollution. The reduction in UBHC may be attributed to the full combustion of the fuel, which increases the supply of oxygen molecules. Figure 5 demonstrates that diesel fuel has a higher thermal efficiency for braking than ethanol, presumably as a result of the latter's lower calorific value.

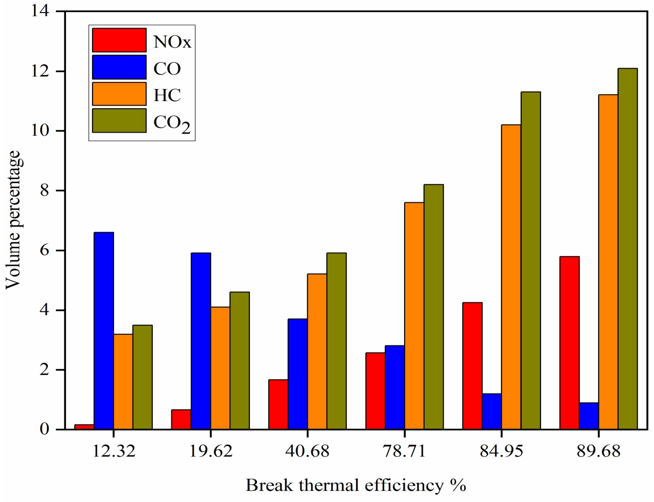

**Fig. 5.** Brake Thermal efficiency *versus* percentage of volume with diesel as fuel.

**Table 2.** Brake Thermal Efficiency *versus* Percentage of Volume with Diesel as Fuel

| | NOx | CO | HC | $CO_2$ |
|---|---|---|---|---|
| 12.32 | 0.16 | 6.6 | 3.2 | 3.5 |
| 19.62 | 0.67 | 5.9 | 4.1 | 4.6 |
| 40.68 | 1.67 | 3.7 | 5.2 | 5.9 |
| 78.71 | 2.56 | 2.8 | 7.6 | 8.2 |
| 84.95 | 4.25 | 1.2 | 10.2 | 11.3 |
| 89.68 | 5.78 | 0.9 | 11.2 | 12.1 |

**Table 3.** Brake Thermal Efficiency *versus* Percentage of Volume at 0.2737 kg $h^{-1}$ Flow Rate of Ethanol Fumigation

| | NOx | CO | HC | $CO_2$ |
|---|---|---|---|---|
| 1.27 | 0.081 | 0.24 | 0.653 | 1.9 |
| 13.09 | 0.127 | 0.19 | 0.632 | 2.3 |
| 21.09 | 0.222 | 0.13 | 0.578 | 3 |
| 26.20 | 0.477 | 0.07 | 0.515 | 4.1 |
| 27.02 | 0.696 | 0.06 | 0.466 | 5.2 |
| 29.7 | 0.802 | 0.052 | 0.408 | 5.7 |

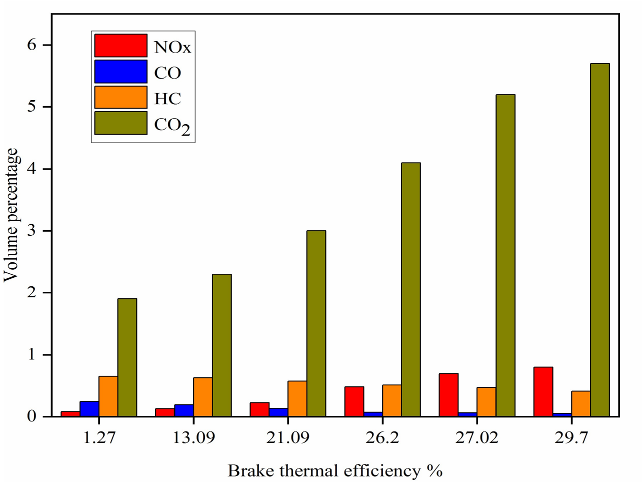

**Fig. 6.** Brake Thermal efficiency *versus* percentage of volume at 0.2737 kg $h^{-1}$ flow rate of ethanol fumigation.

**Table 4.** Brake Thermal Efficiency *versus* Percentage of Volume at 0.4593 kg $h^{-1}$ Flow Rate of Ethanol Fumigation

| | NOx | CO | HC | $CO_2$ |
|---|---|---|---|---|
| 1 | 0.068 | 0.29 | 0.0485 | 1.5 |
| 12.02 | 0.079 | 0.22 | 0.045 | 1.8 |
| 17.98 | 0.232 | 0.19 | 0.0432 | 2.3 |
| 24.27 | 0.391 | 0.09 | 0.0408 | 3.1 |
| 29.78 | 0.584 | 0.07 | 0.0354 | 3.8 |
| 28.61 | 0.569 | 0.067 | 0.029 | 4.2 |

At a flow rate of 0.4593 kg $h^{-1}$ of ethanol fumigation, Fig. 7 and Table 4 show the variation of emissions with brake thermal efficiency. The graph reveals that $CO_2$ emissions have a higher volume percentage than other emissions. NOx emissions began to rise after the brake thermal efficiency reached 17.98%, which may be attributed to the release of more heat thereafter. For all percentage levels of brake thermal efficiency, HC and CO emissions are nearly identical, ranging from 0 to 1%. As compared to other emissions, NOx emissions are lower, which may be due to the presence of more $CO_2$, which decreases the heat of combustion [17-19].

Figure 8 and Table 5 depict the variance of emissions with thermal efficiency at an ethanol fumigation flow rate of

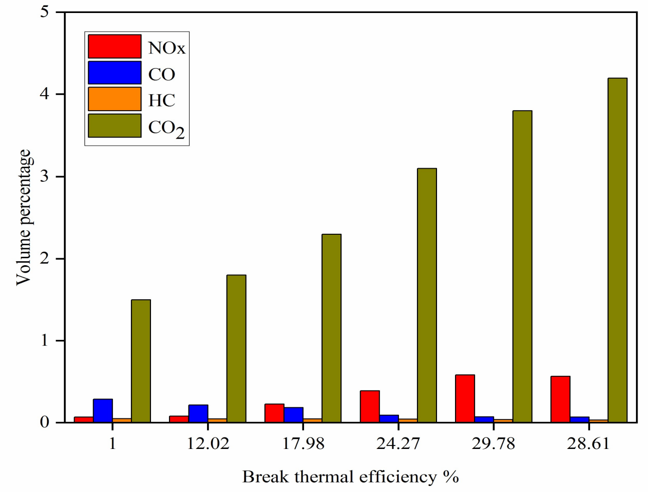

**Fig. 7.** Brake Thermal efficiency *versus* percentage of volume at 0.4593 kg $h^{-1}$ flow rate of ethanol fumigation.

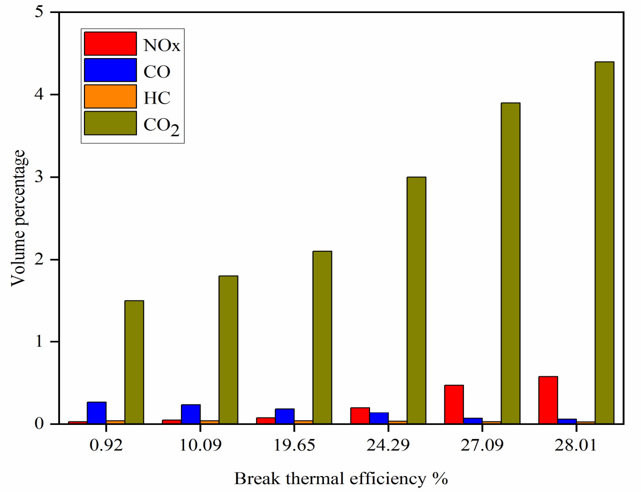

**Fig. 8.** Brake Thermal efficiency *versus* percentage of volume at 0.5743 kg $h^{-1}$ flow rate of ethanol fumigation.

**Table 5.** Brake Thermal Efficiency *versus* Percentage of Volume at 0.5743 kg $h^{-1}$ Flow Rate of Ethanol Fumigation

| | NOx | CO | HC | $CO_2$ |
|---|---|---|---|---|
| 0.92 | 0.027 | 0.27 | 0.0392 | 1.5 |
| 10.09 | 0.048 | 0.24 | 0.0391 | 1.8 |
| 19.65 | 0.077 | 0.19 | 0.0379 | 2.1 |
| 24.29 | 0.204 | 0.14 | 0.0330 | 3 |
| 27.09 | 0.475 | 0.07 | 0.0287 | 3.9 |
| 28.01 | 0.579 | 0.06 | 0.0249 | 4.4 |

0.5743 kg h$^{-1}$. The graphs show that $CO_2$ emissions have a higher volume percentage than other emissions. Other emissions range from 0 to 1% and are found to be higher at lower brake thermal efficiency levels. With an improvement in thermal efficiency, emissions such as CO and HC show a decreasing trend. After 24.29% thermal efficiency, NOx emissions began to rise, which may be attributed to increased heat generation due to the higher efficiency. After 26.29% thermal efficiency, all emissions except $CO_2$ are found to be the same.

Figure 9 and Table 6 depict the variance of emissions with thermal efficiency at an ethanol fumigation flow rate of 0.8767 kg h$^{-1}$. The graphs show that $CO_2$ emissions have a higher volume percentage than other emissions. Other emissions range from 0 to 1% and are higher at lower levels of thermal efficiency. CO, NOx, and HC emissions all display a downward trend as thermal efficiency improves.

Figure 10 and Table 7 depict the relationship between pollution and thermal efficiency at a flow rate of 0.958 kg h$^{-1}$ for ethanol fumigation. The graphs show that the percentages of $CO_2$ and HC increase as the percentage of thermal efficiency increases. When the $CO_2$ emissions are compared, the $CO_2$ emissions are found to be at a higher level, indicating a higher level of thermal efficiency. As compared to other emissions, $NO_x$ emissions are lower, which may be due to the presence of more $CO_2$, which decreases combustion and heat, resulting in higher HC and CO emissions [15,20-22].

**Table 6.** Brake Thermal Efficiency *versus* Percentage of Volume at 0.8767 kg h$^{-1}$ Flow Rate of Ethanol Fumigation

| | NOx | CO | HC | $CO_2$ |
|---|---|---|---|---|
| 0.74 | 0.0027 | 0.26 | 0.0866 | 1.2 |
| 8.51 | 0.0036 | 0.24 | 0.0818 | 1.5 |
| 15.952 | 0.0074 | 0.21 | 0.0779 | 2 |
| 21.69 | 0.016 | 0.1 | 0.0715 | 2.6 |
| 26.29 | 0.0277 | 0.09 | 0.0645 | 3.5 |
| 27.21 | 0.0388 | 0.07 | 0.0612 | 3.8 |

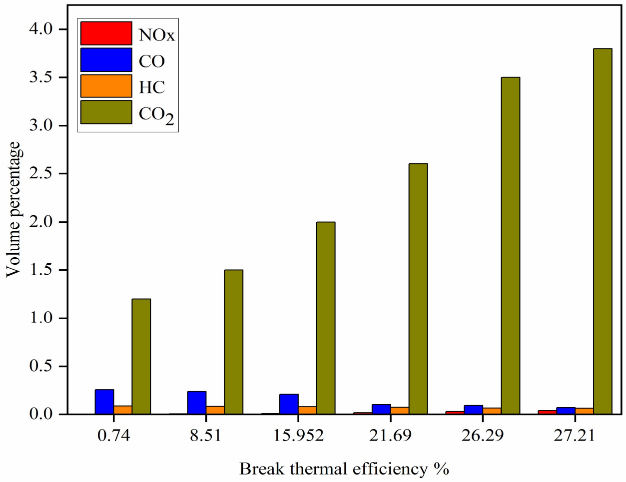

**Fig. 9.** Brake Thermal efficiency *versus* percentage of volume at 0.8767 kg h$^{-1}$ flow rate of ethanol fumigation.

**Table 7.** Brake Thermal Efficiency *versus* Percentage of Volume at 0.958 kg h$^{-1}$ Flow Rate of Ethanol Fumigation

| | NOx | CO | HC | $CO_2$ |
|---|---|---|---|---|
| 0.68 | 0.89 | 21 | 71 | 20 |
| 7.87 | 1.03 | 14.1 | 15.6 | 23 |
| 14.65 | 2.9 | 24.1 | 24.5 | 29 |
| 21.53 | 4.83 | 34.1 | 28.9 | 38 |
| 25.15 | 6.9 | 44.1 | 33 | 49 |
| 26.02 | 8.03 | 54.1 | 39.2 | 55 |

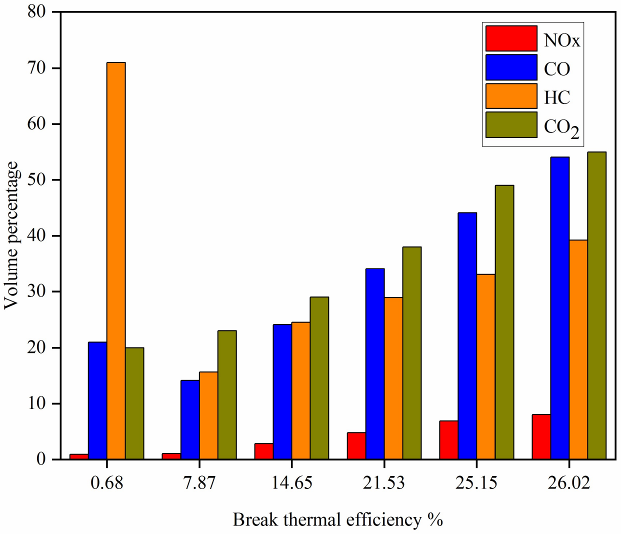

**Fig. 10.** Brake Thermal efficiency *versus* percentage of volume at 0.958 kg h$^{-1}$ flow rate of ethanol fumigation.

According to the data, employing ethanol in diesel engines increases HC and CO emissions while decreasing particle and smoke emissions. The amount of ethanol that can be utilised may be controlled by CO and HC emissions. While these emissions have increased, it's crucial to note that they were always extremely low to begin with, and tiny increases are entirely acceptable. Additionally, the latest generation of diesel engines that are employed with that kind of simple approach may have fewer smoke emissions after being fumigated with ethanol.

## CONCLUSION

This research aimed to investigate and compare the effects of ethanol fumigation on a diesel engine's efficiency and emissions. This was accomplished by using a basic fumigation technique. In any case, fumigation and the application of such a fumigation technique are successful and yield acceptable results. Based on the above findings, the optimum percentage of ethanol tends to be at a mass flow rate of 0.8767 as compared to other fumigation stages, as CO, HC, and NOx emissions are all the same after 21.69 percent thermal efficiency, which could be considered the optimum level of fumigation. A realistic conclusion is that the engineered EFI system can be used safely and efficiently in a diesel engine by substituting ethanol for a portion of the diesel fuel using the fumigation technique. In addition, using this straightforward technique, ethanol fumigation of diesel engines can reduce smoke emissions from the most recent generation of diesel engines in use.

## ABBREVIATIONS

| | |
|---|---|
| NOx: | Oxides of Nitrogen |
| CO: | Carbon Monoxide |
| $CO_2$: | Carbon Dioxide |
| HC: | HydroCarbon |
| FC: | Fuel Consumption, kg/hr |
| PM: | Particulate Matter |
| EFI: | Electronic Fuel Injection |
| SOF: | Soluble Organic Fraction |
| CER: | Constant Equivalence Ratio |
| VER: | Varied Equivalence Ratio |
| SFC: | Specific Fuel Consumption |
| NDF: | Neat Diesel Fuel |
| ECU: | Electronic Control Unit |
| TDC: | Top Dead Centre |
| UBHC: | Unburnt Hydrocarbon |
| Ppm: | Parts Per Million |
| $O_2$: | Oxygen |
| HSU: | HartridgeSmoke Unit |

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