Performance And Emission Characteristics of a Di Diesel Engine Using Hydrogen and Mixed Methyl Ester Blends

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Abstract—**Environmental concerns associated with engine exhaust emissions have driven the search for alternative fuels. Vegetable oils are considered potential substitutes for diesel; however, their direct use in diesel engines results in increased smoke levels and reduced thermal efficiency. This study investigates the feasibility of using hydrogen as an inducted gaseous fuel to enhance the performance of a compression ignition engine fueled with Cotton-Mahua Seed Methyl Ester (CMSME). The primary aim is to mitigate smoke and hydrocarbon emissions typically observed with biodiesel usage. Experiments were carried out by blending CMSME B20 (20% biodiesel, 80% diesel) with two different hydrogen flow rates—4 liters per minute (lpm) and 8 lpm—introduced into the intake manifold. The study revealed that brake thermal efficiency improved with the addition of hydrogen: 33.35% for diesel, 33.65% for CMSME B20 + H_2 (4 lpm), and 35.12% for CMSME B20 + H_2 (8 lpm) at full engine load. The enhancement in thermal efficiency is attributed to hydrogen's high flame speed, which promotes better air-fuel mixing and combustion. Although a slight increase in nitrogen oxide (NO_x) emissions was observed due to elevated combustion temperatures, significant reductions in smoke, hydrocarbons (HC), and carbon monoxide (CO) emissions were achieved with hydrogen enrichment. Notably, CMSME B20 + H_2 (8 lpm) demonstrated emission characteristics closely comparable to diesel, while offering superior efficiency and reduced pollutant output. Therefore, hydrogen-enriched biodiesel presents a viable solution for cleaner and more efficient engine performance.**

***Index Terms*—Methyl ester of cotton-mahua seed oil and mahua seed oil; VCR Engine; Hydrogen; Emissions;**

I. INTRODUCTION

The world is presently confronted with the twin crisis of fossil fuel depletion and environmental degradation. Indiscriminate extraction and lavish consumption of fossil fuels has led to reduction in underground based carbon resources. The search for an alternative fuel, which promises a harmonious correlation with sustainable development, energy conservation, management, efficiency, and environmental preservation, has become highly pronounced in the present context. For the developing countries of the world, fuels of bio- origin can provide a feasible solution to the crisis. The fuels of bio-origin may be alcohol, vegetable oils, bio mass, and biogas. Some of these fuels can be used directly while others need to be formulated to bring the relevant properties close to conventional fuels.

The power used in the agricultural and transportation sector is essentially based on diesel fuels and it is, therefore, essential that alternatives to diesel fuels be developed. Hydrogen is an obvious alternative to hydrocarbon fuels such as gasoline. It has many potential uses, is safe to manufacture, and is environment friendly.

II.MATERIALS AND METHODS

2.1. Materials:
500ml Cotton Seed Oil,500ml Mahua Seed Oil,200 ml methanol (99% pure),14 gm. KOH (Lyn catalyst), Hot plate with magnetic stirrer bar, measuring beakers for methanol and oil, separating funnel (1000ml Glass), Thermometer, Weighing Scale.
2.2. Methods:
CSO (cotton seed oil) and MSO (mahua seed oil) are typically extracted or pressed to obtain CSME (cotton seed methyl ester) and MSME (mahua seed methyl ester). This CSME and MSME contains various impurities, including free fatty acids (FFA), water, sterols, phospholipids, odorants, and other contaminants. The cotton seed methyl ester (CSME) and mahua seed methyl ester (MSME) were mixed

together to produce a combined methyl ester blend. This final mixture, referred to as the mixed cotton-mahua seed methyl ester (CMSME). When used directly in diesel engines, such crude oil can cause numerous issues due to its high viscosity, low volatility, and poor cold flow properties. These characteristics can lead to engine problems such as severe deposits, injector coking, and piston ring sticking. However, converting crude oil into methylester through proper processing can eliminate these challenges. Methyl Ester derived from these oils offers improved properties that make it more suitable for diesel engine

The procedure done is given below: 1000ml of Cotton-mahua seed oil is taken in a container. 14 grams of Potassium hydroxide alkaline catalyst (KOH) is weighed.

200 ml of methanol is taken is a beaker. KOH is mixed with the alcohol and it is stirred until they are properly dissolved. Raw Cotton-mahua seed oil is taken in a container and stirred with a magnetic stirrer and simultaneously heated with the help of a heating coil the speed of the stirrer should be minimal and when the temperature of the raw oil reaches 60 °C the KOH-alcohol solution is poured into the raw oil container and the container is closed with an airtight lid.Now the solution is stirred at high speeds. Care should be taken that the temperature does not exceed 60 C as ethanol evaporates at temperatures higher than 60 °C. Also, the KOH

2.3. Methodology:

Alcohol solution is mixed with the Cotton-mahua seed oil only at the 60° C because heat is generated when KOH and alcohol are mixed together, and the temperature of the raw oil should be more than this when mixing is done if the reactions have to take place properly.

After stirring the Cotton-mahua seed oil-KOH-methanol solution at 60 °C for ½ an hour the solution is transferred to a glass container. Now separation takes place and Methyl ester gets collected in the upper portion of the glass container whereas glycerin gets collected in the bottom portion. This glycerin is removed from the container. Then the Methyl ester is washed with water. Again, glycerin gets separated from the Methyl ester and is removed. The Methyl ester is washed with water repeatedly until no glycerin is there in the Methyl ester. Now this Methyl ester is heated to 100 °C to vaporize the water content in it. The resulting product is Methyl ester which is ready for use

III.RESULTS AND DISCUSSION

3.1. Specific Fuel Consumption:

The brake-specific fuel consumption fuel decreased as hydrogen Enrichment increased. The BSFC decreased at high load is due to the premixing of hydrogen fuel with air. BSFC is the quantity of fuel consumed in 1 hour to produce 1 kW power. The BSFC of diesel is 0.43 to 0.26 kg/kw-hr at lower to higher loads**.** The BSFC was 0.25 (kg/kWh) and 0.24 (kg/kWh) with 4 lpm and 8 lpm hydrogen enrichment at full load compared to pure Methyl ester. The diffusivity and uniform mixing of hydrogen with air lead to near complete combustion of the fuel due to this the fuel consumption gets decreased. Hydrogen with Methyl ester reduces the BSFC due to hydrogen's high calorific value and mass flow rate. When it is replaced by the CMS20 + 8 lpm H2, there is a significant decrease in BSFC up to 0.25 kg/kw-hr, which is 7.69% lower, when compared to diesel. This is due to suitable mixture formation inside the cylinder and the energy share between hydrogen and Methyl ester. The BSFC decreased dramatically as the engine load rose. All blends of methyl ester improved their BSFC after adding hydrogen due to their higher specific gravity.

3.2. Brake Thermal Efficiency:

The Variations of brake thermal efficiency with brake power. The BTE of diesel is 19.97% to 33.35% at 0 to 100% loads; the brake thermal efficiency was 33.7% and 35.5% with 4 lpm and 8 lpm hydrogen enrichment at full load. The high flame velocity of hydrogen contributed to better mixing of methyl ester with air which leads to improvements in thermal efficiency. Due to better mixing of hydrogen with air, the combustion rate gets enhanced resulting in higher brake thermal efficiency. The maximum thermal efficiency was recorded with 8 lpm hydrogen enrichment. The engine noise was observed to be higher while the engine was running in dual fuel mode. The noise level increased with an increase in hydrogen admission

3.3. Smoke Density:

The figure represents the effect of smoke opacity on the difference in engine load for diesel and Methyl ester along with hydrogen addition. The main sources of smoke emissions are rich fuel-air mixtures and lubricant oil burning. The more concentrated visible smoke is produced when there are significant quantities of particulate matter (PM) in the engine. The exhaust neat Methyl ester produces a decreased amount of smoke in high-loading circumstances when compared to diesel. The fuel mixture burns efficiently due to hydrogen's extraordinary flame temperature and flame propagation. Neat diesel produces a smoke opacity of 19.8 to 62.3%, at a load increase from 0 to 100%. When comparing the pure Methyl ester with the Enhanced Methyl ester with hydrogen, the substitution value of 4 lpm and 8 lpm hydrogen enrichment ranged from 24.4 to 66.9% and 23.1 to 61.7% at load

3.4. Hydrocarbon emissions:

According to the experimented data, a graph is being plotted between load and hydrocarbon emissions for diesel, and hydrogen-added Methyl ester blends as shown in the figure**.** Hydrocarbon emission is increased by about 38 ppm to 61 ppm while pure diesel at 0 – 100% loads. The HC emission of the B20 blend of the cottonseed methyl ester with 8 lpm hydrogen is lower compared to diesel. Since hydrogen has no carbon, burning of hydrogen along with B20 blend of cottonseed methyl ester leads to reduced hydrocarbon level. The high oxygen concentrations of Methyl ester and hydrogen create a more complete and cleaner combustion of fuel. Therefore, the unburned hydrocarbon emission decreases. HC emissions were considerably decreased when B20 was used with hydrogen. The HC emissions were 48 to 68 ppm and 41 to 63 ppm with hydrogen enrichment of 4 lpm and 8 lpm at 0 to 100% loads respectively.

3.5. Carbon monoxide Emissions:

The variation of the carbon monoxide with hydrogen enrichment at all loads is shown in the figure. CO emissions in a diesel engine depend on the air/fuel ratio and engine temperature. CO is generated by the incomplete combustion of non-oxygenated petroleum fuels. CO emission for diesel fuel is 0.066% to 0.024 % at 0 - 100 % load. The CS20+H2 8 lpm has the lowest CO emissions of all test fuels, which are 0.019% of volume. CO emissions also increase momentarily when the engine has a lower and higher load. This is due to insufficient engine temperature in the lower load and a rich mixture in the higher load. It was found that the carbon monoxide was decreased with an increase in hydrogen addition. At all the loads induction of hydrogen lowers CO emission levels. The carbon monoxide was 0.02 % and 0.019 % with hydrogen enrichment of 4 lpm and 8 lpm respectively. This is due to the nonexistence of carbon content in the H2 fuel and excess oxygen in the Methyl ester, allowing the fuel to burn entirely also the reason for lower CO emission is due to the absence of carbon atoms in the hydrogen structure.

IV. CONCLUSION

Experiments on a single-cylinder DI diesel engine using cotton-mahua seed methyl ester (CMSME) with hydrogen enrichment at 4 lpm and 8 lpm showed improved performance over diesel. Brake thermal efficiency increased, peaking at 35.12% with 8 lpm hydrogen. BSFC decreased due to better air-fuel mixing. NOx emissions slightly increased with hydrogen, while smoke, CO, and HC emissions were significantly reduced. Peak pressure decreased at 8 lpm hydrogen due to rapid combustion. Overall, CMSME with 8 lpm hydrogen enrichment performed best at full load, indicating the potential of hydrogen-enriched biodiesel blends as a cleaner alternative for CI engines.

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