Co-published by
Institute of Fluid-Flow Machinery
Polish Academy of Sciences
Committee on Thermodynamics and Combustion
Polish Academy of Sciences

http://www.imp.gda.pl/archives-of-thermodynamics/

ARCHIVES OF THERMODYNAMICS

Comparative Analysis of Performance and Emission Characteristics of a CI Engine Fueled with Biodiesel and Pyrolytic Oil Derived from Cottonseed

A. Manikandan, R. Thamizhvel*, K. Kalaiselvan, S. Jassir Iqbal

IFET College of Engineering, Villupuram 605108, Tamil Nadu, India
*Corresponding author email: rthamizhvel@gmail.com

Received: 14.05.202; revised: 23.11.2025; accepted: 25.11.2025

Abstract

The increasing accumulation of biowaste in the environment, hence the need to investigate alternate energy sources has arisen due to the depletion of fossil fuel stocks. Eco-friendly, non-toxic, stable and biodegradable fuels with a high flash point and suitability for combustion are gaining attention. In this study, cottonseed biodiesel and pyrolytic oil were investigated as alternative fuels for compression ignition engines. Transesterification of cottonseed oil with sodium hydroxide as a catalyst and methyl alcohol as a reactant made biodiesel. Pyrolysis, a controlled thermal degradation process that is done in a safe environment, was used to make pyrolytic oil. A compression ignition engine was used to test the extracted biodiesel and pyrolytic oil after they were mixed with diesel in an 8:2 ratio. The performance and emission characteristics of ordinary diesel were compared with those of carbon monoxide, nitrogen oxides, hydrocarbons, smoke emissions, brake specific fuel consumption, brake thermal efficiency and other factors. The B20 blend showed 28.5% brake thermal efficiency, 0.32 kg/kWh brake specific fuel consumption, 22% lower CO, 19% lower HC, and 24% reduced smoke emissions than diesel, highlighting improved combustion and reduced emissions despite higher fuel consumption. According to the findings, cottonseed biodiesel is a suitable substitute fuel for compression ignition engines since it emits less CO and NO_x.

Keywords: Cotton seed; Bio diesel; Pyrolytic oil; Engine performance; Emission

Vol. 47(2026), No. 1, 71–78; doi: 10.24425/ather.2025.156853

Cite this manuscript as: Manikandan, A., Thamizhvel, R., Kalaiselvan, K., &, Iqbal, S.J. (2026). Comparative Analysis of Performance and Emission Characteristics of a CI Engine Fueled with Biodiesel and Pyrolytic Oil Derived from Cottonseed. *Archives of Thermodynamics*, 47(1), 71−78.

1. Introduction

Energy is a vital component for the progress and stability of modern societies. It powers industries, transportation, communication systems and domestic applications, thus serving as a foundation for economic growth and technological advancement. Broadly, energy resources are classified as renewable and non-renewable. Renewable sources such as solar, wind, tidal, and hydro power are sustainable and naturally replenished, while non-renewable sources, including coal, petroleum and natural gas, are finite and depleting with continued exploitation [1]. Historically, biomass, primarily in the form of wood, supplied nearly 70% of the world's energy demand. However, in recent decades, fossil fuels have replaced wood as the dominant energy source due to their high energy density, well-established extraction infrastructure and relatively low cost [1].

Despite these advantages, fossil fuels have serious drawbacks. Large amounts of greenhouse gases, including carbon dioxide (CO_2), nitrogen oxides (NO_x), and sulphur oxides (SO_x),

Nomenclature

Abbreviations and Acronyms

ASTM – American Society for Testing and Materials
B20 – biodiesel 20% and diesel 80%
BP – break power
BSFC – brake specific fuel consumption
BTE – brake thermal efficiency
CI – compression ignition
CO – carbon monoxide
D100 – diesel 100%
FAME – fatty acid methyl esters
FFA – free fatty acid
HC – hydrocarbons
IC – internal combustion
KOH – potassium hydroxide
NO_x – oxides of nitrogen
PID – proportional-integral-derivative (control system)
PY20 – pyrolytic oil 20% and diesel 80%
SO_x – oxides of sulphur
TGA – thermogravimetric analysis
VCR – variable compression ratio

which cause acid rain and contribute to global warming, are released as they burn. Additionally, carbon monoxide (CO) and particulate emissions degrade air quality and pose significant health risks [2].

The search for sustainable energy alternatives has accelerated due to the dual problems of climate change and depleting fossil fuel supplies. Among these, biofuels have gained considerable attention because they can be produced locally from renewable biomass, are biodegradable, and generally result in lower pollutant emissions compared to petroleum-based fuels. Edible and non-edible oils, used cooking oil, agricultural leftovers and animal fats are some of the sources from which biofuels can be made. Two major routes for liquid biofuel production are biodiesel generation via transesterification and bio-oil generation via pyrolysis. Fatty acid methyl esters (FAME) and glycerol are the products of the transesterification process, which produces biodiesel by combining triglycerides with an alcohol (often methanol) in the presence of a catalyst. Animal fats, vegetable oils and leftover cooking oil are just a few of the feedstocks that can be used in this process [3]. Because of their physical and chemical characteristics comparable to petroleum diesel, biodiesel made this way may be utilised in internal combustion (IC) engines without requiring any hardware changes [4]. Additionally, compared to fossil fuel, using biodiesel improves environmental performance by reducing emissions of CO, SO_x and unburned hydrocarbons.

Pyrolysis, in contrast, is a thermochemical conversion process where organic material is heated in the absence of oxygen, leading to the breakdown of macromolecules into smaller, energy-rich products. These products typically include pyrolytic oil (bio-oil), syngas and char. The process is highly versatile, capable of utilising a broad range of feedstocks such as agricultural residues, forestry waste, seeds and even certain plastics [5]. Pyrolytic oil is a liquid fuel that can be directly used in IC engines after suitable upgrading or blending, offering a renewable alternative to fossil fuels. Among the numerous biomass feedstocks available, cottonseed holds significant promise for both biodiesel and pyrolytic oil production.

Cotton is one of the most widely cultivated crops in India, and its seeds are generated in large quantities as a by-product of fibre extraction. Cottonseed oil is non-edible, has a relatively high oil content, and is available in abundance at low cost [6,7]. This makes it an attractive feedstock from both economic and sustainability perspectives. Importantly, utilising non-edible feedstocks like cottonseed avoids the “food versus fuel” conflict associated with biodiesel derived from edible oils. While biodiesel production from cottonseed oil is well documented in the literature, research on pyrolytic oil derived from cottonseed is comparatively limited. This presents an opportunity for further exploration. Pyrolytic oil production offers several advantages over biodiesel in certain contexts. For instance, when the feedstock has a high free fatty acid (FFA) content, biodiesel production requires a pre-treatment esterification step to avoid soap formation (saponification) and improve glycerol separation efficiency [15,16]. Pyrolysis, however, is not hindered by high FFA levels, which can simplify processing and reduce costs. Additionally, pyrolytic oil contains a broader spectrum of combustible compounds, potentially enhancing combustion efficiency under specific engine conditions. Therefore, developing pyrolytic oil from cottonseed could diversify renewable fuel production pathways and reduce the limitations associated with biodiesel. Before selecting and optimising a conversion process, a detailed characterisation of the feedstock is necessary. This is typically achieved through ultimate analysis and proximate analysis. Ultimate analysis quantifies the elemental composition, carbon, hydrogen, nitrogen, sulphur and ash content of the biomass, usually following the ASTM D3176-09 standard [8] (see Table 1). These values influence the fuel’s calorific value and combustion behaviour. Proximate analysis, often carried out according to ASTM D5142, determines moisture content, volatile matter, fixed carbon, and ash content. These parameters are critical for designing an efficient pyrolysis process and predicting product yield and quality.

Table 1. Ultimate and proximate analysis values.

Parameters	Ultimate (%)	ASTM standard	Parameters	Proximate (%)	ASTM standard
Oxygen	31.59	D3176	Moisture	4.51	D3173
Carbon	54.81	D3176	Volatile	79.37	D3175
Nitrogen	4.38	D3176	Ash	3.29	D3174
Hydrogen	8.42	D3176	Fixedcarbon	11.97	D3172

Thermogravimetric analysis (TGA) is another important tool in biomass characterisation, Fig. 1. TGA provides information on thermal stability and breakdown kinetics by measuring changes in sample mass as a function of temperature or time in a controlled environment [9]. It can identify the temperature ranges at which major decomposition phases occur, aiding in the selection of optimal pyrolysis operating conditions. In this study, TGA was conducted on a 10 mg sample of cottonseed using an SDT Q600 instrument in an inert atmosphere. The heating rate was set at 10°C/min, from ambient temperature up to 600°C. The results showed that the primary decomposition occurred between 320°C and 550°C, with a weight loss of approximately 71%, and a stable plateau was reached near 600°C. The maximum decomposition rate was observed around 400°C [10,11]. These findings suggest that the most suitable pyrolysis temperature range for cottonseed lies between 300°C and 550°C, balancing high oil yield with controlled energy input.

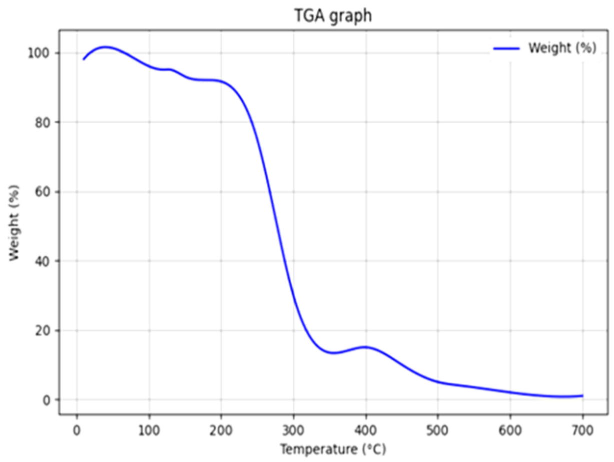

Fig. 1. Thermogravimetric analysis.

For the pyrolysis experiments, cotton seeds were procured from a local market in Villupuram, Tamil Nadu, India [12,13]. Prior to processing, the seeds were dried in an oven at 105°C to remove residual humidity. They were then crushed using a chopper, and oil was extracted using 0.8 L of n-hexane in a water bath for six hours. A rotating evaporator operating under vacuum at 45°C was used to extract the solvent [14]. The FFA content of the extracted oil plays a decisive role in determining its conversion pathway. Oils with FFA content below 2% can be processed directly through transesterification, while those with FFA levels above this threshold require pre-treatment via esterification to reduce FFA and prevent saponification [15,16]. This requirement underscores one of the key benefits of pyrolysis, its ability to handle high-FFA feedstocks without additional processing steps. From a broader perspective, producing pyrolytic oil from cottonseed aligns with multiple sustainability goals. It enables the valorisation of agricultural byproducts, reduces reliance on finite fossil fuels, and supports decentralised energy production, particularly in rural areas where cotton cultivation is widespread. Additionally, pyrolytic oil can be co-fired with petroleum diesel or blended with upgraded bio-oils to meet specific performance and emissions targets, offering flexibility in fuel applications.

The current study is on employing a semi-batch reactor to produce pyrolytic oil from cottonseed, guided by detailed feedstock characterisation through ultimate, proximate, and thermogravimetric analyses. By investigating optimal pyrolysis operating conditions and evaluating the resulting fuel's properties. This work adds to the expanding literature of research on non-food, alternative fuels made from biomass for internal combustion engines. The insights gained are expected to facilitate the development of scalable, cost-effective and environmentally sustainable fuel production processes that can be adapted to regions with abundant cotton cultivation and limited access to petroleum-based fuels.

2. Materials and methods

Cotton is one of the most important agricultural crops in India, serving as the largest source of natural fibre for the textile industry. The optimal temperature range for cotton cultivation in India lies between 25°C and 35°C. A cotton boll typically consists of 35–40% fibre and approximately 60% seed. While the primary economic value of cotton lies in its fibre, the seed is also an important raw material in the edible oil and biofuel industries. Cottonseed oil has been utilised in biodiesel production due to its calorific value and suitability for transesterification processes [17].

However, the relatively low oil content of cottonseed, generally between 17% and 24%, limits the quantity of oil available for commercial use. India, as the world's largest cotton producer, yields an average of about 5800 thousand metric tonnes of cotton annually. Globally, cottonseed production reaches approximately 40 million tonnes, with India contributing a major share, followed by China, the United States, Brazil, Pakistan, and Uzbekistan [18]. Cottonseed is a traditional oilseed crop in India, with around 85% of the harvested seeds processed for oil extraction, while roughly 20% are used as animal feed [19]. The oil extracted from cottonseed can be converted into bio-oil and biodiesel through processes such as pyrolysis and transesterification. Because it is sustainable and has a similar energy content to fossil fuels, bio-oil in particular presents a possible substitute. Cottonseed oil and methanol combine chemically to produce biodiesel when a potent base catalyst, such as potassium hydroxide, is present. This transesterification reaction converts the triglycerides in the oil into methyl esters, the main components of biodiesel, and glycerol as a by-product.

2.1. Preparation of biodiesel

The transesterification was dispensed employing with 1 litre flat bottomed beaker, thermometer, mechanical stirrer, heater and conical shaped beaker. Initially, 500 ml of cottonseed oil is heated on a heating plate to the desired temperature of 60°C, whereas methoxide solutions of 150 ml of methanol and potassium hydroxide KOH were appended to the oil as a catalyst, and the catalyst added solution was stirred constantly with a stirrer at 600 rpm. The experiment was conducted again with raw oil for the whole conversion of the oil into FAMEs. Once the reaction was completed, the solution was moved into a conical formed beaker to simmer down for 10−15 h. The resulting bio-oil is formed at the upper layer, while the bottom is made up of glycerin mixed with other components. The product is washed with a prepared solution to remove water, alcohol and residual catalyst present in the mixture [20]. The flow of cottonseed preparation is shown in Fig. 2.

Fig. 2. Flow of cottonseed preparation.

2.2. Preparation of pyrolytic oil

The experimental setup consists of a pyrolysis reactor, ceramic band heater, proportional-integral-derivative (PID) controller, thermocouple, monitor, condenser and oil collector. The PID controller is used to maintain the temperature of the reactor. The cottonseed is directly fed to the reactor [21]. According to data from thermogravimetric analysis, the pyrolysis temperature is selected between 300−450°C. A semi batch type reactor is used to do this experiment, and the ceramic band heater is vertically inserted in it. The PID controller is used to maintain the constant temperature of the reactor [22]. 250 g of cotton seed has been feed inside the reactor. While heating the reactor, the vapour has been generated inside the reactor and condensed in the water cooled condenser. After passing through the condenser, the pyrolytic oil has been collected. The photographic view of the pyrolytic setup is shown in Fig. 3, and Fig. 4 shows a sample of pyrolytic oil.

Fig. 3. Pyrolytic experimental setup.

Fig. 4. Cotton seed pyrolytic oil.

The fuel properties of cottonseed biodiesel blend of B20 and cottonseed pyrolytic oil blend of PY20 are shown in Table 2. The measured fuel properties show that B20 biodiesel and PY20 pyrolytic oil have slightly higher viscosity and density than diesel. While their heating values are marginally lower, both exhibit higher cetane indices and significantly elevated flash and fire points, indicating improved ignition quality and enhanced safety in handling and storage.

Table 2. Properties of diesel, biodiesel and cotton seed pyrolytic oil.

Property	Diesel	Biodiesel (B20)	Pyrolytic oil (PY20)	ASTM Standard
Viscosity (cSt) at 40ºC	3.1	3.6	3.6	D445
Density at 15ºC	830	890	920	D4052
Heating value (kJ/kg)	42 000	40 000	39 278	D240
Cetane index	46	50.4	52	D976
Flash point (ºC)	58	120	150	D93 (Pensky–Martens)
Fire point (ºC)	62	135	175	D92 (Cleveland Open Cup)

3. Experimentation

Using a variable compression ratio (VCR) direct injection (DI) diesel engine and fuels such as diesel, biodiesel and pyrolytic oil, the current study is conducted, and the experimental setup is shown in Fig. 5. The engine's working state is set by the fuel and air flow, exhaust gas temperature, and the required loads and measurement equipment.

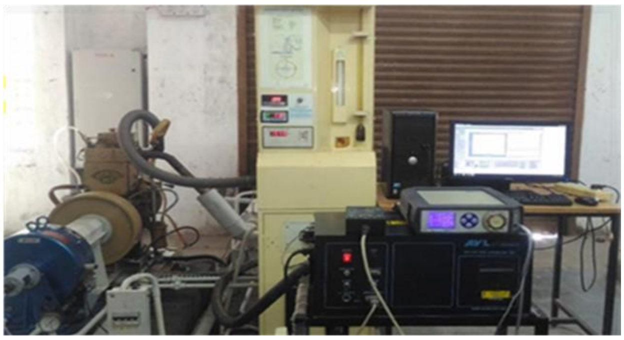

Fig. 5. Compression ignition (CI) engine experimental setup.

The experiment is carried out using different loads, including 0%, 20%, 40%, 60%, 80% and the maximum load. This investigative procedure uses an eddy current dynamometer to alter the load. Thermocouples are used to measure exhaust gas temperature, while emissions such as hydrocarbons (HC), carbon monoxide (CO), smoke and nitrogen oxides (NO_x) are measured using AVL smoke meters and five-gas analysers [23,27]. We quantify diesel engine CO, HC, CO_2, NO_x emissions, as well as brake-specific fuel consumption and thermal efficiency [24,28].

4. Results and discussion

The performance and emission characteristics of the B20 cotton seed biodiesel oil and PY20 cotton seed pyrolytic oil, which are initially utilised independently as fuel in CI engines, are covered here. Efficiency-based load performance graphs, BSFC, and CO, NO_x and HC load emission graphs are displayed.

4.1. Effect on brake specific fuel consumption

The differences in BSFC with BP for diesel D100, B20 and PYRO oil (PY20) blends are shown in Fig. 6. The bio-oil shows higher BSFC compared to diesel. The key factor behind the rise of BSFC is the reduced calorific value of bio-oil, which requires a higher volume of fuel to produce the same power.

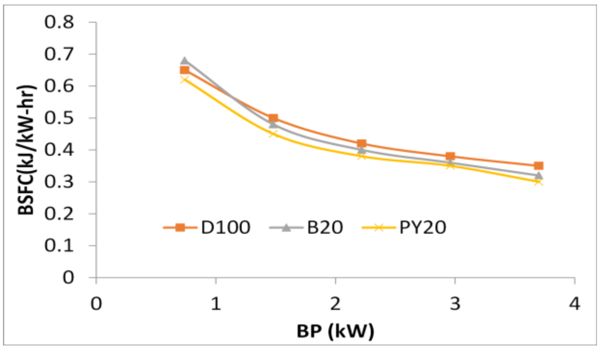

Fig. 6. BP versus BSFC of B20, PY20 and diesel.

4.2. Effect on brake thermal efficiency

Figure 7 shows the differences in brake thermal efficiency (BTE) with brake power (BP) for D100, B20 and PY20 fuels. As the load increases, BTE decreases, which can be attributed to the occurrence of water in the fuel. The results indicate that the B20 blend exhibits better performance compared to the other fuels.

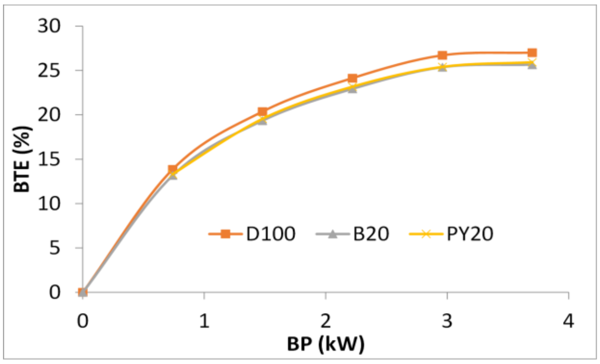

Fig. 7. BP versus BTE of B20, PY20 and diesel.

The higher BTE of B20 and lower BSFC of pyrolytic oil blends are attributed to differences in calorific value and combustion efficiency. Additionally, the lower viscosity of bio-oils compared to diesel facilitates better atomization, further contributing to the improved BTE [25].

4.3. Effect on carbon monoxide

A rich air-fuel combination or inadequate oxygen availability are the main causes of carbon monoxide (CO) emission, a byproduct of incomplete combustion.

The relationship between CO emissions and braking power (BP) for B20, pyrolytic oil (PY20) and diesel is shown in Fig. 8. Because the temperature of the cylinder gas rises with increased load, the data show that CO emissions drop as the braking power increases. The B20 blend had the lowest CO emissions of all the evaluated fuels. An increased oxygen concentration, which encourages the oxidation of carbon atoms and improves combustion efficiency, is the cause of this decrease.

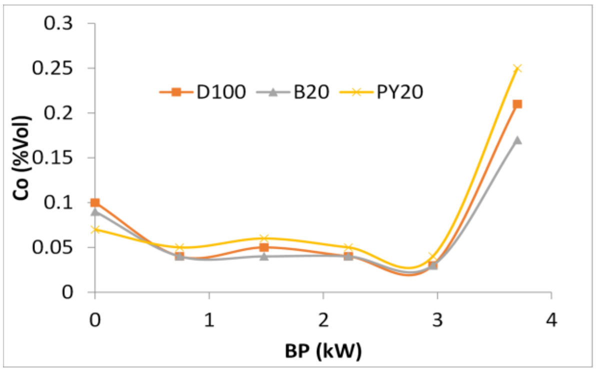

Fig. 8. Variation of CO with brake power.

4.4. Exhalation of oxides of nitrogen

Figure 9 illustrates the difference in NO_x emissions with mechanical power for B20, pyrolytic oil (PY20) and diesel. The results show fluctuations in NO_x emissions across different fuels as brake power (BP) increases. With the increase in cylinder gas temperature, NO_x emissions tend to decrease with increasing load. Among the tested fuels, the B20 biodiesel blend exhibits lower NO_x emissions with respect to diesel. This decrease can be attributed to the presence of moisture in bio-oil, which helps lower the in-cylinder temperature, thereby reducing NO_x formation [26].

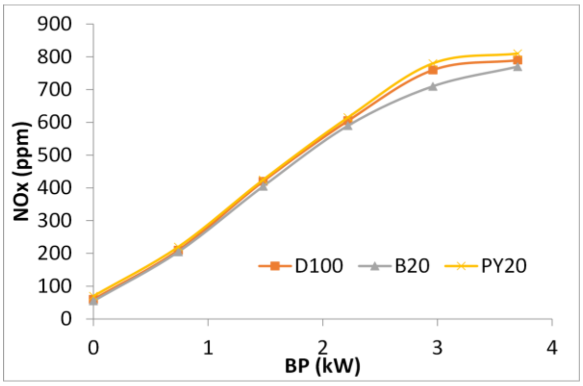

Fig. 9. Variation of NO_x with brake power.

4.5. Effect on hydrocarbon

Figure 10 presents the difference in hydrocarbon (HC) emissions with brake power (BP) for B20, pyrolytic oil (PY20) and diesel. The results indicate that HC emissions reduce as the brake power increases. Among the tested fuels, the B20 biodiesel blend exhibits the lowest HC emissions [27]. This decrease can be attributed to the enhanced combustion efficiency of the B20 blend compared to the other fuels, resulting in more complete fuel oxidation and lower unburned hydrocarbon emissions.

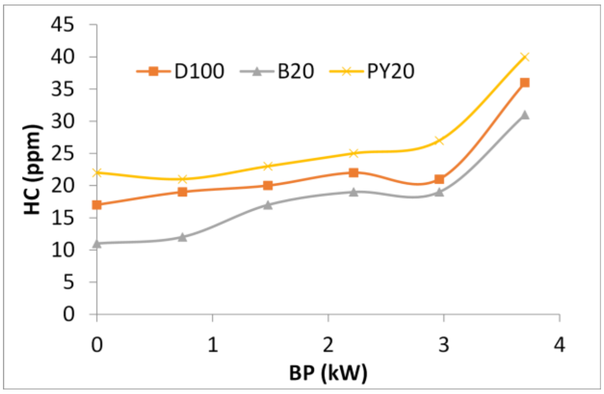

Fig. 10. Fluctuation of HC with brake power.

4.6. Exhaust smoke characteristics

Figure 11 illustrates the difference in smoke emissions with brake power (BP) for diesel, B20 and pyrolytic oil (PY20). The results show that smoke emissions decrease as the brake power increases. Among the tested fuels, the B20 biodiesel blend exhibits the lowest smoke emissions. This reduction is attributed to the quenching result of water in the biofuel, which enhances combustion efficiency, leading to reduced particulate formation compared to the other tested fuels.

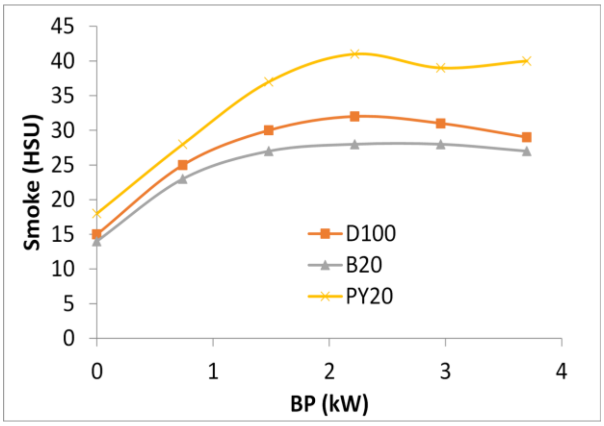

Fig. 11. Variation of smoke with brake power

4.7. Cylinder pressure

Figure 12 illustrates cylinder pressure changes with crank angle for diesel (D100), biodiesel blend (B20), and pyrolytic oil blend (PY20). All fuels display nearly the same pressure profile, with the highest pressure occurring close to the top dead centre. PY20 records a marginally higher peak pressure, followed by B20, while D100 shows the lowest. This outcome suggests that both biofuels provide effective combustion performance comparable to conventional diesel.

4.8. Heat release rate

Figure 13 presents the heat release rate (HRR) versus crank angle for D100, B20 and PY20 fuels. D100 exhibits a sharp peak around top dead centre, reflecting a higher combustion intensity. B20 also shows a notable peak, but slightly lower than for D100. PY20 demonstrates a smaller and broader profile, indicating slower combustion and reduced HRR. Overall, the comparison highlights the stronger performance of diesel and biodiesel blends compared to pyrolysed fuel.

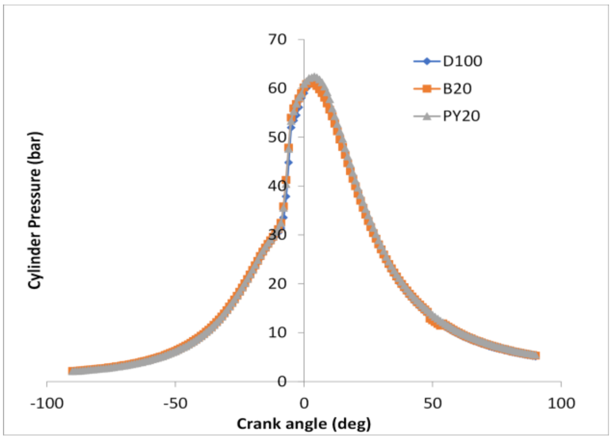

Fig. 12. Cylinder pressure vs. crank angle.

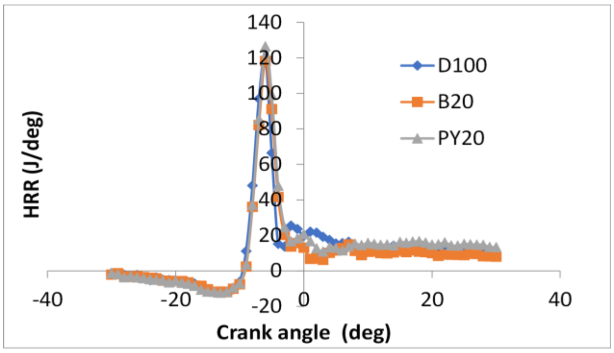

Fig. 13. HRR vs. crank angle.

The similarity in emission trends is attributed to the oxygenated nature of both biodiesel and pyrolytic oil, which promotes more complete combustion. Additionally, higher in-cylinder temperatures influenced by the fuels calorific values have led to simultaneous changes in NO_x along with CO, HC and smoke.

5. Conclusions

In this study, cottonseed oil was successfully converted into biodiesel and pyrolytic oil using transesterification and pyrolysis, respectively. Performance and emission characteristics of a CI engine were analysed using diesel (D100), biodiesel (B20) and pyrolytic oil (PY20) blends under varying loads and compression ratios:

1. Brake thermal efficiency (BTE): BTE of the B20 blend was lower than that of diesel at all loads, primarily due to the presence of moisture and the inherent properties of cottonseed oil. At full load, BTE for B20 was 28.5%, while for diesel, it was 30.2%.
2. Brake specific fuel consumption (BSFC): BSFC of B20 was higher than that of diesel, attributed to its lower heating

value. At full load, BSFC for B20 was 0.32 kg/kWh, compared to 0.29 kg/kWh for diesel, indicating that the same amount of power is produced, and more fuel is needed.

3. Carbon monoxide (CO): B20 exhibited a 22% reduction in CO emissions compared to diesel because biodiesel has a greater oxygen concentration, which improves combustion efficiency.
4. Hydrocarbons (HC): B20 showed a 19% lower HC emission than that of diesel, further demonstrating improved combustion characteristics.
5. Smoke emissions: In B20, there is a 24% reduction in smoke emissions, attributed to the quenching effect of water in biodiesel.
6. Cylinder pressure: The in-cylinder pressure traces of B20 followed a similar pattern to that of diesel, with the peak pressure occurring near the top dead centre. However, B20 exhibited a slightly higher peak pressure, suggesting better premixed combustion due to the oxygenated nature of biodiesel.
7. Heat release rate (HRR): HRR for B20 was lower than that of diesel in the premixed combustion phase, but showed a smoother diffusion phase. This indicates a slower energy release, attributed to the higher viscosity and lower volatility of biodiesel.

Overall, the study demonstrates that B20 biodiesel blend is a viable alternative fuel with reduced emissions and acceptable engine performance, making it a promising option for sustainable energy applications. However, further optimisation in terms of heating value and moisture content can improve its efficiency.

References

[1] Agarwal, A.K., Park, S., Dhar, A., Lee, C.S., Park, S., Gupta, T., & Gupta, N.K. (2018). Review of experimental and computational studies on spray, combustion, performance, and emission characteristics of biodiesel fueled engines. *Journal of Energy Resources Technology*, 140(12), 120801. doi: 10.1115/1.4040584

[2] Ahmed, M.M., Pali, H.S., & Khan, M.M. (2024). Allometry of nanoparticles in diesel-biodiesel blends for CI engine performance, combustion and emissions. *Archives of Thermodynamics*, 45(1), 99–108. doi: 10.24425/ather.2024.150442

[3] Singh, A.K., Pali, H.S., & Khan, M.M. (2024). Experimental investigations of CI engine performance using ternary blends of n-butanol/biodiesel/diesel and n-octanol/biodiesel/diesel. *Archives of Thermodynamics*, 45(1), 109–118. doi: 10.24425/ather.2024.150443

[4] Dubba, S.K., Pisini, R., Kelli, D., Bammidi, R., Vanam, J.P., & Turali, N. (2025). Experimental Investigation of the Performance and Emission Characteristics of Cotton Seed Biodiesel/Diesel Blends with Titanium Dioxide Nanoparticles. *Archives of Thermodynamics*, 46(3) 151−161. doi: 10.24425/ather.2025.156587

[5] Haq, M., Jafry, A., Ahmad, S., Cheema, T., Ansari, M., & Abbas, N. (2022). Recent advances in fuel additives and their spray characteristics for Diesel-Based blends. *Energies*, 15(19), 7281. doi: 10.3390/en15197281

[6] Krishna, M.M., Rao, N.D.P., Prasad, B.A., & Murthy, P. (2014). Comparative Performance with Different Versions of Low Heat Rejection Combustion Chambers with Crude Rice Bran Oil. *Archive of Mechanical Engineering*, 61(4), 627–651. doi: 10.2478/meceng-2014-0036

[7] Ramalingam, S., Rajkumar, T., Subramanian, S., & Palani, S. (2024). Investigation of combustion, emission, and performance parameters of a natural antioxidant additives using hydrogen and biodiesel as dual fuel in CI engine operation. *International Journal of Hydrogen Energy*, 110, 44–54. doi: 10.1016/j.ijhydene.2025.01.425

[8] Thamizhvel, R., Sethuraman, N., Sakthivel, M., & Prabhakaran, R. (2020). Experimental investigation of diesel engine by using paper cup waste as the producer gas with help of down-draft gasifier. *International Conference on Recent Developments in Material Science and Applications*, 25–26 September, Chennai, India. *IOP Conference Series: Materials Science and Engineering*, 988, 012015. doi: 10.1088/1757-899X/988/1/012015

[9] Senthil, R., Thamizhvel, R., & Sudagar, S. (2024). A comparative analysis of pyrolytic oil from medical waste and its suitability as fuel in a Compression Ignition engine. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 46(1), 2040–2058. doi: 10.1080/15567036.2024.2302369

[10] Thamizhvel, R., Vinodraj, S., & Sethuraman, N. (2020). Performance on biomass gasification of groundnutshell in down draft fixed bed reacter. *International Journal of Mechanical and Production Engineering Research and Development*, 10(3), 4963–4970, doi: 10.24247/IJMPERDJUN2020470

[11] Thamizhvel, R., Naveen Raj, S, & Krishna Raj, S. (2025). Production Of Oil From Plastic Waste Through Thermal Degradation Process. *Turkish Journal of Engineering*, 9(3), 409−416. doi: 10.31127/tuje.1535115

[12] Thamizhvel, R., Manikandan, A., Praveen Kumar, S., & Sivasankaran, S. (2023). Potential Use of Cathode Ray Tube as an Abrasive Particle in Abrasive Jet Machine. *2023 International Conference on Energy, Materials and Communication Engineering*, 14−15 December, Madurai, India. doi: 10.1109/ICEMCE57940.2023.10434107

[13] Thamizhvel, R., Suryavarman, K., Velmurugan, V., & Sethuraman, N. (2021). Comparative study of gasification and pyrolysis derived from coconut shell on the performance and emission of CI engine. *Materials today: Proceedings*, 47(4), 978–983. doi: 10.1016/j.matpr.2021.05.350

[14] Sethuraman, N., Surya Varman, K., Venkatakrishnan, R., & Thamizhvel, R. (2021). An experimental investigation of crude glycerol into useful products by using IC engine in dual fuel mode. *Materials today: Proceedings*, 44, 3914–3918. doi: 10.1016/j.matpr.2021.02.160

[15] Kadupu, R., Subramanian, P., Kaliyamoorthy, A., Thamizhvel, R., Subramanian, S., & Rajendran, S. (2024). Assessing the thermal insulation properties of thermoplastic bricks for energy-efficient building solutions. *Matéria (Rio de Janeiro)*, 29(4). doi: 10.1590/1517-7076-rmat-2024-0583

[16] Ramalingam, S., Thamizhvel, R., Sudagar, S., & Silambarasan, R. (2023). Production of third generation bio-fuel through thermal cracking process by utilizing Covid-19 plastic wastes, *Materials Today: Proceedings*, 72(3), 1618-1623. doi: 10.1016/j.matpr.2022.09.430

[17] Sethuraman, N., Karthikeyan, D., Vinodraj, S., Thamizhvel, R., & Kumarasamy, G. (2023). Performance and Emission Characteristics on CI Engine by Using Waste Cooking Oil and Waste Transformer Oil as Substitute Fuel with Coconut Shell as a Catalyst. *Materials Today: Proceedings*, 72(4), 2469–2475. doi: 10.1016/j.matpr.2022.09.457

[18] Thamizhvel, R., Molly Irine, G.S., Vaithianathan, N., & Ganesh, M. (2023). Evaluating the performance and emission characteristics of jackfruit seed as bio-oil in CI engine. *Materials Today: Proceedings*. doi: 10.1016/j.matpr.2023.08.100

[19] Mikulski, M., Ambrosewicz-Walacik, M., Hunicz, J., & Nitkiewicz, S. (2021). Combustion engine applications of waste tyre pyrolytic oil. *Progress in Energy and Combustion Science*, 85, 100915. doi: 10.1016/j.pecs.2021.100915

[20] Patel, H., Rajai, V., Das, P., Charola, S., Mudgal, A., & Maiti, S. (2018). Study of Jatropha curcas shell bio-oil-diesel blend in VCR CI engine using RSM. *Renewable Energy*, 122, 310–322. doi: 10.1016/j.renene.2018.01.071

[21] Prabhahar, R.S.S., Nagaraj, P., & Jeyasubramanian, K. (2020). Promotion of bio oil, H2 gas from the pyrolysis of rice husk assisted with nano silver catalyst and utilization of bio oil blend in CI engine. *International Journal of Hydrogen Energy*, 45(33), 16355–16371. doi: 10.1016/j.ijhydene.2020.04.123

[22] Sudagar, S. (2022). Analysis of Different Production Methods of Biodiesel from Pyrolytic Oil and its Influence on CI Engine. Available at *SSRN.* doi: 10.2139/ssrn.4054241

[23] Syu, J., Chang, Y., Tseng, C., Yan, Y., Chang, Y., Chen, C., & Lin, W. (2014). Effects of water-emulsified fuel on a diesel engine generator's thermal efficiency and exhaust. *Journal of the Air and Waste Management Association*, 64(8), 970–978. doi: 10.1080/10962247.2014.905508

[24] Thanigaivelan, V., Singh, S.K., Rajhans, S.S., & Jagtap, A.S. (2021). Influence of nano additives with cashew nut shell bio-oil in CI diesel engine. *International Conference on Advances in Thermal Engineering and Applications*, 19-20 March, Tamil Nadu, India. *Journal of Physics Conference Series*, 2054(1), 012018. doi: 10.1088/1742-6596/2054/1/012018

[25] Narayanan, S., Subramanian, V., Rajkumar, T., & Nadarajan, V. (2025). Machine Learning Optimisation of CI Engine Characteristics with WSA Algorithm and Prosopis Juliflora Biofuel. *Archives of Thermodynamics*, 46(4), 117–125. doi: 10.24425/ather.2025.156842

[26] Venu, H., & Madhavan, V. (2016). Influence of diethyl ether (DEE) addition in ethanol-biodiesel-diesel (EBD) and methanol-biodiesel-diesel (MBD) blends in a diesel engine. *Fuel*, 189, 377–390. doi: 10.1016/j.fuel.2016.10.101

[27] Senthil, R., Thamizhvel, R., Sudagar, S., & Bahuruteen, A.A.H. (2025). Production of high grade fuels from biomass and waste plastics and its influence in a CI engine. *Polymer Bulletin*, 82, 6095−6114. doi: 10.1007/s00289-025-05740-4

[28] Ramalingam, S., Rajkumar, T., Subramanian, S., & Palani, S. (2024). Investigation of combustion, emission, and performance parameters of a natural antioxidant additives using hydrogen and biodiesel as dual fuel in CI engine operation. *International Journal of Hydrogen Energy*, 110, 44–54. doi: 10.1016/j.ijhydene.2025.01.425