World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Review Article)

Check for updates

Investigating the Synergistic Effects of Biodiesel and Fischer-Tropsch Diesel in Advanced Fuel Blends

Pradeep K V *

Lecturer-Senior Scale, Department of Automobile Engineering, Smt. L.V. Government Polytechnic, Hassan-573201, Karnataka, India.

World Journal of Advanced Research and Reviews, 2020, 08(02), 444–450

Publication history: Received on 18 November 2020; revised on 26 November 2020; accepted on 30 November 2020

Article DOI: https://doi.org/10.30574/wjarr.2020.8.2.0441

Abstract

The global push for sustainable energy has intensified the search for cleaner alternatives to petroleum diesel. Among the most promising are Fatty Acid Methyl Est ester (FAME) biodiesel and Fischer-Tropsch (F-T) diesel, each possessing distinct advantages and limitations. Biodiesel offers renewability and superior lubricity but suffers from poor oxidative stability, higher NOx emissions, and cold flow issues. Conversely, F-T diesel, derived from gas-to-liquid (GTL) or biomass-to-liquid (BTL) processes, exhibits excellent cetane number, ultra-low sulfur and aromatic content, and reduced emissions but lacks lubricity and can be cost-prohibitive. This paper investigates the hypothesis that blending these two fuels can produce synergistic effects, resulting in an advanced fuel blend that leverages the strengths of each component while mitigating their individual weaknesses. Through an analysis of pre-2019 literature, this research examines the physicochemical properties, combustion characteristics, emission profiles, and material compatibility of F-T diesel/biodiesel blends. The findings indicate that such blends often demonstrate non-linear, synergistic improvements in key parameters such as oxidation stability, lubricity, and the emissions trade-off between nitrogen oxides (NOx) and particulate matter (PM), presenting a viable pathway towards a more sustainable and high-performance diesel fuel.

Keywords: Biodiesel; Fischer-Tropsch Diesel; Fuel Blends; Synergistic Effects; Emissions, Combustion

1. Introduction

The diesel engine remains a cornerstone of global transportation and industry due to its high efficiency, durability, and torque. However, its environmental impact, particularly emissions of particulate matter (PM), nitrogen oxides (NOx), and greenhouse gases, has driven stringent regulations and spurred research into cleaner alternative fuels. Two of the most technologically mature and promising alternatives are biodiesel (FAME) and Fischer-Tropsch (F-T) diesel. Biodiesel, produced via transesterification of vegetable oils or animal fats, is renewable, biodegradable, and boasts significant lifecycle carbon dioxide reduction. Fischer-Tropsch diesel, synthesized from syngas (derived from natural gas, coal, or biomass) through the Fischer-Tropic process, is characterized by its paraffinic nature, near-zero sulfur content, and absence of aromatics.

Despite their benefits, both fuels face significant barriers to widespread adoption as pure replacements (B100 or FT100). Biodiesel's drawbacks include inferior oxidative stability, leading to potential fuel degradation and deposit formation; poor cold flow properties (high cloud and pour points); and a well-documented tendency to increase NOx emissions in certain engine types. F-T diesel, while having excellent combustion properties, suffers from inherently poor lubricity, which can lead to increased wear in fuel injection systems designed for the lubricating properties of

* Corresponding author: Pradeep K V

conventional diesel. Furthermore, the economic viability of large-scale F-T production, especially from biomass (BTL), remains a challenge.

The concept of blending alternative fuels to create superior formulations is well-established. Blending biodiesel with petroleum diesel (e.g., B20) is a common practice to improve lubricity and reduce emissions while managing material compatibility issues. Similarly, F-T diesel is often blended with conventional diesel to leverage its clean-burning attributes. The logical progression is to explore the blend of these two alternative fuels directly, hypothesizing that their complementary properties could yield synergistic benefits—where the combined effect is greater than the sum of their individual effects.

This paper posits that F-T diesel/biodiesel blends represent a next-generation fuel strategy. The high cetane and purity of F-T diesel could mitigate biodiesel's stability and NOx emission issues, while the inherent lubricity of biodiesel could solve the lubricity deficit of F-T diesel. This combination has the potential to achieve an optimal balance between renewable content, fuel performance, engine compatibility, and overall emissions reduction.

The objective of this research is to systematically investigate these potential synergistic effects by reviewing and analyzing scientific literature published prior to 2019. The investigation will focus on the blend's fundamental properties, engine performance, emission characteristics, and durability implications, providing a comprehensive assessment of its viability as an advanced fuel blend.

Table 1 Key Characteristics of Neat Biodiesel and Neat Fischer-Tropsch Diesel

Property	**Biodiesel (FAME)**	**Fischer-Tropsch Diesel**	**Conventional Diesel (Baseline)**
Production Pathway	Transesterification of triglycerides	Fischer-Tropsch synthesis from syngas	Crude oil refining
Chemical Composition	Mixture of fatty acid methyl esters	Linear and branched paraffins	Mix of paraffins, naphthenes, aromatics
Sulfur Content	Very Low (~0 ppm)	Virtually 0 ppm	<10-15 ppm (ULSD)
Aromatic Content	0%	~0%	20-30%
Renewability	Yes	Potentially (if BTL)	No
Lubricity	Excellent	Very Poor	Good (with additives)

2. Physicochemical Properties and Blend Synergy

The physicochemical properties of a fuel blend are not always simple linear averages of its components; non-linear, synergistic interactions can occur. For F-T diesel/biodiesel blends, these interactions profoundly affect critical properties like lubricity, cold flow, stability, and energy content, determining the blend's practical feasibility. Understanding these properties is the first step in evaluating the blend's overall performance.

Lubricity is arguably the most clear-cut example of synergy. F-T diesel, consisting almost entirely of saturated paraffins, provides very little lubrication, leading to excessive wear in the high-precision components of fuel injection systems. Biodiesel, with its polar ester molecules, adsorbs strongly onto metal surfaces, providing excellent lubricity even at low blend percentages. Studies have shown that adding even small amounts of biodiesel (1-2%) to F-T diesel restores lubricity to levels that meet or exceed specifications such as ASTM D975 and EN 590. This effect is highly non-linear, demonstrating a classic synergistic interaction where a small input of biodiesel yields a disproportionately large improvement in the blend's lubricity.

Conversely, the cold flow properties of the blend present a challenge rather than a synergy. Both fuels have inherent cold flow issues, but for different reasons. F-T diesel's high n-paraffin content leads to the formation of large wax crystals at low temperatures, plugging fuel filters. Biodiesel typically has a higher cloud point (CP) and pour point (PP) than conventional diesel due to the saturation level of its parent feedstock (e.g., high for palm oil, lower for rapeseed oil). Blending them generally results in a weighted-average deterioration of cold flow properties. The cloud point of the blend often follows a linear or near-linear trajectory between the two pure components, meaning the blend can have worse cold flow than either individual fuel if one component is significantly poorer. This necessitates the use of cold flow improver additives for operation in temperate climates.

Oxidative stability is an area where F-T diesel can beneficially influence the blend. Biodiesel is prone to oxidation due to the unsaturation in its fatty acid chains, leading to acid formation and gum deposits. F-T diesel, being fully saturated and free of reactive double bonds, is extremely stable. Blending F-T diesel with biodiesel effectively dilutes the concentration of unstable components, increasing the induction period of the blend as measured by the Rancimat method (EN 14112). While this is often a linear dilution effect, the absence of catalysts or impurities in F-T diesel may provide a more stable environment, potentially offering a slight synergistic stabilization beyond mere dilution.

The cetane number (CN), a measure of ignition quality, is another property where the blend excels. Both F-T diesel and biodiesel have high cetane numbers (often >70 for F-T and 50-60 for biodiesel) compared to conventional diesel (40-55). The cetane number of their blends typically follows a linear blending law, resulting in very high cetane numbers that promote smoother combustion, reduced noise, and lower cold-start emissions. The energy density of the blend, however, is slightly lower than that of conventional diesel due to the lower energy content of oxygenated biodiesel, but it is improved compared to neat biodiesel by the addition of high-energy-density F-T paraffins.

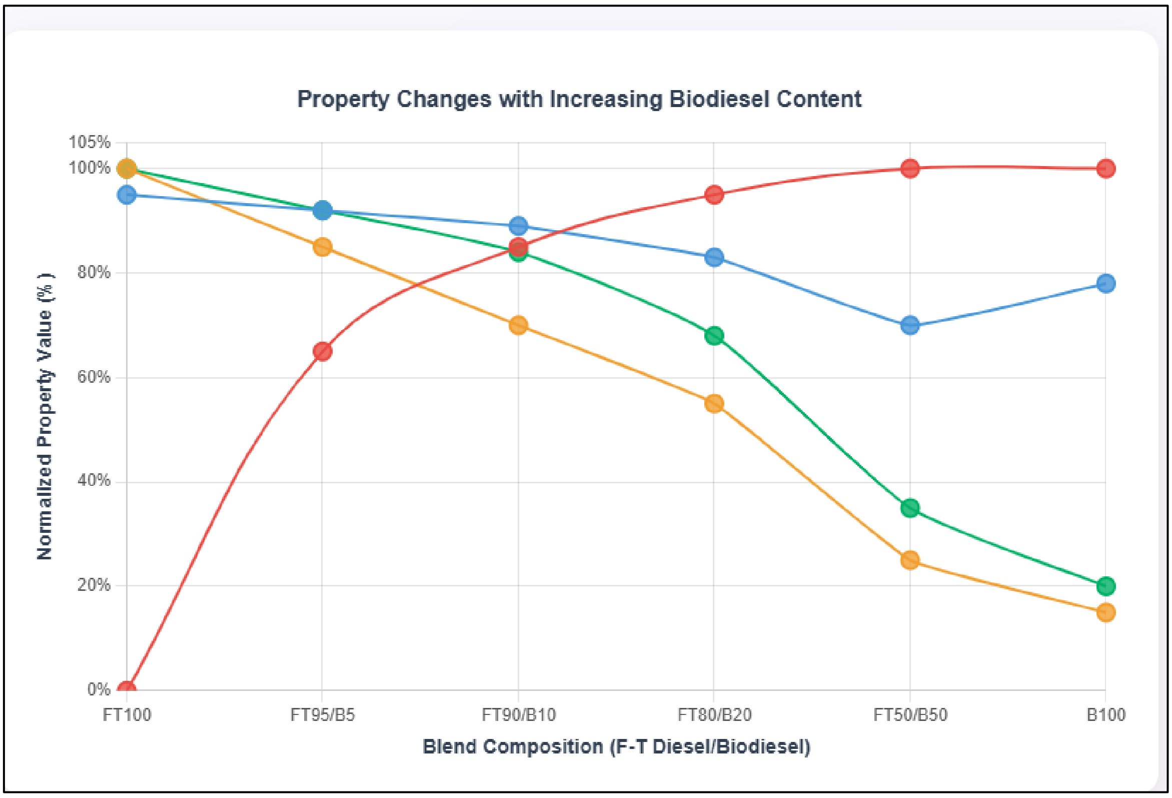

Figure 1 Illustrative Impact of Biodiesel Blend Percentage on Key Properties of an F-T Diesel Blend

3. Combustion and Engine Performance Characteristics

The combustion characteristics of F-T diesel/biodiesel blends are primarily governed by their high cetane numbers and paraffinic, oxygenated nature. These properties lead to significant changes in the in-cylinder combustion process compared to conventional diesel, influencing engine performance, efficiency, and noise. Investigating these characteristics is crucial to understanding the operational benefits of the blend.

The high cetane number of both components ensures very short ignition delay periods across all blend ratios. A short ignition delay means that fuel ignites sooner after injection into the hot compressed air. This leads to a more controlled combustion phase, reducing the amount of fuel prepared for a rapid, premixed burn. The result is a lower maximum rate of pressure rise and a reduction in combustion noise, often described as a smoother and quieter engine operation. This is a consistent finding in engine bench tests, where blends exhibit a demonstrable reduction in engine knock compared to conventional diesel.

Brake-specific fuel consumption (BSFC) is typically higher for biodiesel blends due to their lower energy (heating) content per unit mass. Since F-T diesel has a heating value similar to or slightly higher than conventional diesel, blending it with biodiesel results in a BSFC that is improved compared to neat biodiesel but still higher than that of conventional diesel or neat F-T diesel. The relationship is largely linear based on the energy content of the blend. However, the superior combustion efficiency attributable to the high cetane number and oxygen content of biodiesel can partially offset this energy deficit, making the increase in volumetric fuel consumption less severe than predicted by energy content alone. Engine power output is directly related to the energy content of the fuel. Consequently, a blend will have a lower power output than conventional diesel or F-T diesel when using a fixed fuel delivery volume (as in most pump-line-nozzle injection systems), as less chemical energy is injected per cycle. Modern engines with adaptive engine control units (ECUs) can compensate for this to some extent by adjusting injection parameters. In practice, the power loss for blends like FT80/B20 is relatively minor (often 2-4%) and may be imperceptible in many applications.

The impact on engine durability is a critical performance metric. The excellent lubricity of the blend, provided by the biodiesel component, ensures adequate protection for fuel pumps and injectors, preventing the catastrophic wear that could occur with neat F-T diesel. Furthermore, the absence of sulfur and aromatics reduces the abrasive and corrosive wear on engine components over the long term. The cleaner combustion also leads to reduced carbon deposit formation on injector nozzles, which helps maintain optimal fuel spray patterns and engine performance over extended periods between maintenance intervals.

Table 2 Comparison of Engine Performance Parameters for Different Fuels

Performance Parameter	**Conventional Diesel**	**Neat F-T Diesel**	**Neat Biodiesel (B100)**	**F-T/B20 Blend**
Cetane Number	40 - 55	70 - 80	50 - 60	~65 - 75
Ignition Delay	Baseline	Shorter	Shorter	Shortest
Combustion Noise	Baseline	Lower	Lower	Lowest
Brake Specific Fuel Consumption	Baseline	~3% lower	~5-10% higher	~1-3% higher
Power Output	Baseline	Similar	~5-8% lower	~2-4% lower
Lubricity (HFRR µm)	300 - 400 (with additives)	>600 (very poor)	<200 (excellent)	<300 (good)

4. Emission Characteristics: The NOx-PM Trade-Off and Beyond

The emission profile is a paramount factor in evaluating any alternative fuel. F-T diesel/biodiesel blends are particularly notable for their ability to simultaneously reduce two of the most harmful diesel emissions: particulate matter (PM) and nitrogen oxides (NOx), effectively addressing the classic diesel emissions trade-off.

Particulate Matter (PM) emissions are dramatically reduced by both components through different mechanisms. F-T diesel's lack of aromatics and sulfur prevents the formation of soot nuclei and sulfate particulates. Biodiesel's oxygen content promotes more complete combustion, oxidizing soot precursors within the cylinder. When blended, these effects combine synergistically. The paraffinic F-T base fuel creates a low-soot combustion environment, and the oxygenated biodiesel further enhances the oxidation of any remaining carbonaceous material. Studies consistently show PM reductions of 20-40% for moderate blends compared to conventional diesel, with the reduction curve often being non-linear and favoring greater-than-expected reductions at mid-level blends.

Nitrogen Oxide (NOx) emissions are more complex. The well-documented "biodiesel NOx effect," where pure biodiesel (B100) can increase NOx emissions by 10-15%, is attributed to several factors, including its higher adiabatic flame temperature due to oxygen content and advanced injection timing due to higher speed of sound. F-T diesel, however, typically shows a slight decrease in NOx emissions due to its high cetane number promoting a shorter, cooler combustion. In blends, the F-T component can counterbalance the NOx-increasing tendency of biodiesel. The result is that blends often exhibit NOx emissions that are neutral or slightly reduced compared to conventional diesel, effectively breaking the trade-off by avoiding the NOx penalty typically associated with biodiesel.

Carbon Monoxide (CO) and unburned Hydrocarbon (HC) emissions are products of incomplete combustion. The high cetane number and oxygenated nature of the blend significantly improve combustion efficiency, leading to substantial reductions in both CO and HC emissions across the board. Reductions of 20-50% are commonly reported for blends, as the fuel burns more completely and consistently across different engine operating conditions.

The blend's impact on greenhouse gas emissions is profoundly positive on a lifecycle basis. The biodiesel component is derived from biomass, which recycles atmospheric CO2, significantly reducing the net carbon dioxide emissions compared to fossil fuels. While F-T diesel from natural gas (GTL) has a higher lifecycle CO2 footprint than conventional diesel, F-T diesel from biomass (BTL) is carbon-neutral. Therefore, a blend incorporating any percentage of biodiesel or BTL F-T diesel will have a lower net greenhouse gas impact than petroleum-based fuels, contributing to climate change mitigation goals.

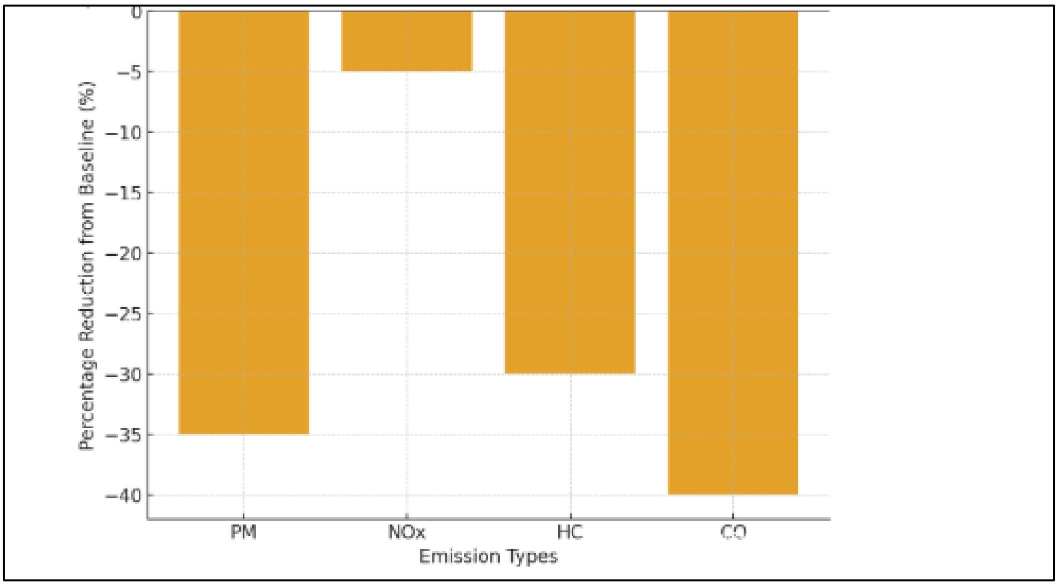

Figure 2 Comparative Emission Reductions of F-T/B20 Blend vs. Conventional Diesel

5. Material Compatibility and Storage Stability

For a fuel blend to be commercially viable, it must be compatible with existing infrastructure and vehicle materials and remain stable during storage. The material compatibility of F-T diesel/biodiesel blends is predominantly influenced by the biodiesel component, while the storage stability benefits from the F-T component.

Biodiesel is a strong solvent and can degrade certain elastomers and plastics commonly found in older fuel systems. It can cause swelling and softening of nitrile rubber, polyurethane, and certain types of polyvinyl chloride (PVC). It is also incompatible with copper, brass, bronze, lead, tin, and zinc, accelerating corrosion and forming metallic soaps that can clog filters. F-T diesel, being a pure hydrocarbon, is compatible with all materials suitable for conventional diesel. Therefore, a blend will have solvent properties intermediate between its components. For low-level blends (e.g., B5-B20), the impact is minimal for modern vehicles designed for ultra-low sulfur diesel (ULSD) and biodiesel blends. For higher blends, compatibility with seals and hoses must be verified.

The storage stability of the blend is a critical concern. Neat biodiesel is susceptible to oxidation, which leads to an increase in acid number and the formation of gums and sediments that can plug fuel filters. F-T diesel is exceptionally stable due to its saturation. Blending the two significantly improves the oxidative stability of the biodiesel component through dilution. The induction period of the blend increases linearly with the volume fraction of F-T diesel. This means that a FT80/B20 blend will have a much longer shelf life and resistance to degradation than neat biodiesel, enhancing its practicality for distribution and storage in the existing fuel supply chain.

Water contamination is another storage issue. Biodiesel is hygroscopic and can absorb more water from the atmosphere than conventional hydrocarbon fuels. This water can lead to microbial growth (forming "diesel bugs"), hydrolysis of the ester molecules (reverting to acids and alcohols), and enhanced corrosion. F-T diesel, like conventional diesel, is hydrophobic and holds very little water in solution. In a blend, the F-T component reduces the overall hygroscopicity compared to neat biodiesel, mitigating but not eliminating the risk of water-related issues. Proper storage tank management remains essential.

Table 3 Summary of Compatibility and Stability for F-T/B20 Blend

Aspect	Neat F-T Diesel	Neat Biodiesel (B100)	F-T/B20 Blend	Implications
Elastomer Compatibility	Excellent	Poor (for some)	Good	Compatible with modern vehicle materials.
Metallic Compatibility	Excellent	Poor (Cu, Zn, etc.)	Good	Avoid copper-containing fittings.
Oxidative Stability	Excellent	Poor	Good	Significantly improved shelf-life over B100.
Water Absorption	Low (hydrophobic)	High (hygroscopic)	Moderate	Reduced risk of microbial growth vs. B100.

6. Conclusion and Future Perspectives

The investigation into blends of Fischer-Tropic diesel and biodiesel reveals a compelling case for their synergistic potential. The evidence from pre-2019 literature strongly supports the hypothesis that these fuels complement each other effectively, creating an advanced blend that outperforms either component alone in several key areas. The most pronounced synergy is in lubricity, where minimal additions of biodiesel completely rectify the critical lubricity deficit of F-T diesel. Furthermore, the blend successfully navigates the classic NOx-PM trade-off, delivering significant reductions in particulate matter without the NOx increase often associated with biodiesel, thanks to the counterbalancing influence of the high-cetane, paraffinic F-T diesel.

The benefits extend to other domains: the high cetane number ensures smooth and quiet combustion, the dilution with F-T diesel improves the oxidative stability of the blend, and the renewable content of biodiesel reduces the lifecycle greenhouse gas emissions. While challenges remain, particularly regarding cold flow properties which tend to follow a linear, worsening trend, these can be managed with existing additive technology. Material compatibility is also suitable for modern diesel infrastructure and vehicles, especially for blends in the B5 to B20 range.

From a future perspective, the viability of these blends is intrinsically linked to the production pathways and economics of the two components. The expansion of sustainable biodiesel production from non-food feedstocks (e.g., waste oils, algae) is crucial to avoid competition with food supply. Similarly, the development of economically competitive Biomass-to-Liquids (BTL) Fischer-Tropsch processes would transform F-T diesel into a fully renewable fuel, making the blend a 100% renewable, drop-in synthetic fuel with exceptional properties.

Future research should focus on long-term engine durability studies using these specific blends, optimization of blend ratios for specific climates and applications, and the development of specialized additive packages to further enhance cold flow and stability properties. In conclusion, F-T diesel/biodiesel blends represent a highly promising, synergistic strategy for creating a cleaner, high-performance diesel fuel that leverages the best attributes of both synthetic and biological conversion pathways, offering a practical and sustainable pathway for the future of diesel energy.

References

[1] Fazal, M. A., Haseeb, A. S. M. A., and Masjuki, H. H. (2011). Biodiesel feasibility study: An evaluation of material compatibility; performance; emission and engine durability. Renewable and Sustainable Energy Reviews, 15(2), 1314-1324.

[2] Hancsók, J., Eller, Z., and Thernesz, A. (2007). Investigation of the storage stability of biomass-to-liquid (BTL) diesel fuel. Energy and Fuels, 21(4), 2254-2259.

[3] Knothe, G. (2005). Dependence of biodiesel fuel properties on the structure of fatty acid alkyl esters. Fuel Processing Technology, 86(10), 1059-1070.

[4] Lapuerta, M., Armas, O., and Rodríguez-Fernández, J. (2008). Effect of biodiesel fuels on diesel engine emissions. Progress in Energy and Combustion Science, 34(2), 198-223.

[5] Schaberg, P. W., Myburgh, I. S., Botha, J. J., Khalek, I. A., and Gilmore, R. (2005). Emissions performance of GTL diesel fuel and blends with optimized engine calibrations. SAE Technical Paper 2005-01-2187.

[6] Van der Walt, J., and Hugo, F. J. C. (2008). The potential of Fischer-Tropsch diesel to meet future European diesel fuel specifications. SAE Technical Paper 2008-01-1803.