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Compatibility and Performance Analysis of E20 Ethanol–Gasoline Blends in BS4 and BS6 Indian Two-Wheelers: A Review

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ABSTRACT

Ethanol blending with gasoline is being promoted globally due to the increasing demand for cleaner and sustainable transportation fuels. In India, the government has introduced the E20 fuel program, which aims to achieve 20% ethanol blending in gasoline to reduce dependence on fossil fuels and lower vehicular emissions. Since two-wheelers represent a major share of the Indian transportation sector, it is important to evaluate the performance and compatibility of ethanol–gasoline blends in engines designed under different emission standards such as BS4 and BS6. This review paper presents an analysis of previous studies on the use of ethanol–gasoline blends (E10–E20) in spark ignition engines, particularly in Indian two-wheelers. The study reviews key physicochemical properties of ethanol blends, including density, calorific value, viscosity, octane number, and volatility, and discusses their influence on combustion and engine performance. It also examines the impact of ethanol blending on fuel economy and exhaust emissions, including CO, HC, and NOx. The review highlights challenges in adopting E20 fuel in existing BS4 vehicles and the readiness of BS6 engines for higher ethanol blends.

1. INTRODUCTION

The increasing demand for transportation fuels, stringent emission regulations, and concerns regarding environmental sustainability have accelerated the adoption of renewable alternative fuels worldwide. In India, the Ethanol Blending Programme (EBP) has been introduced to reduce dependence on imported petroleum, lower greenhouse gas emissions, and promote the utilization of renewable biofuels. As part of this initiative, E20 fuel, comprising 20% ethanol and 80% gasoline by volume, has been identified as a key transportation fuel for gasoline-powered vehicles [3]. Ethanol possesses favorable fuel properties such as higher octane number, increased oxygen content, and improved anti-knock characteristics, which contribute to cleaner combustion and reduced emissions. Several studies have reported significant reductions in carbon monoxide (CO) and hydrocarbon (HC) emissions with ethanol-gasoline blends while maintaining satisfactory engine performance in two-wheelers [1,2,4,10,12]. However, due to the lower heating value of ethanol, a slight increase in fuel consumption is often observed [1,14]. The transition from BS4 to BS6 emission standards has introduced advanced technologies such as electronic fuel injection (EFI), engine control units (ECUs), oxygen sensors, and improved catalytic converters, enabling better adaptation to oxygenated fuels such as E20 [2,14]. Nevertheless, concerns remain regarding the compatibility of E20 fuel with fuel-system materials, elastomers, plastics, metallic components, and catalyst durability, particularly in older BS4 vehicles [3,15]. Previous investigations have demonstrated that ethanol blends can improve combustion efficiency, thermal performance, and power output under optimized operating conditions [4,6,8,16]. Ethanol-blended fuels have also shown considerable potential for reducing regulated emissions; however, increases in certain unregulated emissions such as aldehydes and unburned ethanol have been reported at higher blend ratios [5,10]. Furthermore, factors such as cold-start operation, engine calibration, and long-term material durability play a crucial role in determining the overall suitability of E20 fuel for two-wheeler applications [9,11,15]. Considering the nationwide implementation of E20 fuel in India, a comprehensive assessment of its impact on BS4 and BS6 two-wheelers is essential. This review paper examines the Ethanol Blending Programme in India, the properties of E20 fuel, compatibility issues, engine performance, emission characteristics, and durability aspects of E20 ethanol-gasoline blends. The objective is to provide a consolidated understanding of the opportunities and challenges associated with the adoption of E20 fuel in Indian two-wheelers.

2. PROPERTIES OF ETHANOL GASOLINE BLENS

Ethanol is one of the most widely used renewable oxygenated fuels for spark-ignition engines due to its favorable physicochemical properties. When blended with gasoline, ethanol increases the oxygen content of the fuel, promotes more complete combustion, and enhances the octane rating of the blend. Several studies have reported that ethanol–gasoline blends exhibit higher research octane numbers and improved anti-knock characteristics compared to conventional gasoline, making them suitable for use in modern spark-ignition engines without significant modifications at lower blend ratios [3,5,10]. The higher octane rating of ethanol enables improved combustion efficiency and allows engines to operate at higher compression ratios, potentially enhancing thermal efficiency and performance [6]. The addition of ethanol also influences important fuel properties such as density, volatility, latent heat of vaporization, and calorific value. Ethanol contains approximately 35% oxygen by weight, which facilitates cleaner combustion and contributes to reductions in carbon monoxide (CO) and hydrocarbon (HC) emissions [1,2,4]. However, ethanol possesses a lower heating value than gasoline; therefore, increasing ethanol concentration in the blend generally results in higher fuel consumption to produce the same power output [1,4,14]. Studies conducted on E10, E20, E30, and higher ethanol blends have consistently reported an increase in brake-specific fuel consumption due to the lower energy content of ethanol [4,12,14]. Another important characteristic of ethanol is its high latent heat of vaporization, which cools the intake charge and can improve volumetric efficiency under certain operating conditions [8]. Ethanol blends also exhibit better water tolerance and favorable Reid Vapor Pressure characteristics at intermediate blend levels, which can improve fuel handling and combustion behavior [4]. Furthermore, ethanol can be produced from renewable biomass sources such as sugarcane, corn, agricultural residues, and waste biomass, making it an environmentally sustainable alternative to petroleum-derived fuels [3,10]. Despite these advantages, ethanol possesses hygroscopic properties, meaning it readily absorbs moisture from the atmosphere. This characteristic may lead to phase separation, corrosion of metallic components, and degradation of certain elastomers and plastics during prolonged storage or use, particularly in vehicles not specifically designed for higher ethanol blends [3,15]. In addition, studies have reported that while ethanol blends reduce regulated emissions, higher blend ratios may increase emissions of certain oxygenated compounds such as acetaldehyde, formaldehyde, and unburned ethanol due to incomplete oxidation processes [5,10]. Overall, the combination of higher octane number, oxygen enrichment, renewable origin, and cleaner combustion makes ethanol–gasoline blends attractive alternative fuels for two-wheelers. However, their lower energy content, hygroscopic nature, and potential material compatibility issues must be carefully considered when implementing higher ethanol blends such as E20 in existing BS4 and BS6 vehicles [3,14,15].

Table 1: BS4 vs BS6 Compatibility with E20 Ethanol–Gasoline Blends

Parameter	BS4 Two-Wheelers	BS6 Two-Wheelers	Reference
Design Fuel Compatibility	Primarily designed for gasoline and lower ethanol blends (E5–E10).	Designed considering higher ethanol blends including E20.	[3], [14]
Fuel Delivery System	Carburetor or basic EFI systems in some models.	Advanced Electronic Fuel Injection (EFI) with closed-loop control.	[2], [14]
Engine Control Unit (ECU)	Limited adaptive control capability.	Advanced ECU capable of automatic fuel correction and adaptation to oxygenated fuels.	[2], [14]
Air-Fuel Ratio Control	Less precise fuel metering and mixture control.	Real-time air-fuel ratio optimization using oxygen sensors.	[14]
Oxygen Sensor Availability	Limited or absent in many models.	Standard feature for closed-loop combustion control.	[14]
Catalytic Converter Technology	Basic catalytic converter with lower conversion efficiency.	Advanced catalytic converter with improved emission reduction capability.	[13], [14]
Material Compatibility with Ethanol	Higher risk of elastomer swelling, corrosion, seal degradation, and fuel-system wear.	Improved ethanol-resistant materials, seals, hoses, and fuel-system components.	[3], [15]
Fuel-System Durability	Potential long-term durability concerns with E20 fuel exposure.	Better durability and reliability under prolonged E20 operation.	[3], [15]
Combustion Control	Less accurate ignition and fuel management.	Precise ignition timing and fuel injection control for optimized combustion.	[2], [14]
CO Emissions with E20	Reduced compared to gasoline but less effectively controlled.	Significant reduction due to better combustion and catalyst efficiency.	[13], [14]
HC Emissions with E20	Reduction observed but may vary with operating conditions.	Substantial reduction owing to improved combustion and after-treatment systems.	[13], [14]
NOx Emissions with E20	Moderate increase possible under certain conditions.	Better NOx management, although slight increases may occur due to lean combustion.	[13], [14]
Fuel Economy Adaptation	Limited compensation for ethanol's lower calorific value.	ECU adjusts injection duration to maintain optimum operation.	[2], [14]
Cold Start Performance	More susceptible to cold-start issues with ethanol blends.	Improved cold-start management through electronic control systems.	[9], [14]
Emission Compliance with E20	May require monitoring and periodic maintenance.	Capable of maintaining BS6 emission compliance with E20 fuel.	[14]
Long-Term Reliability	Requires evaluation of fuel-system components and catalyst durability.	Better suited for long-term E20 operation.	[3], [15]
Overall E20 Compatibility	Moderate compatibility; suitable with precautions and monitoring.	High compatibility; preferred platform for E20 implementation.	[2], [3], [14]

3. ENGINE TECHNOLOGIES: BS4 VS BS6

The transition from Bharat Stage IV (BS4) to Bharat Stage VI (BS6) emission regulations represents a significant technological advancement in the Indian two-wheeler industry aimed at reducing vehicular emissions and improving fuel efficiency. BS4-compliant motorcycles primarily relied on carburetor-based fuel delivery systems or basic electronic fuel injection systems, with comparatively less stringent emission control requirements. In contrast, BS6 regulations introduced much stricter limits on pollutants such as carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx), necessitating the adoption of advanced engine management and emission control technologies [13]. To meet BS6 emission standards, manufacturers incorporated electronic fuel injection (EFI) systems, closed-loop engine control strategies, oxygen sensors, advanced engine control units (ECUs), and improved catalytic converters. These technologies enable precise fuel metering, real-time air-fuel ratio correction, optimized ignition timing, and enhanced combustion efficiency under varying operating conditions [2,14]. The ECU continuously receives information from sensors and adjusts fuel injection parameters to maintain stoichiometric combustion, resulting in lower emissions and improved fuel economy. Studies have shown that BS6 motorcycles equipped with EFI systems can automatically compensate for changes in ethanol concentration by modifying fuel injection duration and combustion parameters, making them more suitable for ethanol-blended fuels such as E20 [2]. Comparative investigations between BS-III and BS-VI motorcycles have demonstrated the effectiveness of these technological improvements. Real-world emission measurements revealed that BS-VI motorcycles produced substantially lower CO and HC emissions than older-generation vehicles due to improved fuel-air mixture control and enhanced catalytic after-treatment systems [13]. Similarly, experimental studies on BS-VI compliant EFI motorcycles operating with oxygenated fuels (E10, E20, and M15) reported significant reductions in CO and THC emissions because of improved combustion control and fuel management capabilities [14]. However, the enhanced combustion efficiency and leaner operating conditions in BS6 engines may lead to slightly higher NOx emissions under certain perating conditions [13,14]. Another important distinction between BS4 and BS6 technologies is their compatibility with ethanol-blended fuels. BS6 vehicles are generally designed with ethanol-resistant fuel-system materials, improved injectors, and sophisticated engine calibration strategies that facilitate operation on higher ethanol blends. In contrast, many BS4 vehicles were originally developed for lower ethanol concentrations and may experience issues related to fuel-system compatibility, corrosion, and material degradation during prolonged exposure to E20 fuel [3]. Therefore, BS6 technology provides a more robust platform for the nationwide adoption of E20 fuel owing to its advanced combustion control systems, improved emission after-treatment technologies, and enhanced compatibility with oxygenated fuels [3,14].Overall, the transition from BS4 to BS6 has significantly improved engine efficiency, emission control capability, and adaptability to alternative fuels. These technological advancements play a crucial role in supporting India's Ethanol Blending Programme and facilitating the successful implementation of E20 fuel in modern two-wheelers [2,3,13,14].

4. Performance Characteristics

The performance characteristics of ethanol–gasoline blends in two-wheeler spark-ignition engines have been extensively investigated owing to the favorable fuel properties of ethanol, including higher octane number, oxygen content, and anti-knock characteristics. Several studies have reported that ethanol blends improve combustion quality and engine efficiency by promoting more complete combustion. However, the influence of ethanol on engine performance depends on the blend ratio, engine design, operating conditions, and fuel management system [1,2,4,6,8,12,14,16]. Experimental investigations on motorcycles operating with ethanol–gasoline blends have shown that low- to medium-level blends such as E10, E20, and E30 can maintain or slightly improve engine performance. A comprehensive real-time vehicle study reported that E20 fuel increased engine power and torque by approximately 2% and 3.4%, respectively, compared with neat gasoline, while simultaneously reducing exhaust emissions [12]. Similarly, experiments on variable compression ratio (VCR) engines demonstrated that higher ethanol concentrations improved volumetric efficiency, brake power, and torque because of the cooling effect associated with ethanol's higher latent heat of vaporization [8]. These improvements are attributed to enhanced cylinder filling and improved combustion characteristics. The higher octane rating of ethanol also enables engines to operate efficiently at elevated compression ratios. Studies conducted with E30 fuel revealed that increasing the compression ratio from 9.4:1 to 11.5:1 improved power output, increased peak cylinder pressure, reduced combustion duration, and lowered specific fuel consumption [6]. Furthermore, optimization of spark timing showed that advancing ignition timing by approximately 4° crank angle improved combustion efficiency and engine performance when operating with ethanol blends [6]. These findings indicate that ethanol-blended fuels can deliver superior performance when engines are calibrated specifically for their combustion characteristics. Despite these advantages, ethanol contains a lower heating value than gasoline, which often leads to an increase in brake-specific fuel consumption (BSFC). Studies on E10 and E20 fuels reported a reduction in fuel economy of approximately 6–8% compared to gasoline due to the lower energy density of ethanol [1]. Similar trends were observed in BS-VI motorcycles tested with E10, E20, and methanol-gasoline blends, where fuel consumption increased with increasing oxygen content of the fuel [14]. Investigations involving E30 fuel also reported higher specific fuel consumption despite satisfactory combustion performance [4]. Higher ethanol concentrations have demonstrated mixed performance outcomes. While flex-fuel studies on BS6-compliant motorcycles operating with ethanol concentrations up to E85 reported increases in brake power and improved combustion efficiency, substantial increases in fuel consumption were also observed because of the lower calorific value of ethanol [16]. Likewise, real-world vehicle tests revealed that performance deteriorated at very high ethanol concentrations such as E55 and E85, resulting in reduced power, lower torque, and increased acceleration time compared with gasoline operation [12]. These findings suggest that E20 represents a practical compromise between performance improvement and fuel economy for conventional two-wheeler engines. Overall, the available literature indicates that ethanol–gasoline blends, particularly E20, offer favorable performance characteristics for two-wheelers by improving combustion efficiency, power output, torque, and thermal performance while maintaining acceptable fuel economy. However, optimization of engine parameters such as compression ratio, ignition timing, and fuel injection strategy is essential to fully exploit the benefits of ethanol-blended fuels in BS4 and BS6 motorcycles [4,6,12,14,16].

Power output Vs Ethanol Blends: This graph illustrates the effect of increasing ethanol concentration on the power output of two-wheeler spark-ignition engines. The trend indicates a gradual increase in power output from E0 to E30 due to the higher octane number and oxygen content of ethanol, which promote improved combustion efficiency. However, at very high ethanol concentrations, power output may decline because of ethanol's lower calorific value and the lack of engine calibration for higher blend ratios. Studies have reported that E20 blends can improve engine power and torque while maintaining satisfactory vehicle performance, making them a suitable alternative fuel for existing two-wheelers [6,8,12,16].

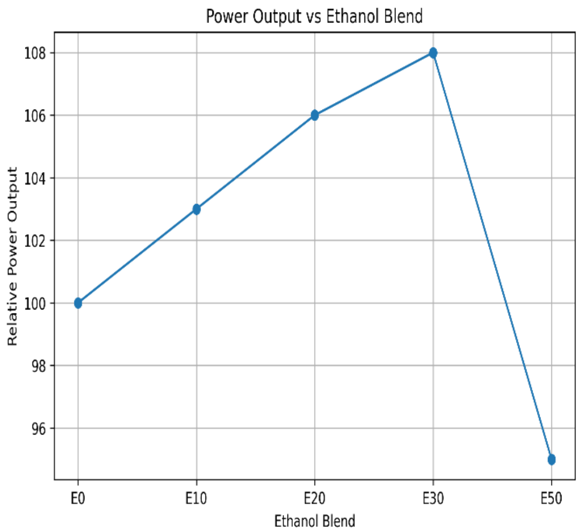

Figure 1: Power output Vs Ethanol blends

Brake Specific Fuel Consumption (BSFC) vs Ethanol Blend: The graph shows the variation of brake specific fuel consumption with ethanol content in gasoline. BSFC generally increases as the ethanol percentage increases because ethanol has a lower heating value than gasoline. Consequently, a greater quantity of fuel is required to produce the same brake power output. Although ethanol improves combustion characteristics, the lower energy density results in a fuel economy penalty, particularly at higher blend ratios. Experimental studies have consistently reported increased BSFC for E20, E30, and higher ethanol blends compared with neat gasoline [1,4,14,16].

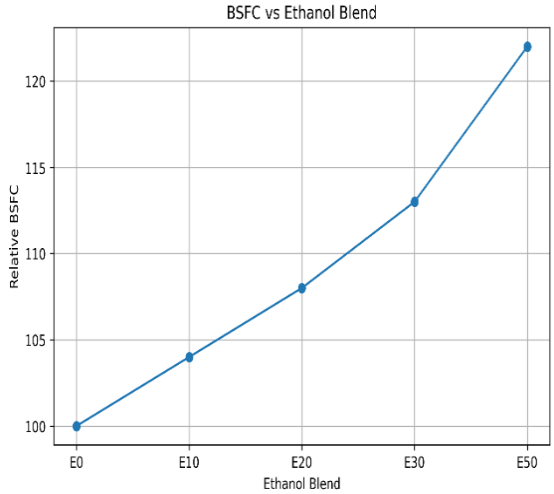

Figure 2: BSFC Vs Ethanol blends

Carbon Monoxide (CO) Emissions vs Ethanol Blends: This figure demonstrates the reduction in carbon monoxide emissions with increasing ethanol concentration. Ethanol contains oxygen within its molecular structure, which enhances fuel oxidation and promotes more complete combustion. As a result, incomplete combustion products such as CO are significantly reduced. Several investigations on motorcycles and two-wheelers have reported substantial reductions in CO emissions when operating with E10, E20, and E30 blends compared to conventional gasoline [1,2,4,14,15,16].

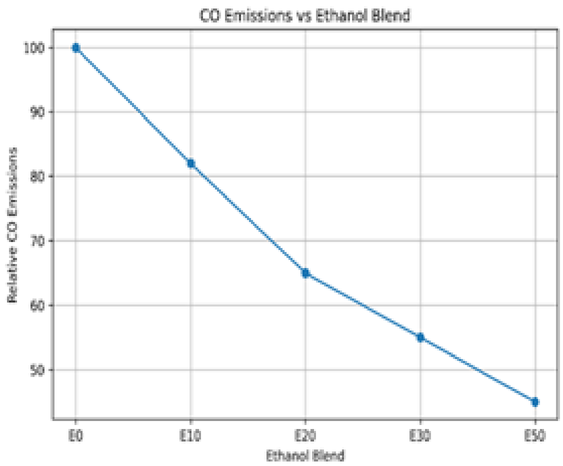

Figure 3: Co Emmission Vs Ethanol blends

Hydrocarbon (HC) Emissions vs Ethanol Blend: The graph presents the trend of hydrocarbon emissions with increasing ethanol content. The oxygenated nature of ethanol improves flame propagation and combustion completeness, leading to a reduction in unburned hydrocarbons. Consequently, HC emissions generally decrease as ethanol concentration increases. However, under certain operating conditions and at higher blend evels, slight increases may occur due to combustion instability or cold-start effects. Overall, ethanol-gasoline blends have demonstrated lower HC emissions than pure gasoline in most experimental studies [1,2,14,16].

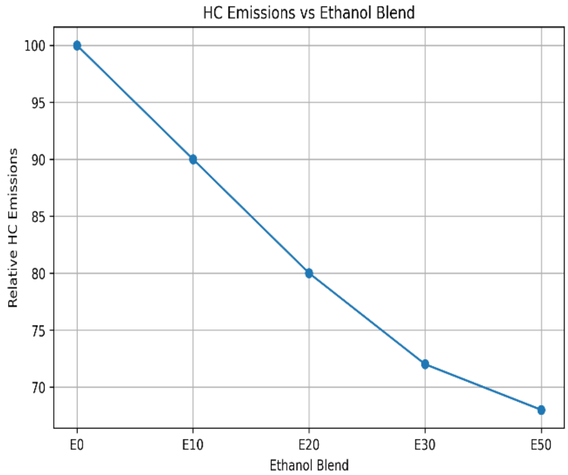

Figure 4: HC Emission Vs Ethanol blends

Nitrogen Oxides (NOx) Emissions vs Ethanol Blend: This graph illustrates the variation of NOx emissions with ethanol concentration. In many cases, NOx emissions increase with increasing ethanol content because improved combustion efficiency and higher in-cylinder temperatures promote NOx formation. The additional oxygen supplied by ethanol can further enhance thermal NOx production. Nevertheless, the magnitude of NOx emissions depends on engine operating conditions, ignition timing, compression ratio, and air-fuel ratio. Several studies have reported a moderate increase in NOx emissions for ethanol blends, particularly under high-load conditions [4,14,16,17].

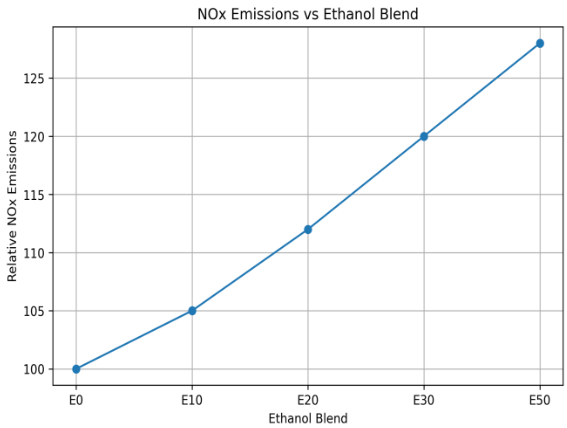

Figure 5: NOx Emission Vs Ethanol blends

BS4 vs BS6 Emission Comparison: This figure compares the emission characteristics of BS4 (or earlier-generation) and BS6 two-wheelers. BS6 vehicles employ advanced technologies such as electronic fuel injection (EFI), oxygen sensors, electronic control units (ECUs), and improved catalytic converters, resulting in substantial reductions in carbon monoxide and hydrocarbon emissions. Although BS6 vehicles generally achieve significantly lower overall emissions, some studies have reported slightly higher NOx and CO_2 emissions under certain operating conditions due to improved combustion efficiency and lean-burn strategies. The figure highlights the technological improvements achieved through the transition from BS4 to BS6 emission standards and their importance in supporting E20 fuel adoption [13,14].

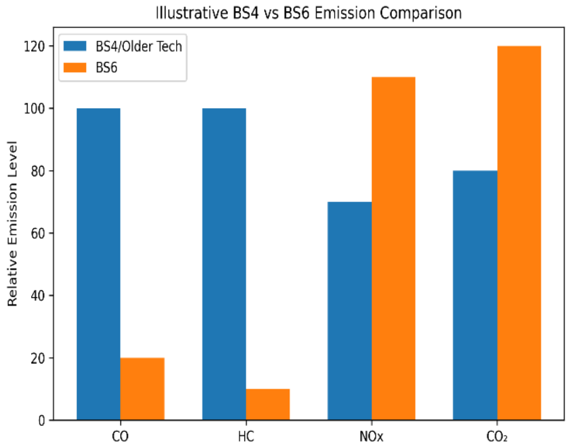

Figure 6: BS4 vs BS6 Emission

Conclusion

E20 ethanol–gasoline blend has emerged as a promising alternative fuel under India's Ethanol Blending Programme due to its renewable nature, higher octane number, and potential to reduce dependence on fossil fuels. The reviewed studies indicate that E20 improves combustion efficiency and significantly reduces CO and HC emissions, while providing acceptable engine performance with slight increases in fuel consumption due to its lower calorific value. However, NOx emissions may increase under certain operating conditions. BS6-compliant two-wheelers demonstrate better compatibility with E20 fuel because of their advanced EFI systems, ECU-based control, oxygen sensors, and ethanol-resistant materials. In contrast, BS4 vehicles may face long-term concerns related to material compatibility and durability. Overall, E20 fuel is a viable and sustainable option for Indian two-wheelers, particularly BS6 vehicles, although further research on durability, real-world performance, and long-term emission impacts is required for its successful large-scale implementation.

Challenges and Future Scope

The successful implementation of E20 fuel in India requires addressing challenges related to material compatibility, fuel economy, NOx emissions, durability, and infrastructure development. Future research should focus on long-term durability assessment, BS4–BS6 comparative studies, advanced combustion analysis, real-world testing, and smart engine optimization technologies. These efforts will facilitate the sustainable and reliable adoption of E20 ethanol–gasoline blends in Indian two-wheelers while supporting national goals of energy security, reduced emissions, and environmental sustainability.

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