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

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ABSTRACT - *The objective of the research is to find the Brake Thermal Efficiency (BTE), Specific Fuel Consumption (SFC) of the Variable Compression Ratio (VCR) Engine and to reduce emissions by operating the VCR Engine using PRUNUS DOMESTICA METHYL ESTER as a biodiesel. 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 on the biofuel will be higher. So, the biofuel is mixed with a 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 (SFC), Brake Thermal Efficiency (BTE) and the emission characteristics from the Variable Compression Ratio Engine is noted. The graph is plotted and compared to get a better result of the engine's performance using PRUNUS DOMESTICA METHYL ESTER as a biodiesel.*

Key Words: Variable Compression Ratio Engine, Prunus Domestica Methyl Ester, Biodiesel, Specific Fuel Consumption, Brake Thermal Efficiency, Emission, Brake Power.

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 (CO_2), 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 [1-7]. 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 [8-19]. In recent years, the investigations were done in single fuel method [8-18] and dual fuel method [19-29]. 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 P. Domestica is converted into Methyl Ester by Transesterification Process [2] and mixed with a diesel in proper ratio to obtain a proper biodiesel blend [19].

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.

The main objectives are

- To reduce the emission from the variable compression ratio diesel engine.
- To increase the quality of the biodiesel (↑ BTE , ↓ SFC).
- To enhance the performance of the variable compression ratio diesel engine.

2. Materials and Methodology

2.1. Materials

Prunus Domestica

The European plum, Prunus Domestica as shown in Fig. 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.

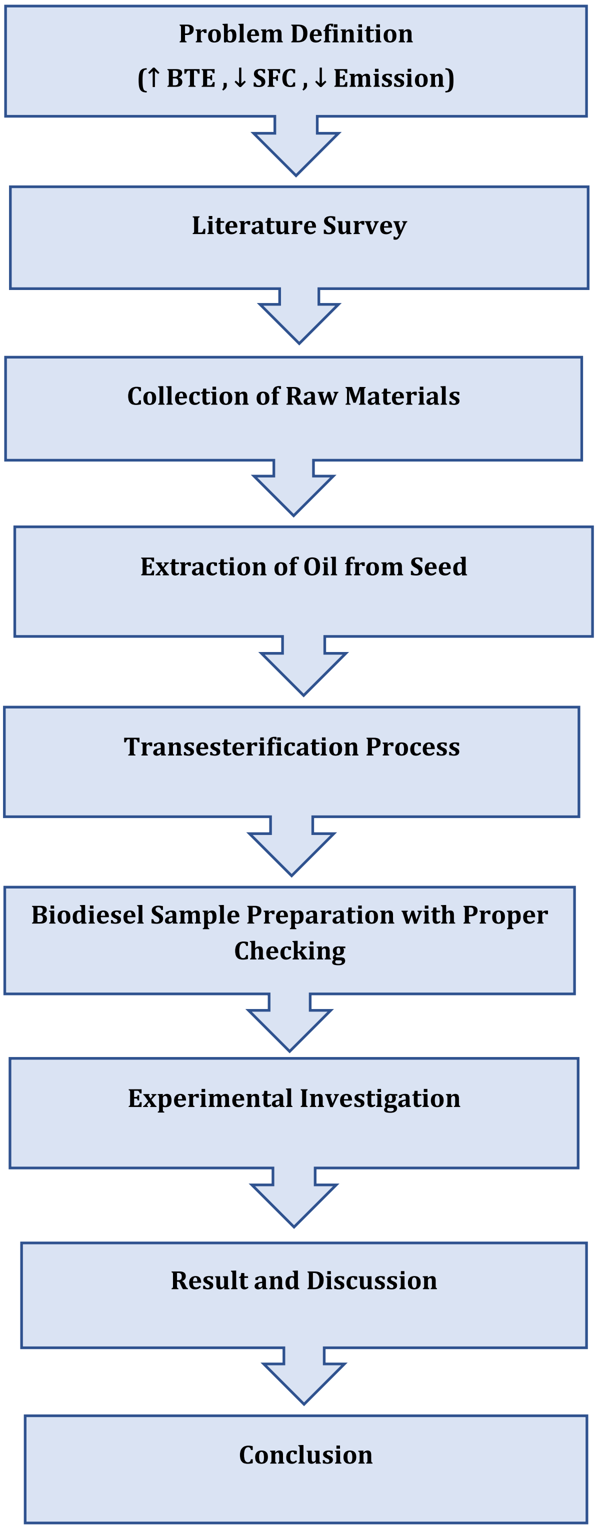
Fig. 1. Prunus Domestica

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. 2. hence requires good compression ignition properties.

Fig. 2. Diesel Fuel

2.2. Methodology



3. Transesterification Process

The process of transesterification involves in the reaction of a 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.

3.1. Transesterification

The process of allowance of non-edible oil to chemically react with alcohol is known as transesterification as shown in Fig. 3. 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.

3.2. Separation of Crude Glycerin

A separatory funnel as shown in Fig. 4. 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.

3.3. 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. 5. Water and biodiesel are two immiscible liquids that are separated into two distinct layers in a separating funnel.

3.4. Prunus Domestica Methyl Ester

Prunus Domestic oil is trans-esterified into neat Prunus Domestica Methyl Ester (PDME) as shown in Fig. 6.

Table-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. 3. Transesterification Crude

Fig. 4. Separation of Glycerin

Fig. 5. Biodiesel Washing

Fig. 6. Biodiesel (PDME)

4. Properties of Prunus Domestica Methyl Ester

4.1. Free Fatty Acid

Oils and fats are hydrolyzed 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.

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

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

FFA of Prunus Domestica oil = 0.846 %

4.2. 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.

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

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

Density for PDME = 0.884 g/cm^3

4.3. 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.

Viscosity = Time in seconds × 0.014 (diameter)

$$= 312 \times 0.014$$

Viscosity for PDME = 4.368 cSt

4.4. 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 Crusible = Weight of Empty Crusible + Weight of Sample

Weight of Empty Crusible = 22.60 g

Weight of Sample = 5.02 g

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

Moisture Content = $\frac{Weight\ of\ Sample\ with\ Crusible - Dry\ Weight}{Dry\ Weight}$ × 100 %

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

Moisture Content for PDME = 0.254 %

4.5. 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. 7.

Corrosion Test for PDME = 1b

Fig. 7. Corrosion Test

4.6. 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.

Calorific Value = $\frac{(Mw \times Cw + W) \times Tr}{Ms}$ – (En + Ec) cal/g

where,

Mw = Mass of water, g

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

W = Water equivalent, cal/°C

Tr = Temperature rise, °C

Ms = 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

4.7. 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

4.8. 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

4.9. 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

4.10. 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 flash point has been found.

Fire Point of PDME = 184 °C

5. Biodiesel Sample Preparation

Prunus Domestica Oil is produced from Prunus Domestica seed. The Methyl Ester 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-2: Sample Ratio

SAMPLE	DIESEL	PDME
S1	90%	10%
S2	80%	20%
S3	70%	30%
S4	60%	40%

6. Experimental Setup

6.1. 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. 8. **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. 8. 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
- PΘ-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. Provide tap with 1” BSP size connection

6.2. 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. 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.

Table -3: Engine Specifications

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

3. Conclusion

The Transesterification Process for Prunus Domestica Oil is done successfully and converted into Methyl Ester. Four Biodiesel samples has been prepared with proper ratios. 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.

References

[1] Górnaś, P., Rudzińska, M., & Soliven, A. (2017). Industrial by-products of plum Prunus domestica L. and Prunus cerasifera Ehrh. as potential biodiesel feedstock: Impact of variety. *Industrial Crops and Products*, *100*, 77–84.

[2] González-García, E., Marina, M. L., & García, M. C. (2014). Plum (Prunus Domestica L.) by-product as a new and cheap source of bioactive peptides:

Extraction method and peptides characterization. *Journal of Functional Foods*, *11*, 428–437.

[3] Mahmood, A., Ahmed, R., & Kosar, S. (2009). Phytochemical screening and biological activities of the oil components of Prunus domestica Linn. *Journal of Saudi Chemical Society*, *13*(3), 273–277.

[4] Niimi, J., Guixer, B., & Splivallo, R. (2020). Odour active compounds determined in the headspace of yellow and black plum wines (Prunus domestica L.). *LWT*, *130*, 109702.

[5] Popov, S. v, Ovodova, R. G., Golovchenko, V. v, Khramova, D. S., Markov, P. A., Smirnov, V. v, Shashkov, A. S., & Ovodov, Y. S. (2014). Pectic polysaccharides of the fresh plum Prunus domestica L. isolated with a simulated gastric fluid and their anti-inflammatory and antioxidant activities. *Food Chemistry*, *143*, 106–113.

[6] Kostić, M. D., Veličković, A. v, Joković, N. M., Stamenković, O. S., & Veljković, V. B. (2016). Optimization and kinetic modeling of esterification of the oil obtained from waste plum stones as a pretreatment step in biodiesel production. *Waste Management*, *48*, 619–629.

[7] Reidel, R. V. B., Cioni, P. L., & Pistelli, L. (2017). Volatile emission of different plant parts and fruit development from Italian cherry plums (Prunus cerasifera and P. cerasifera 'Pissardii'). *Biochemical Systematics and Ecology*, *75*, 10–17.

[8] Banoth, B. N., & Kadavakollu, K. R. (2016). Performance and emission of VCR-CI engine with palm kernel and eucalyptus blends. *Perspectives in Science*, *8*, 195–197.

[9] Bapu, B. R. R., Ganesan, S., Mahalingam, S., Abinash, J., & Bharathwaj, R. R. (2021). Analysis of emission reduction in VCR diesel engine using urea based catalytic convertor. *Materials Today: Proceedings*.

[10] Channapattana, S. v, Kantharaj, C., Shinde, V. S., Pawar, A. A., & Kamble, P. G. (2015). Emissions and performance evaluation of DI CI-VCR engine fuelled with honne oil methyl ester/diesel blends. *Energy Procedia*, *74*, 281–288.

[11] Chebattina, K. R. R., Vadapalli, S., Pathem, U. C., Sirasapalli, A., Lodagala, C. C., Billakurthi, S. M. S. R., Annamdevara, N. C. S., & Mohammad, A. R. (2021). H2O2 as fuel additive in bio-diesel for emission reduction and performance enhancement of variable compression ratio (VCR) diesel engine. *Materials Today: Proceedings*, *47*, 5697–5700.

[12] Ganesan, S., Mohanraj, M., Kiranpradeep, N., & Saran, R. S. G. (2021). Impact of Diisopropyl Ether on VCR diesel engine performance and emission with cashew shell oil using GRA approach. *Materials Today: Proceedings*.

[13] Ganesan, S., Mohanraj, M., Hemanandh, J., & Sankar, S. L. (2021). Experimental studies on VCR diesel engine characteristics using camelina and lemongrass oil biodiesel with butylated hydroxytoluene as a nano additive. *Materials Today: Proceedings*.

[14] Ganesan, S., Hemanandh, J., Venkatesan, S. P., Mahalingam, S., SenthilKumar, J., Padmanabhan, S., & Raj, M. M. (2021). Study of performance and emissions on VCR diesel engine fuelled with camphor oil and N-octanol as a nano additive. *Materials Today: Proceedings*.

[15] Ganesan, S., Mohanraj, M., Khushal, S., & Lokesh, S. (2021). Effect of tertiary butyl hydroquinone on diesel engine performance fuelled with lemon grass oil. *Materials Today: Proceedings*.

[16] Kumar, T. A., Chandramouli, R., & Mohanraj, T. (2015). A study on the performance and emission characteristics of esterified pinnai oil tested in VCR engine. *Ecotoxicology and Environmental Safety*, *121*, 51–56.

[17] Nishanth, S., Gunasekar, N., Nanthakumar, S., Prakash, R., & Kumar, T. S. (2021). Experimental investigation on performance and emission characteristics of VCR engine working with biodiesel and Diethyl Ether. *Materials Today: Proceedings*, *45*, 836–840.

[18] Prabakaran, S., Manimaran, R., Mohanraj, T., & Ravikumar, M. (2021). Performance analysis and emission characteristics of VCR diesel engine fuelled with algae biodiesel blends. *Materials Today: Proceedings*, *45*, 2784–2788.

[19] Sanjeevarao, K., Pavani, P. N. L., Suresh, C., & Kumar, P. A. (2021). Experimental investigation on VCR diesel engine fuelled with Al2O3 nanoparticles blended cottonseed biodiesel-diesel blends. *Materials Today: Proceedings*, *46*, 301–306.

[20] Prabhahar, M., Prakash, S., George, I., & Amith, K. K. (2020). Optimization of performance and emission characteristics of bio diesel fuelled VCR engine using Taguchi approach. *Materials Today: Proceedings*, *33*, 859–867.

[21] Hoeltgebaum, T., Simoni, R., & Martins, D. (2016). Reconfigurability of engines: A kinematic approach to variable compression ratio engines. *Mechanism and Machine Theory*, *96*, 308–322.

[22] Ganesan, S., Mohanraj, M., Guruprakaash, R., & Logeshwar, S. (2021). Impact of bamboo and castor composite catalytic converter on VCR diesel engine emission using Wheat germ oil. *Materials Today: Proceedings*.

[23] Ganesan, S., Mohanraj, M., Karthick, K., & Karthikeyan, M. (2021). Effects of Di Tertiary Butyl Ether fuel additives on diesel engine performance and emission characteristics using bio diesel. *Materials Today: Proceedings*.

[24] Karaman, V., Yildizhan, S., Ozcanli, M., & Serin, H. (2016). Calculation and optimizing of brake thermal efficiency of diesel engines based on theoretical diesel cycle parameters. *International Journal of Engineering Technologies IJET*, *2*(3), 100–104.

[25] Rai, R. K., & Sahoo, R. R. (2020). Taguchi-Grey method optimization of VCR engine performance and heat losses by using Shorea robusta biodiesel fuel. *Fuel*, *281*, 118399.

[26] Sharma, M., & Kaushal, R. (2021). Performance and exhaust emission analysis of a variable compression ratio (VCR) dual fuel CI engine fuelled with producer gas generated from pistachio shells. *Fuel*, *283*, 118924.

[27] Mahesh, R., Muthurajan, K. G., & Senthilkumar, A. (2020). Experimental investigation of Jujube seed oil in VCR for different nozzles. *Materials Today: Proceedings*, *33*, 1198–1205.

[28] Parida, M. K., Joardar, H., Rout, A. K., Routaray, I., & Mishra, B. P. (2019). Multiple response optimizations to improve performance and reduce emissions of Argemone Mexicana biodiesel-diesel blends in a VCR engine. *Applied Thermal Engineering*, *148*, 1454–1466.

[29] Singh, D., Sharma, D., Soni, S. L., Sharma, S., & Kumari, D. (2019). Chemical compositions, properties, and standards for different generation biodiesels: A review. *Fuel*, *253*, 60–71.

[30] Suresh, M., Jawahar, C. P., & Richard, A. (2018). A review on biodiesel production, combustion, performance, and emission characteristics of non-edible oils in variable compression ratio diesel engine using biodiesel and its blends. *Renewable and Sustainable Energy Reviews*, *92*, 38–49.