

EFFICIENCY ENHANCEMENT OF VARIABLE COMPRESSION RATIO ENGINE'S PERFORMANCE USING PRUNUS DOMESTICA METHYL ESTER

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Engineering degree in Mechanical Engineering

By

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**DEPARTMENT OF MECHANICAL ENGINEERING
SCHOOL OF MECHANICAL ENGINEERING**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

**Accredited with grade "A" by NAAC | 12B Status by UGC | Approved by AICTE
JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600119.**

APRIL 2023



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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **J. Jeffin Sam David (39150054)** and **S.S. Rattan (39150110)** who carried out the project entitled “Utilizing the Methyl Ester of Prunus Domestica to increase the performance of a Variable Compression Ratio Engine” under my supervision from December 2022 to April 2023.

Project Guide

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Submitted for Viva-voce Examination Held on 26/04/2023

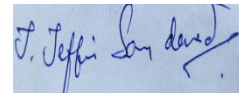
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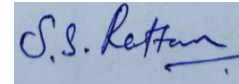
DECLARATION

We **J. Jeffin Sam David (39150054)** and **S.S. Rattan (39150110)** hereby declare that the Project Report entitled **“EFFICIENCY ENHANCEMENT OF VARIABLE COMPRESSION RATIO ENGINE’S PERFORMANCE USING PRUNUS DOMESTICA METHYL ESTER”** done by me under the guidance of **Dr. G. Arunkumar, M.E., Ph.D.**, at Sathyabama Institute of Science and Technology is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering Degree in Mechanical Engineering.

DATE: 26/04/2023



PLACE: Chennai



SIGNATURE OF THE CANDIDATES

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I wish to express my thanks to all Teaching and Non-teaching staff members of the Department of Mechanical Engineering who were helpful in many ways for the completion of the project.

ABSTRACT

The objective of the work is to find the Specific Fuel Consumption (SFC), Brake Thermal Efficiency (BTHE) of the Variable Compression Ratio (VCR) Engine and to reduce emissions by operating the VCR Engine using Prunus Domestica Methyl Ester as biodiesel. The extraction and Transesterification process is done with Prunus Domestica to get Methyl Ester and the Methyl Ester is mixed with diesel in proper composition. 100% of biodiesel cannot be used in the engine, since the investment in biofuel will be higher. So, the biofuel is mixed with pure diesel to get a biodiesel blend. Therefore, four samples are prepared with a proper ratio i.e., 90% of diesel and 10% of biofuel, 80% of diesel and 20% of biofuel, 70% of diesel and 30% of biofuel & 60% of diesel and 40% of biofuel. All the samples are tested in the Variable Compression Ratio Engine. The Specific Fuel Consumption and Brake Thermal Efficiency are noted and emission characteristics from the Variable Compression Ratio Engine are noted. The graph is yet to be plotted and compared to get a better result of the engine's performance using Prunus Domestica Methyl Ester as a biodiesel.

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LIST OF ABBREVIATIONS

VCR	Variable Compression Ratio
PDME	Prunus Domestica Methyl Ester
BTHE	Brake Thermal Efficiency
SFC	Specific Fuel Consumption
BP	Brake Power
NaOH	Sodium Hydroxide
FFA	Free Fatty Acid
BMEP	Brake Mean Effective Pressure
cSt	Centistokes
IMEP	Indicated Mean Effective Pressure
EGR	Exhaust Gas Recirculation
BTDC	Before Top Dead Center
HC	Hydro Carbon
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
O ₂	Oxygen
NO _x	Oxides of Nitrogen

CHAPTER 1

INTRODUCTION

Today's world is mostly dependent upon non-renewable fuel sources for power generation. The research work focus on the enhancement of the efficiency of the Variable Compression Ratio Engine using Prunus Domestica Methyl Ester as a biofuel. The main goal is to improve combustion and fuel economy, to increase Brake Thermal Efficiency (BTE), to reduce Specific Fuel Consumption (SFC) and to reduce emissions like carbon monoxide (CO), carbon dioxide (CO₂), hydro carbon (HC) and unburnt oxides of nitrogen (NO_x). Biofuel plays a vital role in decreasing the limitation of the diesel. The experiment is operated on single cylinder, four stroke, variable compression ratio engine. The experiment is done in various ratio of the biodiesel blend to get a better efficiency.

We have studied about the extraction of oil from Prunus Domestica and Transesterification process of Prunus Domestica oil to get Prunus Domestica Methyl Ester. Efficiency of the engine performance, mainly variable compression ratio engine's performance with different type of biodiesels and different compression ratio [8-30]. The composition of the fuel blend is mixed in different ratios to get more efficiency has been studied.

Many Researchers conducted test on Variable Compression Ratio Diesel Engine fuelled with different types of biodiesels to evaluate the efficiency of engine characteristics. In recent years, the investigations were done in single fuel method and dual fuel method. From the experiments the Specific Brake Thermal Efficiency is increased, slight lower in the Specific Fuel Consumption and reduction in emission characteristics are compared with pure diesel.

Biodiesel is prepared by using Prunus Domestica oil. The oil from Prunus Domestica's seed is converted into Methyl Ester by Transesterification Process and mixed with a diesel in proper ratio to obtain a proper biodiesel blend.

The biodiesel samples are to be tested in Variable Compression Ratio Engine to find Brake Thermal Efficiency (BTE), Specific Fuel Consumption (SFC) and Emission characteristics.

CHAPTER 2

LITERATURE SURVEY

The literature survey is taken related to efficiency enhancement of Variable Compression Ratio Engine and Prunus Domestica Methyl Ester.

Table-2.1: Literature Survey

S. NO.	YEAR	AUTHOR	INFERENCE
1	2021	(M. Sharma & Kaushal, 2021)	The results shows that brake thermal efficiency (η_{BTE}) of 25.71% and 23.81% have been obtained during diesel and DFrun. CO ₂ emission has been measured in DF mode as 17.62-67.14% (at 3.44 Kw brake power) more than diesel run. Under similar conditions, CO emission in diesel mode has been reduced (ranging from 63.06 to 73.37%) when compared with DFrun. Further, hydrocarbon emission level in DF mode has been discerned as 473– 593% higher when compared to diesel run.
2	2021	(Ganesan, Mohanraj, Khushal, et al., 2021)	The tests showed that antioxidants gave high Brake Thermal Efficiency (BTE) but low Specific Fuel Consumption (SFC) than diesel. The samples with antioxidants showed reduction in emission of Carbon monoxide, Oxygen and Hydrocarbon. TBHQ showed reduction of Nitrous Oxide. The Overall except for NOX emissions Propyl Gallate (PG) performed better than tertiary butyl hydroquinone (TBHQ), hence PG is preferred over TBHQ.
3	2022	(Rai & Sahoo, 2020)	The comparative analysis, shows that BTHE, BSFC, HGAS, and NOX emissions enhances 9.4%, 10.71%, 14.16%, and 6.5% respectively, HJW, HC and CO

			emission reduces to 1.3%, 16.76%, and 21.2% respectively, for an optimum condition with respect to diesel fuel. The guessed GRG at an optimum setting (A3B4C3) and the experimental GRG values are 0.6896 and 0.7100, respectively, with an error of 0.0203. The experimental investigation shows that SRME30 could be used as an alternative to diesel fuel for the VCR engine.
4	2021	(Ganesan, Mohanraj, Guruprakash, et al., 2021)	The emission result showed a significant reduction of NOX at the expense increasing of CO, O2 and HC emissions. By using these combinations, we can able to get better results in we can able to stop the flue gases. The result shows that the combination of catalytic converter and diesel Blends produces a surge in Brake thermal efficiency (BTE) and decreases in specific fuel consumption (BSFC).
5	2021	(Mohamed et al., 2021)	From Response Surface Methodology, mathematical models and optimizer plots are employed to find optimal parameters for the BSFC, BTE and HC, CO, NOX. Highest desirability for maximum 1.0 is observed for BSFC, 0.91 for BTE and for minimum 0.95 for NOX, 0.68 for HC and 0.55 for CO. Composite desirability of 0.79 is observed for the blend B10 CR 16:1 and Load 5 kg.
6	2020	(Niimi et al., 2020)	Unique OACs are also detected within the headspace that distinguishes the wines, where 4-ethyl guaiacol was only detected the yellow plum wine and diacetyl was only detected within the black plum wines. The remaining nine OACs are not

			significantly different from each other, suggesting their ubiquity in plum wines. High flavour dilution (FD) values are determined for ethyl isobutyrate, ethyl 2- methyl butyrate, β damascenone, and ethyl cinnamate.
7	2017	(Górnaś et al., 2017)	Recorded differences between the minimum and the maximum value of individual biodiesel parameters obtained for various plum varieties were 4.7 (cetane number), 0.20 mm ² /s (kinematic viscosity), 0.0022 g/cm ³ (density), 0.01 MJ/kg (higher heating value), 2.63 °C (CFPP), 2.61 h (induction period) and 14.7 I ₂ /100 g (iodine value).
8	2009	(Mahmood et al., 2009)	Bioassay screening of oil shows moderate antibacterial activity against Salmonella group (Gram +ve and -ve) by the agar well diffusion method, moderate antifungal activity against the Microsporum canis by the agar tube dilution method and good antioxidant activity by DPPH radical scavenging method.
9	2014	(Popov et al., 2014)	The PD-E fraction failed to have the effect on cell adhesion at the concentrations of 0.05–0.1 mg/ml. PD, PD-1 and PD-E were found to inhibit the production of superoxide anion radicals by reducing the xanthine oxidase activity by 38%, 97% and 47%, respectively. Hence, the PD-1 fraction appeared to be an active fragment of pectic macromolecule isolated from the fresh plum with a simulated gastric fluid.
10	2016	(Kostić et al., 2016)	The activation energy of the esterification reaction slightly decreased from 13.23 - 11.55 kJ/mol with increasing the catalyst

			concentration from 0.049 - 0.172 mol/dm ³ . In the second step, the esterified oil reacted with a methanol (methanol: oil molar ratio of 9:1) in the presence of CaO (5% to the oil mass) at 60°C. The property of the obtained biodiesel were within the EN 14214 standard limits.
11	2020	(Correia et al., 2020)	The optimization with maximization of induction period and minimization of the rate constant showed that black tea extract was most suitable to avoid oxidation. On the first day of test, the optimization indicates that the mixture containing 50% of black tea and 50% of plum pulp extract as a best mixture.
12	2020	(Alviso et al., 2020)	The RSME related to experimental database is lower for GP models, from 3% for CN to 55% for PP, in comparison to the best MLR model for each property. Specifically, most GP regression models reproduce correctly from the dependence of properties on the saturated and unsaturated Methyl Esters.
13	2021	(Almasi et al., 2021)	The result shows the Physicochemical properties of SCKO biodiesel are density of 0.881 gr/cm ³ , kinematic viscosity of 5.03 mm ² /s, flash point of 158 °C, cloud point of 5 °C, and pour point of (−7) °C. All properties of the produced biodiesel of SCKO complies with the standard ASTM 6751 and EN 14214.
14	2019	(Roman et al., 2019)	The kinetic parameters are experimentally determined, and the value of activation energy was 6.8 kJ/mol and the pre-exponential factor was 0.0765 L ² .mol ² .min ^{−1} confirming that the

			ionic liquid, <i>[HMIM]HSO₄</i> , is a better alternative for replacing traditional catalysts for biodiesel production through the esterification reaction.
15	2019	(Esonye et al., 2019)	The quality of the RSM model were analysed using Analysis of Variance(ANOVA). Model statistics of the ANN shown comfortable values of Mean Squared Error (MSE) of 6.005, Mean Absolute Error (MAE) of 2.786 and Mean Absolute Deviation (MAD) of 1.89306. The RSM and ANN models gave a coefficient of determination (R^2) of 0.9446 and correlation coefficient (R) of 0.96637 respectively.
16	2015	(Guo et al., 2015)	Percentages of a fatty acids varied greatly among different species, but all species contained a large percentage of critical oleic acid (35.03–77.02%). The biodiesel properties of seed kernel oil methyl ester of the eight species wae determined and then compared with the relevant specifications of ASTM D6751, EN 14214, and GB/T 20828.
17	2016	(Sajjadi et al., 2016)	The main specifications including Sulphur content, viscosity, density, flash point, cloud point, pour point, cold filter plugging point, cetane number, heating value, iodine number, acid value and carbon residual before and after transesterification (vegetable oil and biodiesel, respectively) were analysed in detail.
18	2017	(Reidel et al., 2017)	A total of 136 compounds are identified corresponding to 90.1 to 99.6% of the whole aroma profile of the cherry plum

			samples. Non-terpenes are the most abundant class of constituents present in the volatile emission of all analysed samples.
19	2015	(Petronikolou & Nair, 2015)	The determinants for ligand recognition were analysed by kinetic analysis of structure-based active-site variants. These studies shows how an architectural fold employed in plant natural product biosynthesis is used in the bacterial fatty acid <i>O</i> -methylation.
20	2021	(Carmona-Cabello et al., 2021)	Principal component analysis shows a fatty acid profile similar to soybean oil and solid food waste oil. Microbial oil was transesterified into biodiesel with the satisfactory performance considering a European standard EN 14214.
21	2016	(P. Verma & Sharma, 2016)	The study shows that for optimum biodiesel production reaction temperature should be in the range of 50°C to 60 °C, molar ratio of alcohol to oil should be in range of 6 to 12:1 with the use of an alkali catalyst having optimum concentration 1% by weight. The optimal reaction time for transesterification process is 120 minutes.
22	2016	(M. P. Sharma, 2016)	As per the availability, CFP and oxidation stability, the oils can be recommended for the biodiesel production. These oils can be recommended for the biodiesel production having a best CFP and oxidation stability.
23	2018	(Goel et al., 2018)	At modified conditions brake specific fuel consumption, smoke opacity, unburned hydrocarbon and carbon monoxide emission decreases and brake thermal efficiency and nitrogen oxide emission

			increases as compared to without modified ones. The result also reveals that retarded injection timing as compared to the original injection timing, emission of a nitrogen oxide decreases.
24	2019	(Munir et al., 2019)	The determined fuel properties, such as density (0.8612kg/L), kinematic viscosity (4.11 mm ² /s), cloud point (-9 °C), flash point (73°C) and pour point (-10°C) of synthesized biodiesel agreed with International Standards of China GB/T 20828 (2007), American (ASTM-951, 6751) and European Union (EU-14214). Pseudo-first-order kinetics was fitted well with the experimental data ($R^2=0.9172$).
25	2019	(D. Singh et al., 2019)	The low concentration of polyunsaturated FAME and long-chain saturated FAME is more favorable for the oxidation stability, low-temperature operability, and satisfactory performance. American Society for Testing and Materials (ASTM), European committee for standardization (CEN), Bureau of Indian Standards (BIS),etc. provided specifications for the biodiesel and their blends.
26	2012	(Khallouki et al., 2012)	The peels contained only 3,4-dihydroxybenzoic acid (270 mg/kg) and rutin (186 mg/kg), the flesh exclusively echinoids (723 mg/kg), whereas the pits contained a rich variety of phenolic compounds (4.2 g/kg) dominated by amygdalin (3.8 g/kg), but with significant contributions from a vanillin (102 mg/kg), guajacyl-glycerin-coniferyl aldehyde isomers (87 mg/kg), dehydro-diconiferyl

			aldehyde (52 mg/kg), and vanillin diglucoside (48 mg/kg).
27	2014	(González-García et al., 2014)	Extracted proteins had digested using Alcalase, Thermolysin, Flavourzyme, and Protease P enzymes. Alcalase was the enzyme yielding the extracts with highest ABTS radical scavenging capacity and lipid peroxidation inhibition capacity.
28	2020	(Natić et al., 2020)	Kernel oil from those species contains high levels of the unsaturated fatty acids, where oleic acid and linoleic acid were dominant. In addition, the oils were rich in other bioactivity compounds such as minerals, vitamins, phytosterols, carotenoids, phenolic compound, tocopherols, tocopherols, and squalene.
29	2022	(Bitire & Jen, 2022)	The BTE of BC50 fuel was found to be higher than those of other tested fuel samples. In addition, BSFC was reduced to substantial amount of 3.28% for BC50 compared to the B0 fuel sample. Furthermore, the BC50 blend reduced emissions of CO, HC, and NO _x by 5.7%, 1.6%, and 4.7% but higher emissions of the carbon dioxide (2.15% increase) in comparison to B0.
30	2021	(Devarajan et al., 2021)	Experimental variables like methanol to oil molar ratio, KOH, and time remained for optimization is based on Taguchi technique. The outcome of the work was 6:1 M ratio, 1 wt% KOH, 150 min and 55°C is optimal experimental conditions for the maximum conversion efficiency of 93.2%.

31	2021	(Ganapathy et al., 2021)	The maximum BTE and minimum BSFC obtained for 2V98P fuel were 32.05% and 0.3255 kg/kWh respectively as against 32.8% and 0.3126 kg/kWh for the diesel operation at a rated load with the compression ratio of 20.
32	2021	(Nishanth et al., 2021)	The results indicated that the proposition in which Jatropha Curcas is in 25% proposition and diethyl Ether of 5% has a brake thermal efficiency improved by 6.32%, mechanical efficiency improved by 3.15% and the emission characteristics like HC, NO _x emissions has reduced than Diesel.
33	2021	(Prabakaran, Manimaran, et al., 2021)	Algae-biodiesel blend (B20) at CR18 gives a closer approximation of the effects of diesel in better brake thermal efficiency, hydrocarbon (HC) and lower carbon monoxide (CO) emissions along with oxides of nitrogen (NO _x) found to be slightly high.
34	2021	(Ganesan, Mohanraj, Hemanandh, et al., 2021)	Samples S1, S2, S3, S4 and S5 was prepared using ultrasonic bath. The measuring parameters was BTHE, SFC and emission parameters. Results reveals that S4 gives better performance than D100 and other biodiesel samples. The results showed that camelina oil and lemon grass oil with BHT produced an increase in SFC and BTHE.
35	2021	(Ganesan, Hemanandh, et al., 2021)	At the rated brake power conditions, the B25 & B30, followed by B10 blends emit lower level of NO _x related to the diesel. At the rated load, NO _x emissions from B25 and B30 blends are 25% lower than the diesel fuel. By analysing the different

			outcomes and determining that blend provides the best solution.
36	2021	(Murugapoopathi et al., 2021)	The optimum factor such as 21 CR with 8kg of load blend 20 and injection pressure of 150bar gives an error of less than 10% with all response with composite desirability of 0.995867. It has found that the emission NO _x and CO decreases with lesser than 5% of experimental value with increase in compression ratio for lower blends.
37	2021	(Bidir et al., 2021)	Emission results revealed that in most reviews, NO emission was increased by up to 55%, while HC, CO and PM were decreased significantly. It was concluded from the study that the diesel engine could be effectively run and give better performance and effective regulated emissions on the application of added nanoparticles with a biodiesel and their blends as fuel in CI engine.
38	2020	(Prabhakar et al., 2020)	Lemongrass methyl ester with three parameters viz. blended with diesel (B20, B40 & B60), VCR (16.5:1, 17.5:1 & 18.5:1) and load varied at (0%, 50% and 100%). The objective of the study was to determine the optimum blend of lemongrass biodiesel and the diesel oil that would result in a better engine performance along with minimum emission characteristics.
39	2021	(Chebattina et al., 2021)	The test result shows that the engine fueled with biodiesel and H ₂ O ₂ blend improves engine performance and decreases the NOX and CO Emissions

			compared with biodiesel (B100). The 10% H ₂ O ₂ blend has performed equal to diesel.
40	2021	(Bapu et al., 2021)	Emissions values were plotted on graphs and compared to pure diesel emissions. The experiments were carried out on a four stroke diesel engine with a single water cooled cylinder that ran at 1500 rpm.
41	2021	(Ganesan, Mohanraj, Kiranpradeep, et al., 2021)	A final experiment is used to verify the Initial design factor combination based on the highest ranking of grey grade. The best engine parameter is deduced using the grey method A3B3C1 factors and levels combination.
42	2021	(Saiteja & Ashok, 2021)	An interpretive investigation on HCCI engine with other advanced combustion mode engines disclosed their greater significance and potential outcomes. Besides, the predicaments in the paradigm shift of conventional to HCCI engine was discussed with probable solutions for future enhancements.
43	2020	(V. Sharma et al., 2020)	Use of renewable biofuel mixture on non-road diesel engines will cut carbon footprint on the environment and it is better than biodiesel derived from a single feedstock based on composition, performance, fuel properties and emissions.
44	2021	(EdwinGeo et al., 2021)	Wintergreen oil is one of the dense and comparatively less viscous fuels among the other chosen biofuels; shows 6% improvement in brake thermal efficiency, 3% reduction in brake specific energy consumption, 7% increase in peak pressure, 20% reduction in CO ₂

			emissions, 17% in HC and 20% decrement in smoke.
45	2020	(Narad & Joshi, 2020)	As the coating thickness increases the brake thermal efficiency (BTE) is also increased by approximately 6% for 250 μm and by 8% for 500 μm . On the other hand, the brake specific fuel consumption (BSFC) reduces by approximately 18% for 250 μm and 20% for 500 μm .
46	2020	(M. S. Kumar et al., 2020)	Performance result found that LGBD and LGBD+C has a improved physico-chemical properties of diesel/biodiesel and produces an increased result of brake thermal efficiency and brake specific fuel consumption than diesel at the rate of 4.58%, 10.6% and 6.625%, 19.9% respectively.
47	2020	(Al-Hwaiti et al., 2020)	The sulfur content of Handal oils is 193 mg/kg, which is higher than the Handal biodiesel value of 62 mg/kg, but significantly lower than that of the diesel fuels (≤ 100 ppm). Similar engine performance regarding brake thermal efficiency between pure diesel and biodiesel at different engine speeds and loads were detected.
48	2015	(Channapattana, Kantharaj, et al., 2015)	There is a major reduction in Carbon monoxide and the Hydrocarbon emissions with 100% biodiesel as a fuel compared to diesel at compression ratio of 18.
49	2022	(Dhande et al., 2022)	Training and testing data had regression coefficients were almost identical to 1. The research revealed that the ANN model can be the better option for predicting engine performance with a higher level of accuracy.

50	2020	(Mahesh et al., 2020)	The engine performance had been analysed for different nozzle and blends. Nitric oxide (NO _x) and Particular matter (PM) are slightly gained. Carbon dioxide (CO ₂) is apparently increases with load whereas HC were found to be decreasing with load. Carbon monoxide (CO) emission is higher.
51	2017	(Srinivas et al., 2017)	Performance and Combustion Characteristics were increased whereas, the emissions are lowered upon increase in Injection Pressure, Compression Ratio, and the blending percentage of an Eucalyptus oil in the fuel when compared to the conventional diesel fuel.
52	2021	(Ganesan, Mohanraj, Karthick, et al., 2021)	Biofuel with a di-tert-butyl ether fuel additive performs well and emits fewer pollutants. The combined NO _x , HC, and CO produced by sample 15WCO85D30PPMC8H180 were reduced. The emissions are compared with other samples as well as diesel.
53	2015	(Channapattana, Pawar, et al., 2015)	The NO _x emission increases with increase in IP. The NO _x emission increases as the blend proportion is increased. B20 blend gives better thermal performance compared with the other blend of Honne biodiesel, but it causes higher levels of exhaust emissions.
54	2021	(T. S. Singh et al., 2021)	The model found that the load of 64.634, CR of 16.50 and 20% blend would provide BTE of 31.357% and BSFC of 274.97 g/kWh with lower values of CO ₂ (869.075 g/kWh), PM (0.2807 g/kWh) and NO _x (1804.97 ppm), respectively. The confirmation test shows the closeness of

			the predicted result with those of experimental values.
55	2021	(Dhande et al., 2021)	Hydrocarbon and carbon monoxide emissions are reduced, while increasing the ratio of the ethanol relative to the pure gasoline, except PE10 blend. The combustion characteristics were also studied. Lower value of coefficient of variation showed stable combustion. This study concluded that PE15 can be used as an alternative fuels.
56	2020	(Yadav et al., 2020)	Properties like viscosity, calorific value, density, flash point and fire point were measured of biodiesel. For analysing the fatty acid composition of different biodiesels, gas chromatographic has used that consists of supelcowax type column for the flame ionization detection phenomenon.
57	2016	(Thomas et al., 2016)	The result shows that the brake thermal efficiency increases with CR at all loads. Further, the experimental results shown the scope of improving the part-load efficiency of SI engine by adopting the concept of VCR technology, especially when fuels with better anti-knock characteristics were used.
58	2022	(Elnajjar et al., 2022)	From the experimentation, overall parametric variation of 4.15%, 57%, 64.7% and 76.61% in thermal efficiency, CO, and opacity respectively has observed. However, with increase of hydrogen content resulted in increased engine performance, increased in NO _x emission and reduction in CO emission with the same WCO biodiesel flow rate.

59	2019	(Baranitharan et al., 2019)	The RSM and ANN models gave the average correlation coefficient (R) of 0.998 and average coefficient of a determination (R^2) of 0.991 respectively. The experimental, RSM and ANN analysis result depicts that A20D80T blend delivered the enhanced performance and better emission behaviours compared with neat diesel fuel (D).
60	2018	(Suresh et al., 2018)	The need for switch over to VCR engine is that it provides better fuel efficiency, up to 30% reduction in fuel consumption, better control at peak cylinder pressure, ability to use multi-fuel and reduction in the exhaust emissions when compared to the constant compression ratio diesel engine.
61	2022	(A. Verma et al., 2022)	With increases in the blending percentage, the engine performance went lower. From the research work carried out, it has found that the sample blends with lower per cent of a blend of ethanol, that is F2 performed substantially well and can be used as a substitute for currently used regular gasoline.
62	2019	(Wittek et al., 2019)	A fuel consumption reduction was up to 4% was found at part-load, where combustion phasing tended to be an optimum. Penalties in the fuel consumption at high loads are present due to knock-limited spark-timing. Result shows that an even higher compression ratio variation range would further reduce fuel consumption in both low and high load.
63	2020	(Venkatesan & Nallusamy, 2020)	The biofuel blends outperformed conventional Petro-diesel in terms of

			smoke, carbon monoxide (CO) and unburnt hydrocarbon (HC) with a slight penalty on NOX emissions. Up to 50% pine oil blended biodiesel (P75SNB25, P50SNB50) fuel can be used in the diesel engines without affecting its performance, emission and combustion characteristics.
64	2020	(Alves-Fortunato et al., 2020)	The acknowledging of this sedimentation or “de-mixing” process leading to deposit can be a key features to develop strategies to prevent deposit formation in real systems.
65	2020	(Laurens, 2020)	The discussion is accompanied by a link to the large-scale application of this process as the whole biomass conversion pathway.
66	2013	(Lebedevas et al., 2013)	As the result of performing measurements of emission of hazardous components, it was observed that throughout the storage period, the maximum reduction of CO reached 7% to 10%, whereas the decreases in HC was 5% to 8% and that of NOX was approximately 4%. The most significant effect was detected in the case of smoke intensity, where the reduction reached 20% to 25%, and the useful effect increased to 4%.
67	2015	(Chinnamma et al., 2015)	The physicochemical features of CME strongly support to the functional similarity of CME with that of the diesel as per the requirement of a fuel quality. The low carbon residue, minimal acidity and the absence of sulphur elements further supports the fuel energy of CME as an eco-friendly fuel.

68	2010	(Erazo Jr et al., 2010)	The flame temperature decreased more rapidly for the CME biofuel spray flame than for the 2nd diesel fuel spray flame in both axial and radial directions. CME biofuel spray flames produced lower in- flame NO and CO peak concentrations than 2nd diesel fuel spray flames.
69	2015	(Kwon et al., 2015)	Order of loading catalytically active metals on honeycomb monolithic catalyst supports affect the catalytic activities and the stabilities of honeycomb monolithic catalysts. Calcium oxide stabilizes catalytic activities of formulated monolithic catalysts. Conversion of the canola oil fluctuates repeatedly with increased reaction times in the honeycomb monolithic catalyst flow reactor.
70	2022	(Akinwumi et al., 2022)	As a renewable fuel, this fuel source's improvement may added to the sustainable energy and fuel additive market's growth. Consequently, the advantages and limitations of PHA-based biofuel production, its physicochemical parameters, and the commercial use prospect.
71	2020	(M. Sharma & Kaushal, 2020)	With dual mode CO and hydrocarbon emissions were increased in the range of 62.21% to 72.53% and 83.25% to 87.60% correspondingly as compared to diesel mode. Further, diesel mode maximum CO ₂ fraction was 2.13% & 3.41% for dual mode.
72	2020	(Saravanan et al., 2020)	The obtained result has showed that, the blend BL20 gave the best performance and it is closest to diesel fuel. Further, based on the experimental results the

			BTE of the blend BL20 was found to be 2.79% lesser than diesel fuel.
73	2018	(Dubey & Gupta, 2018)	Dual biofuel blend (JBT 50) results at full load and compression ratio 20, there is 2.17% increase in BTE and 13.04%, 17.5%, 4.21% and 30.8% decrease in CO, HC and NOX and smoke opacity respectively while CO ₂ was observed to increase by 11.04%.
74	2022	(Estrada et al., 2022)	The dual-fuel operation results in higher NOX emissions than neat diesel, with 2% to 6 % and 19% to 48 % increments for the lower and higher engine speeds. H ₂ emerges as a versatile energy carrier with potential to tackle current energy and emissions challenges; however, the dual fuel strategy requires careful management of NOX emissions.
75	2021	(Saxena et al., 2021)	It was found that utilization of methanol in CI-engine has a potential to improve the performance and simultaneously with a significant reduction in NOX, CO, Soot, and nano-particle emissions in comparison to neat diesel operation. However, unburnt HC emissions reduce for methanol-diesel blended fuel operations whereas HC emission is higher for methanol-diesel dual-fuel operation.
76	2021	(Hall & Kassa, 2021)	This study examines the advances that have been made in the combustion control on conventional and more advanced dual fuel engines that utilise natural gas along with diesel fuel and discusses the remaining challenges in this field.
77	2021	(Koli & Rao, 2021)	Mechanical efficiency, brake thermal efficiency was found increased by 30%

			and 19% respectively. Also, brake specific energy consumption has reduced by 19%. CO ₂ and HC emissions decreased by 4% and 56% respectively, however, increased CO and NOX emissions observed at elevated load conditions and low CR.
78	2022	(Dinesh & Kumar, 2022)	Excessive NOX emissions are a drawback that can be successfully controlled by installing after the treatment or exhaust gas recirculation technologies. Ammonia is another important key element to reduce NOX emissions from vehicles because it is used in SCR.
79	2021	(Rosa et al., 2021)	The economic analysis made it clear that operational cost increased when the engine worked with ethanol replaces partially diesel fuel. However, with a slight increase in operational cost, especially in São Paulo state, it is possible to reduce pollutant emissions. For the baseline test, the operating cost were 0.354 U\$/kWh. The specific fuel cost reaches the maximum of 0.441 U\$/kWh, 25% higher than the respective baseline test, increasing ethanol fraction.
80	2021	(H. Sharma et al., 2021)	The increase in hydrogen proportion results in escalated emission of oxides of nitrogen (approximately 30% to 60%) contrasting to diesel mode by virtue of higher in-cylinder temperature. Additionally, a detailed study was presented on the bottlenecks in hydrogen application for dual fuel mode.
81	2021	(Zhang et al., 2021)	The bioethanol double injection strategy at 3:1 split ratio intensified the stability of local heat release process, increasing

			thermal efficiency by 1.4%. Increasing bioethanol injection pressure diminished the possibility of the local misfire increasing combustion efficiency.
82	2021	(Liu et al., 2021)	The temporal and spatial distribution of cylinder temperature, NOX and CH ₄ emissions analysis shows that the higher diesel fuel ratio will generate the widely distributed high temperature region, which is beneficial for methane oxidation.
83	2021	(Legrottaglie et al., 2021)	The reduction of CO ₂ emissions is higher than 20%. Moreover, the proposed engine can tolerate larger variations in a composition of the biogas, without the significant drop of thermal efficiency.
84	2022	(Rao & Prasad, 2022)	The test results showed that the addition of 10% EGR to POME 20 is found 23% reduction of NO _x emissions when compared to POME 20 operated at standard operating conditions.
85	2021	(Khayum et al., 2021)	HC, CO and smoke emissions were found to be lesser than 55.5%, 3.5% and 19.1% respectively than diesel at full load. Moreover, for the same CR and 240 bar, advancing from 24.5°CAbTDC to 26°CAbTDC resulted in a bad performance.
86	2019	(Xu et al., 2019)	At high load, compared to the VVT strategy, a further decreased effective compression ratio can be utilized for VCR strategy, which allows early fuel injection, leading to improvements of fuel efficiency and soot emissions.
87	2021	(Vijayakumar et al., 2021)	The characteristics that mean brake thermal efficiency, specific fuel consumption, hydrocarbon, carbon

			monoxide, oxides of nitrogen, smoke, cylinder pressure and heat release rate were superior at CR 18:1 and the blend B20, but considering the engine vibration and noise of the CR is limited to a value of 18:1.
88	2020	(García et al., 2020)	The fuel improvements were higher as the electrification levels increased, with 8% for MHEV-VCR and around 20% for FHEV-VCR. In terms of emissions, the two clear benefits with FHEV-VCR were the reduction of particle number and unburned hydrocarbons of around 60% and 15%, respectively, as compared to the conventional DISI.
89	2021	(Shetty et al., 2021)	The signals are modified and interpreted by the intermediate software's which is analysed for various compression ratios, it was found that Audio technology can be efficiently pick up engine sounds which can be processed by interfaces for identification of Knock.
90	2021	(Ravikumar et al., 2021)	The experimental result showed that increase in blends of rice bran biofuel with diesel reduces the carbon monoxide and increases the carbon dioxide and hydrocarbon in emissions.
91	2016	(Hoeltgebaum et al., 2016)	The kinematic chains from all classes of VCR engines are analysed in order to investigate topological and structural characteristics which are compared with works from Freudenstein and Maki (1983) and Tsai (2000).
92	2020	(Wittek et al., 2020)	The moto of this work was to investigate the dynamic behaviour by means of fired engine testing. For this purpose, a VCR

			connecting rod was attached with sensors and the measured data was acquired synchronously to crank angle.
93	2020	(López et al., 2020)	The result shows that slow CR transitions lead to fuel consumption penalties, which suggests the need to optimizing the control strategies of the VCR system. Even though this penalty, once the gear up shift speed is optimized for each drive cycle, the VCR system is still enable fuel consumption reductions up to 3% on the WLTC driving cycle, up to 4% on the proposed urban driving cycles and up to 3% on highway driving cycles with respect to fixed CR.
94	2021	(K. S. Prasad et al., 2021)	For the Bu100 (diesel) and Bu20 test fuel this optimum value is 260bar, whereas for the Bu40 test fuel, it is 240bar. At the higher CR of 18, Bu40 gives the best performance with BTE of 30.14%.
95	2021	(Guan, Liu, et al., 2021)	Using external exhaust gas recirculation strategy, greatly alleviate a knocking combustion and reduced heat transfer rate through the combustion chamber wall, which is beneficial to increase the indicated thermal efficiency and adiabatic efficiency.
96	2021	(Hosamani et al., 2021)	The thermal performance and emissions of VCR engine is estimated by using proposed ANN model is found to be quite close to experimental values with reasonable accuracy as correlation coefficient is ranging from 0.97 to 0.99.
97	2020	(B. S. N. Prasad et al., 2020)	The performance result shows a good agreement of improvisation of 25% increase in BTE, and BSFC reduced by

			19% at compression ratio 10:1. At higher compression ratio 10:1, there was a significant decrease observed in CO and HC by 30% to 40%, and the same trend is observed at all speeds; however, NOX emission increased with the increasing CR.
98	2020	(Hotta et al., 2020)	Enhancing the CR from CR 10 to CR 12, limited the intensification of NOX and unburnt hydrocarbon emission by 10.17% and 15.6%, at 1400 rpm. Hence, CR 12 is recommended as optimum CR and its combination with 1400 rpm and WOT setting is recommended as the best operating condition of the engine.
99	2019	(Clenci & Descombes, 2019)	As an energetic source, the autonomy standpoint, the internal combustion engine remains an actual solution for road mobility with an immediate perspective.
100	2019	(Parida et al., 2019)	Output responses from the mathematical modelling such as BTE 26.77%, BSFC 0.284 kg/kWh, CO 0.0059%, HC 114.84ppm, NO _x 905.6ppm respectively were obtained using D-optimal test with composites desirability of 0.97009. The predictions of RSM results was obtained in concurrence with the experimental ones, with error less than 5% excepting for CO model.
101	2020	(Sundar & Udayakumar, 2020)	B20 blends of MECISO and MERBO produce low emission than diesel, thus these fuel blends be the replacement of diesel in standard diesel engine to cutdown worldwide energy demand and to reduce the environmental pollution hazards.

102	2020	(Yuvaraj & Viswanath, 2020)	The present investigation is to measure together with these parameters emissions like Hydro Carbons, Carbon monoxide, Carbon dioxide, Oxides of nitrogen and smoke were taken. 15:1, 16.5:1, 17.5:1 and 18:1 are the four compression ratios selected to find engine emission characteristics.
103	2015	(T. A. Kumar et al., 2015)	The yield of biodiesel is by transesterification process was 73% at 55 °C. This fuel was tested in variable compression ratio engine with blend ratios of B10 and B20. During test runs the compression ratio of the engine was varied from 15:1 to 18:1 and torque is adjusted from zero to maximum value of 22 Nm.
104	2021	(Mahesh et al., 2021)	From the study it is found that the emission characteristics of Carbon monoxide, Hydrocarbon and Oxygen in biodiesel are less. On the otherhand Nitrogen oxide and Carbon dioxide are less for diesel. The specific fuel consumption and brake thermal efficiency of these blends are high for biodiesel.
105	2016	(Banoth & Kadavakollu, 2016)	All test fuels were used in computerized 4 stroke single cylinder variable compression ratio engine at five different loads (0, 6, 12, 18 and 24 Nm).
106	2017	(M. Krishnamoorthi & Malayalamurthi, 2017)	The energy efficiency of B2 fuel has been found 63.88% fuel input at CR17.5 with 100% engine load. Increasing number of nozzle holes improves the performance of diesel engine fueled with bael blends in terms of reduced brake specific energy consumption, increased BTE and reduced

			emissions like hydrocarbon (HC), carbon monoxide (CO) and smoke.
107	2018	(Satyanarayana, Rao, Kumar, Rao, et al., 2018)	The results of thermo-mechanical analysis show that when the engine is running, the stress in the region is compressive, caused by the thermal loading and combustion pressure. The fatigue analysis is carried out to know the factor of safety and life of cylinder head it indicates maximum life of 1×10^6 cycles at all compression ratios are determined through finite element analysis.
108	2021	(Guan, Li, et al., 2021)	The result shows that BSFC and NOX is reduced by 16.37% and 74.18% based on NSGA-II algorithm. Thus, an integrated platform for engine performance optimization and the verification has been developed.
109	2018	(Pathak et al., 2018)	The optimum level of control parameters were found to be at 10:1 for compression ratio, 20° for spark Advance, 1.2 kW for load, 1 turn for air screw and fuel having less knocking tendency. It is seen from the ranking of the process parameters that load is the most dominant factor on output response followed by compression ratio and spark advance.
110	2021	(Sanjeevarao et al., 2021)	Improvement in brake thermal efficiency observed with B20ANP100ppm compared to diesel and the brake specific fuel consumption of B20ANP100ppm slightly increased compared to diesel. CO, HC&CO ₂ emissions reduced by using the cottonseed blends compared to diesel and small amount of NO _x increased compared to diesel.

111	2019	(M. Krishnamoorthi et al., 2019)	Three optimization works are conducted for 65%, D+25% and SVO+10% DEE blend, in optimization-1 (opti-1) considered 0% exhaust gas recirculation (EGR), Opti-2 considered 5% EGR and Opti-3 considered 10% EGR. Compared to the diesel, carbon monoxide (CO), oxides of nitrogen (NO _x), and hydrocarbon (HC) were reduced by 12.8%, 4.19% and 9.61% for blend fuel in opti-2.
112	2021	(S. Krishnamoorthi et al., 2021)	The result showed that the Spirulina B20 with 3 hole nozzle and preheated at 60°C gave performance value nearer to diesel and also the emission characteristics were lowered to a considerable level.
113	2018	(Thirunavukkarasu et al., 2018)	This ceramic material is preferred because of the nominee material for coating the piston crown as a result of its fascinating properties like high constant of thermal enlargement, high Poisson's ratio, low thermal conductivity and stable part structure at higher Temperature conditions as well as this experimental study was conducted on VCR Engine at single, four and five holes nozzle injectors to check its impact on performance and emission by diesel fuel at 9kg of load.
114	2016	(Bharadwaz et al., 2016)	At this optimized operating conditions of engine the responses such as brake thermal efficiency, brake specific fuel consumption, carbon monoxide, unburnt hydrocarbons, nitric oxide, and smoke found to be 31.95%, 0.37 kg/kW h, 0.036%, 5 ppm, 531.23 ppm and 15.35%.

115	2019	(Bhatti et al., 2019)	The conclusion drawn from the study that applying both energy and exergy analysis give a more valuable understanding of performance and the improvement of internal combustion engines by locating and then reducing the exergy loss at that location.
116	2016	(Bora & Saha, 2016)	There is a reduction in the carbon monoxide and hydrocarbon emissions by 17.67% and 17.18% when CR is increased from 17 to 18. However, for same setting of CRs, there is an increase of oxides of nitrogen as well as carbon dioxide emissions by 42.85% and 14.13%.
117	2021	(Rajeesh et al., 2021)	The percentage variation of peak pressure was 7.24, 6.83 and 14.7 bar from simulation is observed for CRs 14:1, 16.5:1 and 18:1 as compared to experimental values. Similarly, it is observed that, the HRR in the cylinder at CR 14:1, 16.5:1 and 18:1 is 36.33 J at CA 364, 32.85 J at CA 364 and 27.54 Joules at CA 363 for CFD analysis respectively.
118	2019	(Rathore et al., 2019)	We have an experimented to monitor and analyse the performance of pure diesel fuel against various blends (B20 to B50) of Jatropha biodiesel & Coconut biodiesel at a fixed compression ratio that is eighteen. The performance limits that were under study and compared are variation of BSFC & BTE with various loads for many fuel blends.
119	2019	(Rosha et al., 2019)	Increasing compression ratio from 16:1 to 18:1, average reduction in emissions of hydrocarbon, carbon monoxide and smoke opacity are observed to be 47.8,

			41.0 and 35.7%, respectively whereas, oxides of nitrogen emissions increased by 41.1%. Thus, it is inferred that B20 fuel performed well at a high engine compression ratio.
120	2020	(Polat et al., 2020)	The experimental result showed that high-efficiency HCCI operation is feasible at an engine compression ratio as low as 9.2 once engine variables are properly optimized and an appropriate level of supercharging is utilized. An increase in the indicated thermal efficiency was seen as boost pressure increased.
121	2017	(Nayyar et al., 2017)	Brake thermal efficiency is improved by 5.54% and smoke & nitrogen oxides decreased by 59.56% & 15.96% respectively for B20 in comparison to the diesel at full load condition.
122	2019	(Pratap et al., 2019)	It was found that optimum values of BSFC, BTE, HC, CO & NO _x was 0.456kg/kWh, 19.725%, 38.43ppm, 0.026% and 348.74ppm respectively at the load of 10kg, CR of 18, and blend 20%.
123	2020	(Hariram et al., 2020)	The performance parameters include brake thermal efficiency, brake specific fuel consumption and emission parameters include unburned hydrocarbon, carbon monoxide, oxides of nitrogen and smoke were assessed. Optimal operating parameters of the engine was analysed by incrementing and decrementing the compression ratio upto CR18 and CR17.
124	2018	(Patel et al., 2018)	The optimum conditions were CR 18.00, load 6.665 kg, and blend 12.22%. Under

			optimum conditions, experimental values of response variables were fairly comparable with the model predicted values.
125	2020	(Iyer, 2020)	The experimental result had revealed that increase in CR in a close range of 8:1 with larger cleavage on the piston crown geometry enhances engine performance for Biogas fuelled small S.I. engine 100cc category. It has been observed during comparative analysis that maximum power produced by biogas fuelled engine has improved by 13.4%, BSEC has increased by 23.30% and there is an 18.18% improvement in BSFC.
126	2020	(John et al., 2020)	The focus of this study is to understand the combustion behavior by varying compression ratios using third grade sesame oil. Blended fuel (B20) and its fuel properties are found to be within stipulated standards. The in-cylinder pressure increases as the compression ratio is increased.
127	2020	(Sanaye & Khakpaay, 2020)	The total fuel cost consumption reduced due to heat recovery for 9.8×10^4 \$/year (31%), and the annual CO ₂ and NO _x emission production decreased for 3.02×10^4 \$/year. The payback period of optimized integrated system is 3.63 years.
128	2014	(De & Panua, 2014)	The result shows that various parameters such as thermal efficiency, CO and NO _x emissions are very close to the mineral diesel for lower blend concentrations. But, it is observed that for higher blend concentrations, performance and

			emissions were much inferior compared to the diesel.
129	2021	(Duan et al., 2021)	Some effective techniques and controlling strategies, such as fuel management, homogeneous charge preparation, exhaust gas recirculation, etc. are widely used in the HCCI engine.
130	2018	(M. Krishnamoorthi et al., 2018)	Minimum carbon monoxide (CO) of 0.41% was observed at IP of 230bar and CR of 18 with 25°bTDC IT and oxides of nitrogen (NOX) of 205.7 ppm was found at 250bar IP and 16 CR with 25°bTDC IT for F(1) fuel.
131	2019	(Calam et al., 2019)	With increase of CR, CO and HC emissions decreased however NO _x emissions increased. Maximum thermalefficiency was obtained as 38.2% at 800rpm and 12:1 CR with RON40 fuel. The widest operational region was obtained with RON20 fuel at CR of 10:1 with the minimum BSFC value of 210g/kWh.
132	2021	(Kang et al., 2021)	The results of this study provides fundamental information for future CI- ICRC engine optimization, and can also be utilized in providing a reference guidance for DWI implementation within modern internal combustion engines.
133	2022	(D. K. Singh & Tirkey, 2022)	The corresponding optimal repose valuesof BP, BTE, BSFC, CO, UHC, CO ₂ , and NOX were observed to the value of 3.54 kW, 28.23%, 0.38 kg/kWh, 0.0231 (% vol), 4.2539 (ppm), 0.9569 (vol %), and 9.6958 ppm. Maximum diesel saving at compression ratio (CR) 16, 17, and 18 observed was 14.38%, 22.48%, and

			49.05% respectively using a Dual fuel mode.
134	2021	(Prabakaran, Mohanraj, et al., 2021)	At peak load condition, AME30 test fuel with CR18:1 gives the reduction of CO (14.0%), HC (12.06%) and smoke opacity(5.88%) and slight increment in NOX (2.46%) emissions as well as reduced BTE (10.20%) and increased BSEC (17.33%) were obtained related to a diesel fuel.
135	2020	(Polat, 2020)	The coefficient of variation of indicated mean effective pressure increased with increase of the ethanol fuel ratio in mixture at misfiring region. The maximum pressure rise rate, ringing intensity and combustion noise level were tended to increase with increase of the equivalence ratio at all test conditions.
136	2018	(Satyanarayana, Rao, Kumar, Prasad, et al., 2018)	From this analysis we observed that the Thermal Conductivity and the Factor of Safety plays a vital role in selecting the material for Piston. Hemispherical piston with Al 6061 alloy material having the high factor of safety for a given loading condition.
137	2021	(Baskar et al., 2021)	The bio-diesel thus obtained is blended with neat diesel in ratios 2080 (B20) and 6040 (B60) per litre. The blended mixture is then tested for performance and combustion using the Variable Compression Ratio (VCR) Engine set up. The emission characteristics are tested using the computerized AVL Smoke Metre.
138	2014	(Javaheri et al., 2014)	The analysis indicates an increase in ratio of thermo-mechanical exhaust availability

			to fuel availability by CR with a maximum near stoichiometry, whereas, it is shown that chemical exhaust exergy is not dependent on the CR and reduces with AFER.
139	2021	(Sahoo & Srivastava, 2021)	The result shows that the knock intensity was high at CR 12 and 7 bar Indicated Mean Effective Pressure (IMEP) for gasoline fueled engine. The maximum CR was limited to 12 for the gasoline engine. However, the Knock was not observed even at CR 16 for CNG engine. The engine was successfully operated at the CR 16 with CNG.
140	2021	(Yilmaz, 2021)	The hydrogen enrichment firstly increased and then decreased brake thermal efficiency of the low compression ratio engine. Ringing intensity increased with increasing the engine load and hydrogen amount.
141	2022	(Taib et al., 2022)	The ambient intake temperature was sufficient for the hydrogen ignition in low CR with minimal heat flux effect. The best intake temperature for optimum engine efficiency in a low CR engine is 340 K and engine compression ratio for optimum engine efficiency at ambient intake temperature is CR12 with an acceptable cylinder wall heat flux values.
142	2021	(Ali et al., 2021)	The experimental test result shows that the improvement in performance characteristics of the VCR engine due to the addition of Cerium Oxide (CeO ₂) and Magnesium Oxide (MgO) nanoparticles to different blends of the WCO biodiesel compared to that of neat diesel.

143	2020	(Vali & Wani, 2020)	The emissions of the CO, HC were reduced significantly whereas CO ₂ emissions were increased for ZnO nanoparticles blended test fuels with an increase in CR.
144	2018	(Hosamani & Katti, 2018)	The result shows that blends results in higher cylinder gas pressure, lesser heat release, the higher rate of pressure rise and increased combustion duration. Increasing the CR improve the combustion characteristics of engine.
145	2020	(Kattimani et al., 2020)	The blend B40D60 gives a better result in comparison to all other blends with respect to the brake thermal efficiency(BTE) and smoke emissions at compression ratio (CR) 17.5:1 and 4 holes fuel injector having 0.25 mm diameter at 260 bar IOP.
146	2016	(Karaman et al., 2016)	Theoretical study showed that compression ratio significantly affects the engine characteristics that calculated in this study. Experiments revealed that the higher compression ratio results with higher brake thermal efficiency (BTHE) and thus lower specific fuel consumption (SFC). The calculation study showed that increasing cut-off ratio caused to decrease of brake thermal efficiency.

CHAPTER 3

MATERIALS AND METHODOLOGY

MATERIALS

Prunus Domestica

The European plum, *Prunus Domestica* as shown in Fig. 3.1, is a species of flowering plant from Rosaceae family. It is a deciduous tree that encompasses a wide range of fruit trees that are commonly referred as plums in English, not all the plum varieties are members of this species. The *Prunus Domestica* subspecies also includes damsons and greengages.



Fig. 3.1 *Prunus Domestica*

3.2.2 Pure Diesel

Diesel engine is a type of internal combustion engine where the ignition of fuel occurs without a spark as a result of compression of the input air and subsequently injection of fuel, diesel fuel is especially made to use in compression engine. Diesel fuel as shown in Fig. 3.2, hence requires good compression ignition properties.



Fig. 3.2 Diesel Fuel

METHODOLOGY

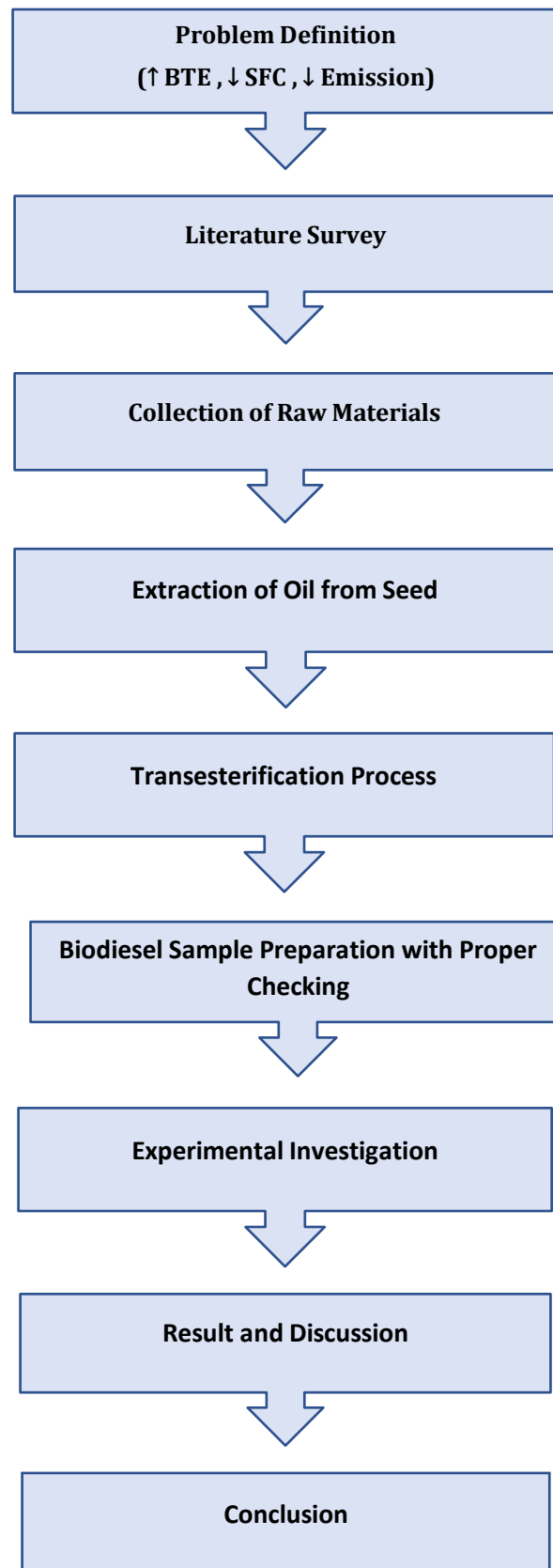


Fig. 3.3 Methodology Flow Chart

CHAPTER 4

TRANSESTERIFICATION PROCESS

The process of transesterification involves in the reaction of oil with an alcohol to produce esters and glycerol. The reaction rate and yield are enhanced with the application of a catalyst (5 gram of NaOH). Alcohol in excess is used to move the equilibrium to product side because the reaction is reversible.

TRANSESTERIFICATION

The process of allowance of non-edible oil to chemically react with alcohol is known as transesterification as shown in Fig. 4.1. They are readily available and inexpensive. Ethanol and methanol are the most often employed alcohols in this process. This process has been widely used to turn triglycerides into ester and to lessen the viscosity of non-edible oil.

SEPARATION OF CRUDE GLYCERIN

A separatory funnel as shown in Fig. 4.2, is used to separate the immiscible liquids. Two layers are visible when two immiscible liquids are put into a separatory funnel. The top layer will contain the biodiesel and the lower layer will contain the crude glycerin.

BIODIESEL WASHING

A biodiesel washing is a process of neutralizing the biodiesel to neutral (PH value to 7). This process is done by mixing hot water (105 °C) and biodiesel in separating funnel as shown in Fig. 4.3. Water and biodiesel are two immiscible liquids that are separated into two distinct layers in a separating funnel.

PRUNUS DOMESTICA METHYL ESTER

Prunus Domestic oil is trans-esterified into neat Prunus Domestica Methyl Ester (PDME) as shown in Fig. 4.4.

Table-4.1: Transesterification of Prunus Domestica oil

S.NO	PARAMETERS	RESULTS
1	Free Fatty Acid	0.846 %
2	Catalyst (NaOH) Quantity	5 grams
3	Oil to Methanol Molar Ratio	1:6
4	Temperature	60 °C
5	Reaction Time	90 minutes
6	Yield	89.3 %

FLOWCHART



Fig. 4.1 Transesterification



Fig. 4.2 Separation of Crude Glycerin



Fig. 4.4 Biodiesel (PDME)



Fig. 4.3 Biodiesel Washing

CHAPTER 5

PROPERTIES OF PRUNUS DOMESTICA METHYL ESTER

Free Fatty Acid

Oils and fats are hydrolysed to make free fatty acids (FFA). As a result of the oils and fats being subjected to different environments, such as storage, processing, heating, or frying. The level of FFA is dependent on temperature, time and moisture content.

$$\text{FFA} = \frac{28.2 \times (\text{Volume of Titrant} - \text{Blank Volume}) \times \text{Normality}}{\text{Weight}} \% \quad (\text{eq 1})$$

$$= \frac{28.2 \times 1.5 \times 0.1}{5}$$

FFA of Prunus Domestica oil = 0.846 %

Density

Density is the mass of a material per unit volume. Grams per cubic centimeter is the unit of measurement for density. A liquid's density is a gauge of how heavy it is relative to the amount is being measured. The liquid that weighs heavy is more denser if you weigh two liquids with similar volume or amount. A substance that is less dense than water that will float if it is gently introduced to the water surface.

$$\text{Density} = \frac{\text{Weight of Empty Gravity Bottle} - \text{Empty Gravity Bottle with Sample Weight}}{\text{Capacity of Gravity Bottle (25 ml)}} \text{ g/cm}^3 \quad (\text{eq 2})$$

$$= \frac{19.76 - 41.86}{25}$$

Density for PDME = 0.884 g/cm³

Viscosity

The physical quality of kinematic viscosity is very important for biodiesel. It directs the whole combustion of the fuel in the diesel engine. Temperature, the amount of double bonds, and the number of carbon atoms all affect the kinematic viscosity of the biodiesel.

$$\text{Viscosity} = \text{Time in seconds} \times 0.014 (\text{diameter}) \quad (\text{eq 3})$$

$$= 312 \times 0.014$$

Viscosity for PDME = 4.368 cSt

(Note: The value of viscosity is little higher, which may result in increase in NO_x)

Moisture Content

The term "moisture content" (MC) referred to how much moisture is present in a given sample. This value is expressed as a percentage of the mass of the substance. There are numerous ways to measure how much moisture is present in an object, such as moisture metres or oven-dry tests.

Weight of Sample with Crucible = Weight of Empty Crucible + Weight of Sample

Weight of Empty Crucible = 22.60 g

Weight of Sample = 5.02 g

Weight of Sample with Crucible = 22.60 + 5.02 = 27.62 g

$$\text{Moisture Content} = \frac{\text{Weight of Sample with Crucible} - \text{Dry Weight}}{\text{Dry Weight}} \times 100 \% \quad (\text{eq 4})$$

$$= \frac{27.62 - 27.55}{27.55} \times 100$$

Moisture Content for PDME = 0.254 %

Corrosion Test

To determine how corrosive sulphur compounds are in biodiesel, scientists use the copper strip corrosion test (CSCT). When performing the CSCT, a strip of clean, polished copper is submerged in a biodiesel for a predetermined amount of time at a specific temperature before being "rated" against a standard as shown in Fig. 5.1.

Corrosion Test for PDME = 1b



Fig. 5.1 Corrosion Test

Calorific Value

Calorific value, which is calculated by the complete burning of a predetermined quantity under constant pressure and under some typical circumstances. It is the amount of heat energy present in fuel. It is additionally known as calorific power.

$$\text{Calorific Value} = \frac{(M_w \times C_w + W) \times \text{Tr}}{M_s} (\text{En} + \text{Ec}) \text{ cal/g} \quad (\text{eq 5})$$

where,

M_w = Mass of water, g

C_w = Specific heat capacity of water, cal/g °C

W = Water equivalent, cal/°C

Tr = Temperature rise, °C

M_s = Mass of fuel sample, g

En = Energy equivalent calculated with respect to nichrome wire, cal/g

Ec = Energy equivalent calculated with respect to cotton thread, cal/g

$$= \frac{(2000 \times 1 + 503.6) \times 2.25}{0.5} (2.3 + 3600)$$

Calorific Value for PDME = 7663.9 cal/g

Cloud Point

The cloud point is a temperature at which a clear solution either experiences a liquid to liquid phase separation to create an emulsion or a liquid to solid phase transition to produce a stable sol or a suspension that precipitates. The cloud point is comparable to the "dew point," which is the temperature at which water vapour (humid air) undergoes a gas to liquid phase transition known as condensation to generate a liquid water (dew or clouds). The dew point becomes the frost point when the temperature drops below 0 °C, when water vapour transitions from a gas to a solid state known as deposition, solidification, or freezing.

Cloud Point of PDME = -9 °C

Pour Point

The temperature below which a liquid substance loses its ability to flow is known as the pour point. It is described as the lowest temperature at which oil can pour down from a beaker.

Pour Point of PDME = -21 °C

Flash Point

Flash point is the lowest temperature at which a liquid (often a petroleum product) will produce a vapour in the atmosphere at its surface that will "flash," or momentarily ignite when in contact with a flame. The flash point is a indicator of a liquid's combustibility or flammability.

Flash Point of PDME = 176 °C

Fire Point

A volatile combustible substance's fire point is the lowest temperature at which its vapour continues to burn in the atmosphere as when heating after the flashpoint has been found.

Fire Point of PDME = 184 °C

CHAPTER 6

BIODIESEL SAMPLE PREPARATION

Sample Ratio

Prunus Domestica oil is produced from Prunus Domestica seed. The MethylEster is extracted from the Prunus Domestica Oil. By transesterification process the oil is converted into biodiesel.

For this experiment, four samples of biodiesel are prepared with different ratio.

Table-6.3: Sample Ratio

SAMPLE	DIESEL	PRUNUS DOMESTICA METHYL ESTER
Sample 1	90%	10%
Sample 2	80%	20%
Sample 3	70%	30%
Sample 4	60%	40%

Cost of Biodiesel Sample

The cost of biodiesel is very high because the oil is extracted from a rich plum's seed which is imported from Europe.

Cost of Sample 1

90% Diesel and 10% PDME costs 324.6 per litre.

Cost of Sample 2

80% Diesel and 20% PDME costs 555.2 per litre.

Cost of Sample 3

70% Diesel and 30% PDME costs 785.8 per litre.

Cost of Sample 4

60% Diesel and 40% PDME costs 1016.4 per litre.

CHAPTER 7

EXPERIMENTAL SETUP

VARIABLE COMPRESSION RATIO ENGINE

An electric start, single-cylinder, four-stroke diesel engine with a variable compression ratio is coupled to an eddy current dynamometer for loading. By using a specifically created tilting cylinder block arrangement, the compression ratio can be altered without stopping the engine and without changing the geometry of the combustion chamber. The setup comes with the tools required to measure crank angle and combustion pressure. For PPV diagrams, these signals are interfaced to the computer via the engine indicator. Additionally, there is room for the interface of load monitoring, temperature, fuel flow, and airflow. A stand-alone panel box with an air box, two fuel tanks for a blend test, a manometer, a fuel measuring unit, transmitters for measuring the flow of both air and fuel, a process indicator, and an engine indication are all part of the setup. Rotameters are provided for cooling water and calorimeter water flow measurement.

Fig. 7.1 VCR Engine



The configuration allows for the investigation of the braking power, indicated power, frictional power, BMEP, IMEP, mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio, and heat balance for VCR engines as shown in Fig. 7.1. with EGR. For online performance assessment, the Labview-based Engine Performance Analysis software package "Enginesoft" is offered.

A computerized Diesel injection pressure measurement is optionally provided.

Features

- Compression Ratio could be changed without stopping the engine
- No alteration in Combustion chamber geometry
- Water cooled EGR
- Electric start with battery and charger
- Arrangement for blend test
- PO-PV plots, performance plots and tabulated results Data logging, editing, printing and export, Configurable graphs
- IP, IMEP, FP indication, combustion analysis

Range of Experiments

- Study of VCR engine performance (Computerized mode)
- Study of emissions with EGR variation
- Study of combustion with different fuel blends
- Study of pressure volume plot and indicated power High CR Low CR

Utilities Required

Electric supply

230 +/- 10 VAC, 50 Hz, 1 phase

Computer

IBM compatible with standard configuration

Water supply

Continuous, clean and soft water supply @ 1000 LPH, at 10 m. head. Providetap with 1" BSP size connection

Software

Apex Innovations Pvt. Ltd. created the Labview-based software package EngineSoft for engine performance monitoring systems.

Most engine testing application demands, such as monitoring, reporting, data entering, and data logging, can be met by EngineSoft. The computer programme assesses power, efficiency, fuel use, and heat release. It can be altered depending on the engine setup.

Different graphs are produced under various operating conditions. The required signals are scanned, saved, and shown in a graph while the engine is being tested online in the RUN mode as shown in Fig. 7.2. In order to examine the data in graphical and tabular modes, a stored data file is accessed. Printing the results and graphs is an option. You can utilise the data in excel format for additional analysis.



Fig. 7.2 Gas Analyzer

Table-7.1: Engine Specifications**Product****VCR Engine test setup 1 cylinder, 4 stroke, Diesel with EGR (Comp.)**

<i>Product Code</i>	234
<i>Engine</i>	Make Kirloskar, Type 1 cyl., 4 stroke Diesel, water cooled, power 3.5kW at 1500rpm, stroke 110mm, bore 87.5mm. 661cc, CR17.5, Modified to VCR engine CR 12 to 18. With electric start arrangement, battery and charger
<i>Dynamometer</i>	Type eddy current, water cooled,
<i>Propeller shaft</i>	With universal joints
<i>Air box</i>	M S fabricated with orifice meter and manometer
<i>Fuel tank</i>	Capacity 15 lit with glass fuel metering column
<i>Calorimeter</i>	Type Pipe in pipe
<i>EGR</i>	Water cooled, SS, Range 0-15%
<i>Piezo sensor</i>	Range 5000 PSI, with low noise cable
<i>Crank angle sensor</i>	Resolution 1 Deg, Speed 5500 RPM with TDC pulse.
<i>Data acquisition device</i>	NI USB-6210, 16-bit, 250kS/s.
<i>Piezo powering unit</i>	Model AX-409.
<i>Temperature sensor</i>	Type RTD, PT100 and Thermocouple, Type K
<i>Temperature transmitter</i>	RTD PT100, Range 0–100o C, 3 Nos; Thermocouple, Range 0-1200 o C, 2 Nos
<i>Load indicator</i>	Digital, Range 0-50 Kg, Supply 230VAC
<i>Load sensor</i>	Load cell, type strain gauge, range 0-50 Kg
<i>Fuel flow transmitter</i>	DP transmitter, Range 0-500 mm WC
<i>Air flow transmitter</i>	Pressure transmitter, Range (-) 250 mm WC
<i>Software</i>	“EngineSoft” Engine performance analysis software
<i>Rotameter</i>	Engine cooling 40-400 LPH; Calorimeter 25-250 LPH
<i>Pump</i>	Type Monoblock
<i>Overall dimensions</i>	W 2000 x D 2500 x H 1500 mm
<i>Optional</i>	Computerized Diesel injection pressure measurement with injection variation 0-25 deg BTDC

CHAPTER 8

RESULT AND DISCUSSION

RESULT

The efficiency of Variable Compression Ratio Engine's performance is yet to be found using Prunus Domestica Methyl Ester as a biodiesel.

DISCUSSION

Prunus Domestica oil has been converted into Biodiesel by Transesterification Process with the help of **Centre for Waste Management, Centre of Excellence for Energy Research, International Research Centre, Sathyabama Institute of Science and Technology**. The samples are ready to be tested in the VCR Engine at **Thermal Laboratory, Department of Mechanical Engineering, Sathyabama Institute of Science and Technology**.

CHAPTER 10

CONCLUSION

The Transesterification Process for Prunus Domestica Oil is done successfully and converted into Methyl Ester. Four Biodiesel samples has been prepared with properratios. The Biodiesel samples are yet to get tested in Variable Compression Ratio Engine to check the Efficiency of the Engine's Performance and Emission Standards.

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