Engine Performance and Emission Characteristics of Four-Stroke Single Cylinder Diesel Engine by Using Rice Bran Oil as Fuel

Gugulothu SK* and Siva Surya M²

¹Department of Mechanical Engineering, JNTU Hyderabad, Telangana, India
²Department of Mechanical Engineering, Gitam University, Andhra Pradesh, India

Abstract

This project is presented in context of research project at GiTAM University to understand and improve the performance of Diesel engine by using different Blends. Biodiesel was distinguished as a potential option to petro-diesel fuel since it has fuel properties as diesel. Utilization of consumable oils in biodiesel will creates foundations at raise of costs, yet couple of edible oils, for example rice bran oil have prohibitive heating conditions when contrasted with non-edible oil are accessible in a few nations such as soybean oil in USA. Inside this job, the performance examination of single chamber, 4-stroke, and water-cooled diesel engine was done utilizing rice bran oil methyl ester as biodiesel contrasting option to diesel fuel. Trial tests have been directed with scope of engine loads utilizing rice bran oil methyl ester (RBOME) and its diesel mixes with biodiesel in the proportion of B10, B20, B30 and B0 i.e., petro-diesel 100% by volume. In this exploration work, brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), brake specific energy consumption (BSEC) and exhaust gas temperature (EGT) are considered as engine execution attributes. The examination revealed that B20 mix of biodiesel has similar brake thermal efficiency as diesel. B20 has most minimal and has most astounding BSFC, BSEC after all the biodiesel mixes. B2OR has shown practically identical execution as diesel and it can be considered as other option to diesel fuel.

Keywords: Fuel; Diesel; Emission

Introduction

Energy is fundamental components for budgetary development, however bringing in petroleum from overseas impact the nations have lost adjust of instalment in every year. After the crises of World’s oil in 1971, each nation have excited and attempted to discover a new energy that can replace petroleum diesel by utilizing their area energy exceptionally Bio fuels. The world’s economy to a much degree is in the consuming of fossil fuel. Fossil fuel proportionate to somewhere in the range of 180 million barrels of oil is being scorched every day.

The fuel utilization rate works out to be proportionate to a yearly consuming of fuel mass what nature took about one million years to a mass as fossil stores. The world at present is gone up against with the twin emergencies (i) fuel exhaustation and (ii) Environment debasement.

Aimless extraction and rich utilization of fossil fuel have prompt to the lessening in underground carbon assets. The scan for other option which guarantees a congruous connection with feasible improvement, energy protection, administration proficiency and condition conservation, has turned out to exceedingly articulate and need of the world. For the creating nations of the world like India, powers of bio source can give an achievable arrangement of the emergencies. The powers of bio-source might be liquor, vegetable oil, biomass and biogas. Some of these powers can be utilized specifically while others should be planned to bring the relevant properties near conventional fuels. The power utilized as a part of the rural also, transportation area is basically in light of diesel powers and it is subsequently, fundamental that other options to diesel powers be produced urgently.

The fossil fuels assume an imperative part in the improvement of businesses, transportation and agriculture and to meet numerous other fundamental needs of the people. The fossil fuels are constrained assets and draining step by step as the energy utilization is expanding quickly. India imports 70% of the oil it employments. Pressure start engines are utilized especially in the field of overwhelming transportation and agribusiness by virtue of their higher temperature effectiveness and toughness. The diesel engines are the significant givers of oxides of nitrogen and particulate discharges. Thus, more stringent standards are forced on fumes emanations. Along these lines, the look for option renewable energies is required [1-5].

Most appropriate option sorts of fuel for diesel engines might be viewed as vegetable oil or fuel acquired from the creature fat, on the grounds that their attributes are like those of basic diesel oil. There are number of plants creating oils which can be utilized as a part of inner ignition engines. Utilization of straight vegetable oil (SVO) in Diesel engines is not another thought. Rudolf Diesel initially utilized seasoned nut oil as a fuel for showing of CI engine created by him in the year 1910. At the period of world war - II vegetable oils were again utilized as fuel in crisis circumstances when fuel accessibility turned out to be rare. Lately the endeavours have been made by a few specialists for the similarity of straight vegetable oils in diesel engines, for example, oils from Jatropha, Karanja, palm, soybean, sunflower, Rice grain and so forth. Utilization of vegetable oils as fuel in diesel engines causes issues, for example, poor fuel atomization, and low instability because of their high consistency, high sub-atomic weight and thickness. Over a long stretch of utilization of vegetable oils, these issues may prompt to engine disappointment. Thickness of the vegetable oils must be lessened with a specific end goal to enhance its engine execution. Heating, mixing with diesel and transesterification are a portion of the strategies used to diminish consistency of vegetable oils. Transesterification is a moderately costly compound process as it includes the utilization of chemicals, impetuses and process warm.

*Corresponding author: Gugulothu SK, Research Scholar, Department of Mechanical Engineering, JNTU Hyderabad, Telangana, India, Tel: 91-40-32422256; E-mail: santoshk1988@gmail.com

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The investigation of the test outcomes demonstrate that the diesel fuel oxygenated with ethanol up to 10% volume and more can be utilized to enhance the execution and diminish the emissions. Alcohols and liquid esters give totally broke up rapseseed oil blends with the incorporation rate up to 29% and 33%, however ethanol blends legitimately just up to 9%. The above examinations uncover that the blending of ethanol decreases the thickness of the vegetable oils. Gvidonas Labeckas, Stasys Slavinskas blended mineral petrol with the rapseseed oil and watched that the brake particular fuel utilization increments marginally, NOx outflows increments, and CO, CO₂ and smoke mistiness diminishes. The above examination uncovers that the mineral petrol can be blended with vegetable oils to decrease their consistency and outflows like CO, CO₂ and smoke haziness. Kouremenos, Rakopoulos and Kotsiopoulos utilized fuel as supplements in swirl chamber diesel engines and it uncovers that the emissions can be decreased. From the above writing review, it is presumed that the ethanol and petrol can be utilized to enhance the execution and to decrease the emissions of the diesel motor [6-8].

Rice is the principle development in subtropical southern Asia, and it is a staple sustenance for a vast piece of the world’s human populace particularly in east, south and south-east Asia, making it the most expended oat grain. Rice Bran Oil (RBO) is separated from the germ and internal husk (called wheat) of the rice. Rice wheat is for the most part slick inward layer of rice grain which is warmed to deliver RBO. Despite the fact that India is the second biggest maker of rice, barely half of the grain is used for delivering RBO and just 19% of eatable review is utilized as supplements in swirl chamber diesel engines and it uncovers that the emissions can be decreased. From the above writing review, it is presumed that the ethanol and petrol can be utilized to enhance the execution and to decrease the emissions of the diesel motor [6-8].

Based on the experimental analysis, Kusy et al. were investigated and confirmed that engine torque and power dropped five percent when fuelled with soybean oil ethyl-ester and that unmistakable smoke was like operation on diesel fuel.

Rakopoulos et al. were directed a test inquire about to review to gauge and look at the utilization of different vegetable oils, for example, corn oil, cotton seed oil, soybean oil, sunflower oil, rapseseed oil, palm oil, and olive part oil what’s more, their relating methyl esters at mix proportions of 10/90 and 20/80, in a standard, completely instrumented, 4-stroke diesel engine situated at research facility. The distinctions in the deliberate execution and fumes discharge parameters from the benchmark operation of the motor, i.e., when working with flawless diesel fuel were resolved and looked at. Hypothetical parts of diesel motor ignition, joined with the broadly varying physical and substance properties of these diesel fuel supplements against the typical diesel fuel were utilized to help the right elucidation of the watched motor conduct.

As per Ventura et al. tentatively recorded parameters of the engine were ordinary amid the engine testing. The engine greasing up framework in any case, drew nearer crumple since the greasing up oil began to thicken. Engine testing both all through the research centre were expected to substantiate these visual perceptions.

Murayama et al. were done the trials to assess execution, fumes gas outflows, and carbon stores in DI diesel engine fuelled with palm oil, rapseseed oil, methyl ester of rapseseed oil, and these energizes mixed with ethanol or diesel fuel with various fuel temperatures and uncovered for here and now operation that both of vegetable oil created a pleasant motor execution and fumes gas discharge levels, however they created store of carbon construct ups and staying of cylinder rings after augmented operation.

Vell Guth have assessed the CIDI motor’s execution with vegetable oil and revealed that diesel can be supplant with vegetable oils for yet long haul operation and unmodified motor cok e up.

Nwaofer et al. led analyze utilizing rapseseed oil mixes as fuel in direct infusion diesel motor furthermore, here and now motor tests demonstrated great potential for rapseseed oil mixes and long-haul perseverance tests how genuine motor issues, for example, ring staying, gum development, injector stifling.

Barsic et al. did examinations utilizing vegetable oil to lessen the thickness by warming it before infusion and built up that the preheated vegetable oil tackles the issue of channel obstructing.

Schlick et al. were directed trials and assessed the execution of 2.59 L, 3 chamber Ford diesel engines working on soybean oil and sun-bloom oil mixed with no:2 diesel fuel on a 25:75 v/v premise and watched that the power steadily consistent all through 200 h of operation. A lot of carbon stores on all burning chamber parts keep the utilization of above oil mixes. Bhattacharya et al. were utilized diesel-liquid miniaturized scale emulsions and recognized that the SFC has expanded because of their lower net warmth of ignition. The CO outflows were lessened just about half with various emulsions when contrasted with diesel. The hydrocarbon discharge was hardly higher for all heaps and NO outflows were lower.

Hasimonglu et al. were revealed in their examinations that, there was tumble off motor power and torque with biodiesel because of higher thickness. Higher SFC was seen because of lower warming qualities. The in-barrel ignition temperature was brought due down to lower warming estimations of biodiesel, and less warmth lost to motor parts.

**Literature Survey**

Numerous specialists have directed tests with vegetable oils with and without heating for diesel engine and found that the vegetable oils have higher viscosities, lower heating values, low volatility and modestly higher densities that affect the engine issues, for example, nozzle coking, moderate blazing, enormous stores, high smoke discharges, unpredictable burning and engine sturdiness. Lin et al. have shown from their examinations that the maximum and minimum contrasts in engine power and torque at full load between petroleum diesel and 8 sorts of vegetable oil methyl ester fills were just 1.49% and -0.64%, 1.39% and -1.25%, individually, due to higher consistency, higher BSFC, higher oxygen content and higher ignition rate of biodiesel.

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Mahanta et al. were recognized from their examinations utilizing 15-20% Pongamia biodiesel mixes and jatropha methyl ester mixes with diesel in diesel motor shows increment in brake warm effectiveness and decrease in break particular fuel utilization particularly at higher burdens. There is a significant decrease in CO and HC emissions for B15 and B20 at medium and higher power yield. Agrawal et al. have the execution of low warmth dismissal diesel engine working with biodiesel of rice wheat oil, it was watched that NOx outflows with bio diesel was higher because of nearness of atomic oxygen. A fumes gas distribution was utilized for controlling the NOx discharges. In any case, utilization of EGR came about in higher BSFC, expanded HC, CO and particulate discharges.

Dhinagar et al. were tried with three vegetable oils: neem oil, rice grain oil and karanji oil in the low warmth dismissal motor and uncovered that without warming, the outcomes demonstrated a lower brake warm productivity of 1-4% when contrasted and the standard diesel motor. At the point when these thick vegetable oils were warmed and utilized in LHR motors the brake warm effectiveness makes strides.

Spataru et al. utilized soya methyl ester (SME) and canola methyl ester (CME) diesel mixes in a Detroit Diesel motor. It was watched that the emanations of CO₂, NOx, and particulate matter has expanded and diminishments in all out hydrocarbons. It was additionally detailed that the motor wear was inside satisfactory breaking points amid toughness tests directed.

Hemmerlein et al. were led different present-day diesel as for execution, fuel utilization, debilitate outflows and toughness qualities utilizing slick (100%) rapeseed oil as fuel and watched that vitality utilization and execution were practically same as diesel, and higher fumes discharges with rapeseed oil.

Hwang et al. were led explore utilizing biodiesel created from waste cooking oil on the residue particles in a diesel motor was contrasted and slick diesel fuel and it demonstrated that the diesel sediment was essentially made out of carbon and hydrogen and WCO biodiesel ash contained high measure of oxygen species.

Kalam et al. were led tests to examine the fumes gas discharges and store attributes of a little diesel motor utilizing preheated unrefined palm oil and its emulsions with 1%, 2% and 3% water. The outcomes demonstrated that preheated CPO diminished fumes emanations, for example, containing less CO₂, HC and PM when contrasted with OD and CPO emulsified fills and expanded NOx discharge when contrasted with OD and CPO emulsified powers.

Grimaldi et al. have detailed the consequences of a similar investigation performed on a cutting-edge DI, basic rail, turbocharged engine utilizing three diverse bio-determined fuels (assault seed, soybean, and squander cooked oil) and ordinary fossil diesel fuel. It was watched that NOx emanations of biodiesel fuels were same or insignificantly higher than fossil diesel fuel. They have watched the couple of issues, for example, carbon develop on infusion spouts, staying cylinder rings and greasing wear oil polymerization in direct infusion diesel engines with delayed utilization of crude sunflower oil. They presumed that vegetable oils can be specifically utilized for here and now motor operation with no adjustment and long-haul tests will influence the motor sturdiness. Alptekin were utilized methyl esters created from five palatable vegetable oils mixed with two unique fills with various proportions. As methyl ester rate in the fuel mix expanded the consistency and thickness of all mixes were seen to be expanded. With increment in the measure of ethyl esters in the mixes bubbling extents were seen to be nearer. The outcomes demonstrated that fuel properties of the mixes were near those of diesel fuel at focuses up to 20% of methyl esters.

Georgios Fontaras et al. exhibited a point by point think about directed on a Euro-3-consistent diesel traveler auto and a high infusion weight test seat motor utilizing 10% cotton seed oil-90% diesel mixes as fuel. The test included fuel utilization and discharge estimations. The point of the investigation was to precisely assess the impact of bio-fuel on a typical rail motor. The estimation convention incorporated the estimations of directed discharges, fuel utilization and in-barrel weight at different operation modes. Comes about because of the seat motor estimations were in accordance with those recovered from the vehicle and demonstrate that under specific conditions it can be connected as car fuel in a more extensive scale.

Recep Alton et al. examined the impacts of vegetable oil powers and their methyl esters (crude sun bloom oil, crude cotton seed oil, crude soybean oil and their methyl esters, refined corn oil, refined opium poppy oil and refined rapeseed oil) on a direct infused, four stroke, single chamber diesel motor. This comes about demonstrate that from the execution perspective, both vegetable oils and their esters were promising choices as fuel for diesel engine. On account of their high thickness, drying with time and thickening in frosty conditions, vegetable oil fills still have issues, for example, low atomization and overwhelming particulate outflows.

Stalin et al. delivered bio-diesel from Karanja oil by salt catalyzed trans-esterification prepares. The execution of I.C. motor utilizing Karanja bio-diesel mixed with diesel at different mixing proportions has been assessed. The test outcomes demonstrated that the double fuel
blend of B40 can be utilized as a part of diesel engine without making any motor change.

Masjuki et al. displayed a - trial result, which was completed to assess fumes gas discharges and store qualities of a little diesel motor when worked on preheated unrefined palm oil (CPO) and its emulsions with 1%, 2%, and 3% water. The test was led for 100 hrs utilizing each of these test powers at a consistent speed of 2700 rpm and at 5.50 Nm stack. The motor was dismantled after the test to rub carbon stores from the cylinder and chamber dividers. Common diesel fuel (OD) rub was utilized for examination purposes. It was watched that the fumes discharges, for example, CO, HC and PM were lessened, when the motor was worked with preheated CPO when contrasted with the OD and CPO emulsified energies. This was essentially ascribed to the way that the preheating of CPO lessens its thickness to the level of OD, which enhances the fuel splash and atomization attributes and delivers finish burning. Be that as it may, preheated CPO expanded the NO discharge when contrasted with OD and CPO emulsified powers. This was fundamentally ascribed from the store trademark result, which demonstrated that the preheated CPO expanded the most astounding part of cinder store when contrasted with OD and CPO emulsified powers and this was the purpose behind expanded NO, discharges.

Experimental Setup

An arrangement of test runs has been carried-out utilizing a single cylinder, 4-stroke, diesel engine with assess. Those execution qualities of the diesel motor and the test motor picture will be exhibited clinched in Figure 1.

Rice bran biodiesel of B10, B20, B30 and diesel fuel were used as fuel in the test diesel engine. After the engine has reached the stabilized working condition at constant speed of 1500 rpm, readings were recorded for each applied load for each blend percentage, and then calculated the selected performance characteristics of CIDI engine (Figure 2).

Dynamometer

A dynamometer, or "dyno" for short, is a device for measuring force, moment of force (torque), or power. For example, the power produced by an engine, motor or other rotating prime mover can be calculated by simultaneously measuring torque and rotational speed (rpm).

Calorimeter

A calorimeter is an object used for calorimetry, or the process of measuring the heat of chemical reactions or physical changes as well as heat capacity. Differential scanning calorimeters, isothermal microcalorimeters, titration calorimeters and accelerated rate calorimeters are among the most common types. A simple calorimeter just consists of a thermometer attached to a metal container full of water suspended above a combustion chamber.

Rotameter

Rotameter or variable area meter is an instrument used to measure the flow rate of a fluid by using a simple float (let us say a small triangle shaped block) to float in the moving fluid.

Exhaust gas analyzer

An exhaust gas analyzer or exhaust CO analyzer is an instrument
for the measurement of carbon monoxide among other gases in the exhaust, caused by an incorrect combustion, the Lambda coefficient measurement is the most common (Table 1).

**Material and fuel composition**

Rice wheat oil might have been purchased from neighborhood merchant furthermore utilized transesterification methodology to get ready biodiesel. In the transesterification process, methanol might have been utilized within vicinity for impetuses for transesterification incorporate sodium hydroxide and furthermore potassium hydroxide. A triglyceride needs an atom about glycerin similarly as its base with three long chains greasy. Acids connected What’s more fat qualities cam wood a chance to be resolved by the way of the greasy acids appended of the glycerin. That way of the unsaturated fat acids can, done turn, influence the qualities of the biodiesel. In this worth of effort methyl liquor might have been utilized within. Transesterification transform in the vicinity from claiming sodium hydroxide might have been utilized.

Transesterification may be a substance process which places an ester may be reacted for a liquor to structure an additional ester What’s more in turn liquor for the formation for biodiesel, triglyceride oils (esters) would react with methanol (liquor) to process Biodiesel (fatty corrosive alkyl esters) also glycerin. Concerning illustration demonstrated over figure, in the substance response about transesterification. Procedure R1, R2, Furthermore R3 need aid long hydrocarbon chains, frequently all the known as greasy liver chains. There would just five chains. That needs aid as a relatable point over practically vegetable oils and the five methyl esters determines those fuel’s physical properties (Figure 3).

**Results and Discussion**

The experimental test results obtained from single cylinder, 4-stroke diesel engine when fuelled with rice bran oil methyl ester were analyzed and presented in the subsequent paragraphs (Figure 4).

**Torque (Load) v/s mechanical efficiency**

In four strokes single cylinder diesel engine the mechanical efficiency with brake power variation is shown in the graph. It is observed that as load increases the mechanical efficiency also increases due to lowest frictional power of rice bran oil when compared to diesel. Mechanical efficiency obtained at maximum load are 26.49%, 25.86%, 26.69%, 26.19% for diesel, B10, B20 and B30 fuels respectively so, the maximum efficiency obtained among the three blends of rice bran oil is 26.69%, which is of B20. Hence this B20 blend is selected as optimum blend for future investigation (Figure 5).

**Torque v/s brake specific fuel consumption**

In four strokes single cylinder diesel engine the Brake Specific Fuel Consumption with Brake Power variation is shown in the graph. It is observed that as load increases the mechanical efficiency also increases due to lowest frictional power of rice bran oil when compared to diesel. Mechanical efficiency obtained at maximum load are 26.49%, 25.86%, 26.69%, 26.19% for diesel, B10, B20 and B30 fuels respectively so, the maximum efficiency obtained among the three blends of rice bran oil is 26.69%, which is of B20. Hence this B20 blend is selected as optimum blend for future investigation (Figure 5).

**Torque v/s indicated specific fuel consumption**

In four strokes single cylinder diesel engine the Indicated specific fuel consumption were analyzed and presented in the subsequent paragraphs (Figure 4).
fuel consumption with brake power variation is shown in the graph. It is observed from graph that because of better fuel combustion there is improvement in ISFC, which may be attributed to the oxygen pressure in the blend. ISFC obtained at max load condition for the fuels: diesel, B10, B20, B30 are 0.05%, 0.05%, 0.048% and 0.055% respectively. The maximum ISFC obtained among the three blends of rice bran oil is 0.048% which is B20. Hence this B20 blend is selected as optimum blend for future investigation (Figure 7).

**Torque v/s brake thermal efficiency**

In four strokes single cylinder diesel engine brake thermal efficiency with load variation is shown in the graph. It is observed from graph that the brake thermal efficiency is increases as the load increases. The main reasons for this may be the leaner combustion of biodiesel, extended ignition delay which is the reason for resulting in larger amount of fuel burned in the premixed mode of the ethanol blends. Brake thermal efficiencies at max load condition obtained for the fuels: diesel, B10, B20, B30 are 20.18%, 27.5%, 29.85% and 28.34% respectively. Maximum BTE obtained among three rice bran oil is 29.85% which is of B20 blend. Hence this B20 blend is selected as optimum blend for future investigation (Figure 8).

**Torque v/s carbons monoxide**

In single cylinder four stroke diesel engine the CO emissions with brake power variation is shown better in graph. It is observed from graph that as compared to TPO blends under loading conditions the engine emits more CO for diesel. CO emissions obtained at max load conditions for fuels of diesel, B10, B20, B30 are 0.05%, 0.05%, 0.04% and 0.057% respectively. The concentration of CO increases for B10 and for B30 blends and it has been decreased for B30. The oxygen present in B20 aids for complete combustion at lower rice bran oil concentration. However, as the concentration of rice bran oil increases, viscosity which is the main reason for negative effect and the complete combustion process due to small increase in specific gravity suppression, which is ultimately the main reason for producing high amount of CO (Figure 9).

**Torque v/s carbon dioxide**

In single cylinder four stroke diesel engines the carbon dioxide with brake power variation is shown better in graph. It is observed from graph that different specified blends are indicated. CO2 emissions obtained at max load conditions for fuels of diesel, B10, B20, B30 are 4.9%, 4.5%, 3.8% and 4.6% respectively. The trend of CO2 emissions increases with respect to load for TPO except B20 blend. The main reason behind converting CO emissions into CO2 emission content is the presence of high amount of oxygen in the specified fuel blends (Figure 10).

**Torque v/s oxygen**

In single cylinder four strokes diesel engine the oxygen’s with brake power variation is shown better in graph. It is observed from graph that different specified blends are indicated. O2 emissions obtained at max load conditions for fuels of diesel, B10, B20, B30 are 13.03%, 13.51%, 11.42% and 12.69% respectively. The trend of O2 emissions increases with respect to load for TPO except B20 blend. The main reason behind converting O2 emissions into O2 emission content is the presence of high amount of oxygen in the specified fuel blends (Figure 11).

**Torque v/s nitrogen oxides**

In single cylinder four stroke diesel engine the nitrogen oxides with
brake power variation is shown in graph. It is observed from graph that different specified blends are indicated. All the fuels tested for NOX emissions follows the increasing trend with respect to load. NOX emissions obtained at max load conditions for fuels of diesel, B10, B20, B30 are 550 ppm, 570 ppm, 530 ppm and 568 ppm respectively. The reason could be the residence time at higher loading conditions and can be the higher average gas temperature. When compared to diesel the emission reduction for all the blends were noted. The corresponding emission reduction in NOX was noticed and the reduction was remarkable for B10, B20, B30 blends with increase in the rice bran oil content.

Conclusion

The experimental analysis were conducted on single cylinder four stroke diesel engine, Water cooled DI-CI engine by using the pure diesel at a speed of 1500 rpm along with blends of rice bran oil of B10, B20, B30 respectively. It can be concluded from first set of results that the blend B20 has better performance among the rest of B10, B30 in terms of mechanical efficiency, specific fuel consumption, volumetric efficiency & brake thermal efficiency and emission parameters. No injector blocking, no engine seizing were found during the time of entire operation, while the engine was running with pure diesel and along with different blends of rice bran oil. Hence B20 can be used as alternative fuel and can save us 20% of diesel that we people are importing & increasing the economy.

- It is observed form the analysis reports that as the load increases the brake specific fuel consumption (BSFC) decreases. Among the 3 different blends of the rice bran oil the minimum fuel consumption obtained for B20 is 0.19%. Hence this B20 blend is selected as optimum blend for future investigation.

- It is observed form the analysis reports that as the load increases the brake thermal efficiency is also increased. Among the 3 different blends of the rice bran oil the maximum fuel consumption obtained for B20 is 29.85%. Hence this B20 blend is selected as optimum blend for future investigation.

- At maximum loading conditions when compared to rice bran blends the engine emits more CO for diesel. The minimum CO among the 3 blends of rice bran oil is obtained for B20 is 0.04%. Hence this B20 blend is selected as optimum blend for future investigation.

References