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Effects of Flex Fuel in Light Duty Power Generators on the Environment and Circular Bio-Economy

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ABSTRACT

Environmental sustainability encompasses various problems, including clean air, renewable energy, climate change, safe environments, and the capacity to live in a healthy community. One possible strategy for addressing these global problems is the circular bio-economy. Cleaner and lower-carbon environments may be fostered via the production of bioenergy and biomaterials, which can also help to maintain the energy-environment connection. To improve sustainability and the state of the planet, scientists are looking at renewable energy sources like ethanol. Compared to gasoline, ethanol has a reduced carbon footprint and a greater energy density, making it a viable alternative fuel. This study gives an overview of ethanol as a possible alternative fuel for flex-powered power generators in India to meet the goals of the circular bio-economy. This paper details the results of flex-fuel testing conducted on a light-duty power generator using an ethanol-gasoline mix. The findings reveal improved thermal efficiency and lower fuel consumption rates than basic fuel. The emissions of both carbon monoxide and unburned hydrocarbons were shown to be reduced.

INTRODUCTION

A flexible-fuel or dual-fuel vehicle is one whose internal combustion engine can operate on multiple fuel types. It may use regular gasoline in combination with an alcohol or ethanol-based fuel. Fuel injection and spark timing in modern flex-fuel engines may be automatically modified based on the actual blend detected by a fuel composition sensor, allowing for the combustion of any percentage of the resultant blend in the combustion chamber. About 60 million cars, motorbikes, and light-duty trucks have been produced and sold across the globe that can run on ethanol, making it the most popular commercially accessible flex fuel. Vehicles with a flexible fuel engine may run on either pure gasoline or a mixture of gasoline and ethanol up to 83% by volume (Stein et al. 2013, Thamilarasan et al. 2022).

The term "circular economy" refers to an economic model intended to be restorative and regenerative. Its primary objective is to maintain the highest possible level of utility and value for all products, components, and materials at all times, distinguishing between technical and biological cycles. The circular economy primarily emphasizes the effective use of limited resources. It ensures that those resources are recycled and utilized for as long as it is economically viable. To close loops of raw biomass materials, minerals, water, and carbon, bio-refining is one of the most important fundamentals enabling methods of the circular economy. As a result, bio-refining is the most effective technique for the bio-economy's large-scale, environmentally responsible use of biomass. It will result in the cost-competitive co-production of food and feed components, bio-based products, and bioenergy, along with optimum societal, economic, and environmental consequences (Venkatesh et al. 2018, Venkatesh 2022, Ranjbari et al. 2022).

The researcher's investigation focused on how ethanol was burned in a flex fuel engine. An investigation was

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conducted into applying high-compression hydrous ethanol reforming and supercharging lean-burn situations to improve performance and thermal efficiency. Adding ethanol to gasoline increased the emissions of nitrogen oxides (Gravalos 2011). Hydrocarbon and carbon monoxide emissions are brought down to their overall lowest levels. Under a wide range of loading situations, it was discovered that changing the percentage of ethanol to gasoline in the fuel mix led to significantly different levels of energy efficiency as well as pollution. According to the data, the emissions concentrations increased as the engine load grew but decreased as the ethanol level increased (Jesus et al. 2021).

Analytically analyzed steady-state engines were used in the study to investigate the effect that a combination of ethanol and gasoline would have on power, torque, amount of fuel consumed, and emissions. The vast bulk of the research that has been done so far on gasoline-ethanol blends in engines has focused on ethanol mix ratios up to twenty percent, with varying degrees of effectiveness (Doğan et al. 2017). The findings of multiple trials indicated little or no reaction to ethanol concentration up to 10% by volume, which suggests that engine operating circumstances have a more substantial impact on the engine's characteristics and the pollutants it produces at low ethanol blend levels. The performance of spark-ignition (SI) engines operating on ethanol-gasoline blends while maintaining a constant fuel-air ratio has recently garnered much attention (Stein et al. 2013).

When the speed of the engine is increased, as well as when the quantity of ethanol in the fuel mix is decreased, there is a tendency for the volumetric efficiency to drop. This is something that can be observed. There is a discernible reduction in the quantity of exhaust gas emissions produced whenever there is an increase in the ratio of ethanol to gasoline fuel that is used (Tibaquirá et al. 2018)increasing gasoline octane rating and reducing dependence on petroleum products. However, recently environmental authorities in large urban centers have expressed their concerns on the true effect of using ethanol blends of up to 20% v/v in in-use vehicles without any modification in the setup of the engine control unit (ECU. When the amount of ethanol in the fuel mix was increased to a level greater than 20%, there was a concomitant increase in saturated hydrocarbon emissions. The emission of more aromatic compounds and unburned ethanol was caused by higher concentrations of ethanol in the fuel mixture than when ethanol was present in lower concentrations. A general reduction in the emissions produced accompanied the vehicle's acceleration. This is because one ethanol molecule has a significantly higher number of oxygen atoms than molecules of other alcohol. The gasoline will take more oxygen to catch fire, so plan accordingly (Koten et al. 2020).

The mixtures that contain between 10 and 15% ethanol have proven to be the most popular, which is likely because they can completely cut emissions. Those fuels that contained a greater proportion of ethanol in their overall makeup had much fewer emissions when compared to the traditional alternatives. When dual fuels were utilized, there was a discernible reduction in the amounts of carbon monoxide, hydrocarbons, and smoke produced. On the other hand, an increase in both the oxidation of the combustion process and the temperatures at which the combustion took place led to a rise in the amount of carbon dioxide and nitrogen oxides released into the atmosphere (Ramadhas et al. 2016, Sambandam et al. 2022).

The quantity of energy required to make ethanol is impacted by the volume of water combined with the ethanol throughout the manufacturing process. Hydrous ethanol had a positive effect on the flame's growth and the time it took for the flame to propagate, but it did not affect the flame's stability. After combining gasoline, methanol, and ethanol, it was examined to see if the resulting mixture was consistent and homogenous (Bielaczyc et al. 2013)but increase others. Ethanol is rarely used neat as an automotive fuel; blends with standard gasoline are much more common. Low (5%–15%. Under every and all conditions of operation, a mixture that contains even a small amount of methanol produces more power than gasoline on its own. Because of the unique qualities exhibited by mixtures of methanol and gasoline, ethanol and gasoline, and their respective combinations, the combustion system has been adapted to accommodate these new fuels. Because of the aforementioned factors, it is challenging to pinpoint the principles of how ethanol or methanol affects emissions. This is because of the complexity of the relationship between these factors. When low-ethanol mixes comprising less than 20% ethanol were utilized, there was no noticeable change in engine efficiency or torque.

On the other hand, there was a reduction in the engine performance when the proportion of blending was increased (Koç et al. 2009, Mohammed et al. 2021, Padmanabhan et al. 2022). This study gives an overview of ethanol as a possible alternative fuel for a flex-powered power generator to meet the goals of the circular bio-economy. This paper details the results of flex-fuel testing conducted on a light-duty power generator using an ethanol-gasoline with an incremental blend.

MATERIALS AND METHODS

Ethanol is an eco-friendly, ecological-made fuel that outperforms gasoline thanks to its higher octane rating. Jobs in ethanol production are especially welcome in rural areas that lack other economic opportunities. Ethanol, a bio-organic fuel, has the potential to displace fossil fuels in vehicles. Potentially helpful in reducing transportation-related carbon emissions and enhancing environmental outcomes (Ramadhas et al. 2016). Blending ethanol with gasoline and its influence on fuel qualities are discussed. In this case study, we use real-world data to demonstrate how adding ethanol to gasoline significantly improves knock resistance and full-load performance. The basic impacts of ethanol combustion and the decreased enrichment need under high speed/high load situations are discussed, along with the potential for downsizing and slowing down that is made possible by higher ethanol concentration (Stein et al. 2013).

For spark-ignition engines, ethanol may be used either alone as a fuel source or blended with gasoline. In 2013, India's BIS Specification 2796: 2013 allowed for a 10% ethanol mix in gasoline, and that number might rise in the future. Studying the effects of using ethanol-blended fuel in a modern gasoline engine is extremely desired. To reduce oil imports, the Indian government previously mandated a 10% ethanol component in gasoline (Ramadhas et al. 2016).

In India, light duty power generator engines are still widely used for power generators that produce greater pollution levels. However, various modifications will be necessary to improve the combustion rate and thermal efficiency of these engines because renewable energy sources are not always accessible in all parts of India and during all seasons. Ethanol is a fuel derived mostly from agricultural resources such as sugarcane and maize. Because of this, ethanol is an enticing replacement for gasoline to decrease dependency on fossil fuels and lower carbon net emissions into the environment. Adding OH components to gasoline improved full combustion and reduced hazardous emissions. This reduction in hazardous emissions affected the combustion potentiality or capacity to burn for a shorter amount of time, which was the shortcoming that the gasoline engine was trying to overcome (Sambandam et al., 2022). The properties of gasoline and ethanol were tabulated in Table 1 (Sambandam et al. 2022).

An investigational experiment was conducted on a low-duty power-generating engine capable of running on Flex Fuel (FF). It was determined to carry out this experiment

Table 1: Properties of flex fuel.

Sl.No	Property	Unit	Ethanol	Gasoline
1.	Lower Heating Value	[MJ.kg^{-1})	26.9	44.0
2.	Kinematic Viscosity, at 20°C	cSt]	1.5	0.5
3.	Density, at 15°C	[kg.m^{-3}]	785	737
4.	Flash Point	[°C]	14	-40
5.	Research Octane Number	RON	115	90
6.	Motor Octane Number	MON	100	82
7.	Oxygen (%)	-	35	0
8.	Stoichiometric Air/Fuel Ratio	-	8.9	14.5

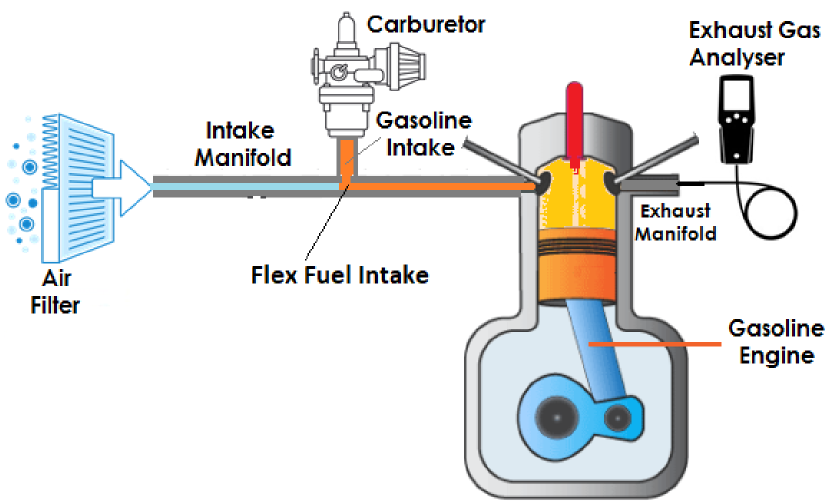

Fig. 1: Schematic diagram of the Flex Fuel setup.

using a spark ignition engine with a compression ratio of 4.5:1 and a peak output of 2.89 kW at an engine speed of 3200 rpm. This engine was a single-cylinder, four-stroke air-cooled engine with 180 cc of work capacity. To guarantee the best possible performance and the fewest amount of harmful emissions, the required test runs, both with and without an ethanol blend, were carried out under four distinct load circumstances, ranging from 25% to 100% capacity. An air-cooled, spark-ignition, single-cylinder, four-stroke engine with an incremental load was employed in this study work to investigate the effects of ethanol blends as flex fuel on the performance and emission characteristics of the engine. The mechanical loading resulted in a change to the incremental load. Fig. 1 presents a diagrammatic representation of the utilization of a light-duty power generation engine (Sambandam et al. 2022).

RESULTS AND DISCUSSION

Impact on Brake Thermal Efficiency

Fig. 2 depicts the variation in thermal brake efficiency as a function of load, and, as was previously said, adding ethanol led to improved combustion. Maximum thermal efficiency of ethanol rises to 9.3%, 16.3%, and 26%, respectively, demonstrating a notable performance boost at full load. Ethanol speeds up combustion, allowing for more efficient use of energy. It is more efficient and displays characteristics that bring the cycle closer to the goal of constant volume combustion.

Higher hydrogen flame velocities and a wider variety of flames contribute to this improvement, making the flex fuel engine more potent. Testing an engine without ethanol under varying loads slows down the combustion process. On the other hand, ethanol greatly increased the combustion rate, leading to greater thermal efficiency. The stoichiometric ratio between ethanol and gasoline is also lower. The increased fuel mass may now be burned with the same air volume. More fuel is used because the lean mixture fills the remaining space.

Impact on Specific Fuel Consumption

The specific fuel consumption of the brakes under four different loads is shown in Fig. 3 for both ethanol-mixed and regular gasoline. Even if the engine load was initially decreased, it was proven that fuel consumption would increase regardless of the mix condition. In addition, ethanol's smaller heating valve than gasoline means that temperature swings will depend on loads. When ethanol is added to the mixture, the engine's specific fuel consumption drops by 6% to 28% across the blends. The results showed

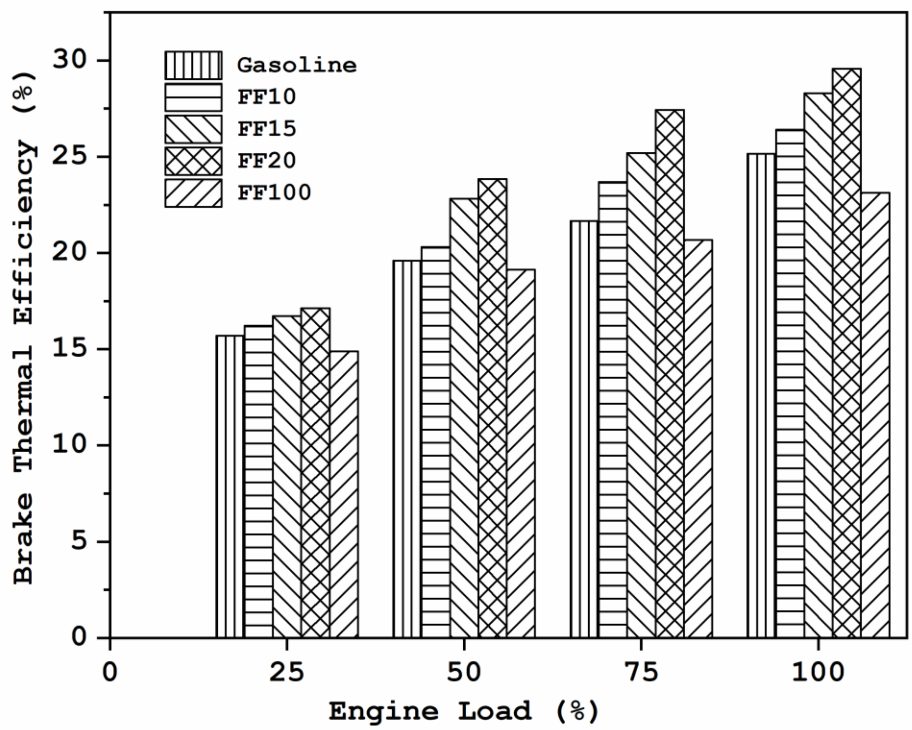

Fig. 2: Impact of flex fuel on brake thermal efficiency.

that using 20% ethanol reduced fuel consumption by 28% compared to gasoline. Adding hydrogen and oxygen to gasoline created a more turbulent mixture of air and fuel, leading to more efficient combustion and a larger flame thrust, and higher calorific values than could have been achieved with gasoline alone.

Impact on Carbon Monoxide Emission

Fig. 4 depicts the CO emission rate versus engine load. Combustion efficiency and the ratio of air to fuel are the primary factors in determining CO emissions. The engine was run at its optimum midrange speed to lower carbon

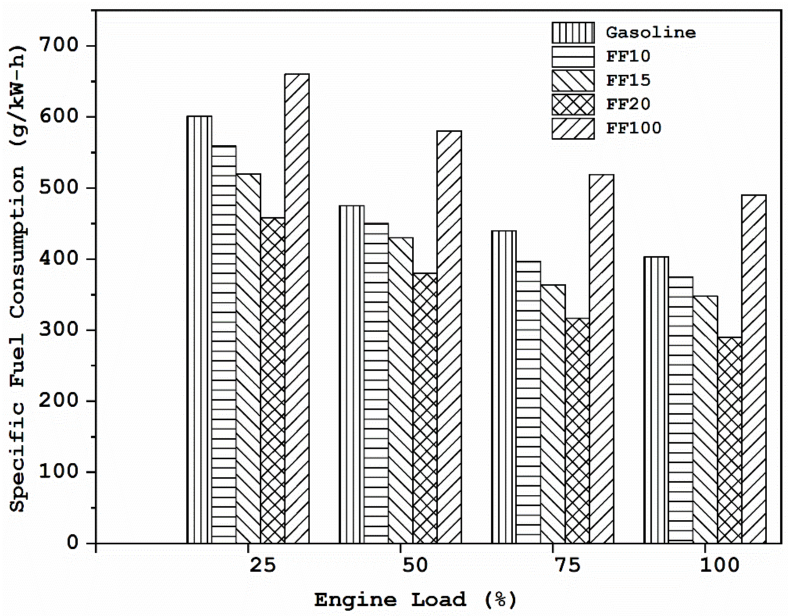

Fig. 3: Impact of flex fuel on specific fuel consumption.

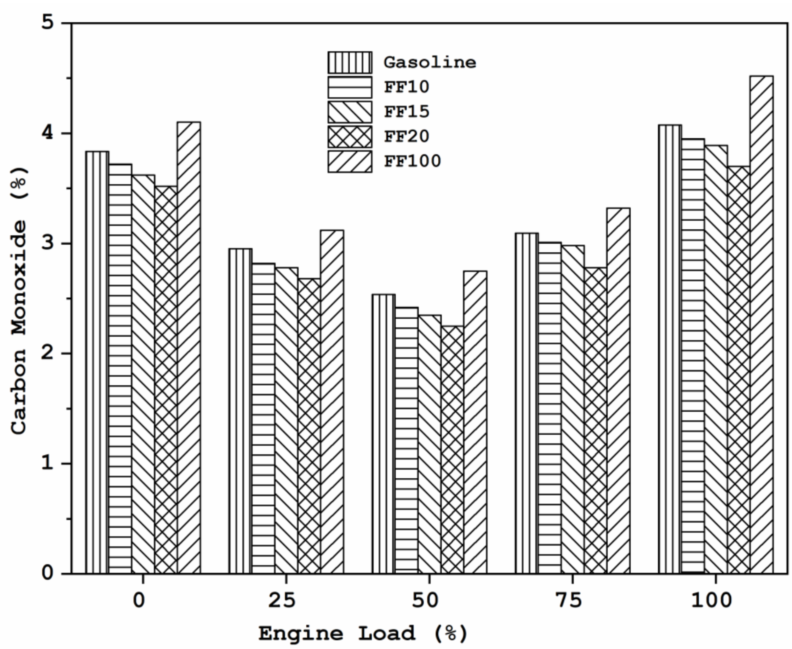

Fig. 4: Impact of flex fuel on carbon monoxide.

monoxide emissions. Combining ethanol and oxygen improved the combustion process, and CO emissions were reduced. It is possible that the introduction of oxygenated compounds that improve CO combustion in the cylinder or post-combustion activities led to a reduction in emissions. However, lowering CO emissions might involve more than watering the gas. Ethanol blends that increase combustion and improve lean-running engine performance can reduce CO by 6% to 23% ethanol percentages, respectively. The chemical properties of ethanol are superior, as it has a wider spectrum of combustibility and a faster flame speed. The rapid and complete combustion of an ethanol-gasoline combination destroys pure gasoline.

Impact on Unburned Hydrocarbon Emission

It can be seen in Fig. 5 that when ethanol was present, the amount of unburned hydrocarbons emitted into the exhaust dropped for all loads. For all loads studied, it was found that the combination of ethanol and HC resulted in a substantial decrease in HC content. Ethanol improved engine performance and led to complete combustion. Since the volumetric flow rates of ethanol differed, the percentage reductions in unburned hydrocarbon volume ranged from 3% to 11%. Compared to gasoline, hydrogen has a shorter quenching time, which reduces hydrocarbon emissions. Ethanol blends decreased hydrocarbon emissions because of the ethanol's low flammability and the relatively high in-cylinder pressure and temperature produced by the rapid flame velocity. Complete combustion occurs due to the additional oxygen provided by the ethanol combination, resulting in less HC emissions.

Impact on Circular Bio-Economy and Environmental

Because of worldwide environmental and health concerns about fossil fuel usage, investment in biofuels as sustainable alternatives has gained steam over the past decade. Therefore, to successfully make the shift to a low-carbon and circular economy, it is essential to properly manage the various components of the biofuel supply chain, such as the production of biomass feedstock, the logistics of transporting biomass, the biofuel production in bio-refineries, and the biofuel distribution to consumers (Ranjbari et al. 2022).

Bio-waste must be converted into high-value energy and resources to achieve a circular bio-economy. Recycling and bioconversion integration for increased process performance is also evaluated. This endeavor aims to reduce barriers to bio-waste recycling in the circular economy. More study, market analysis, and finance are needed to commercialize alternative commodities and encourage their use. To maximize bio-waste usage, utilize a holistic, rigorous strategy that draws on various disciplines and uses data to improve and establish new methods (Xu et al. 2022). The circular bio-economy can help solve global issues. Bioenergy and biomaterials production could lessen environmental impact

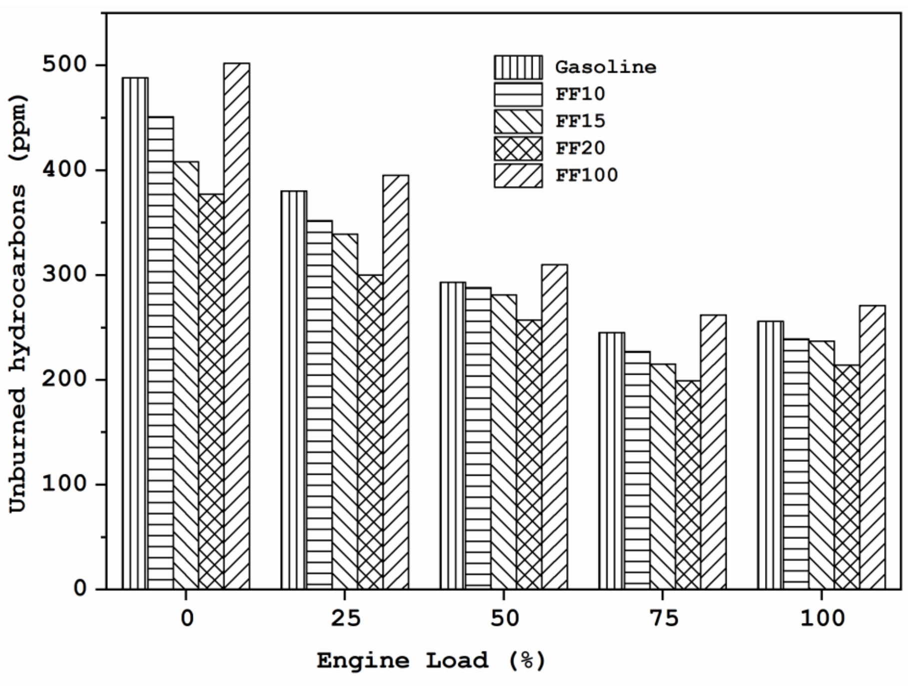

Fig. 5: Impact of flex fuel on unburned hydrocarbon.

by substituting petroleum as an industrial feedstock. The waste bio-refinery linked to the circular bio-economy may help with carbon management and greenhouse gas emissions. Implementing a waste bio-refinery circular bio-economy method exemplifies a low carbon economy by reducing greenhouse gas emissions (Leong et al. 2021).

Ethanol may have certain benefits over fossil fuels in terms of safety because it is water-soluble, biodegradable, and easily evaporated. Ethanol fuel is the most cost-effective alternative to other forms of energy since it can be manufactured in virtually any country. Ethanol is a fuel that may be produced from several plants, including maize. There are several distinct kinds of ethanol, but the one that is most frequently used is E10, and the proportion of E10 to other ingredients in blends can range anywhere from 10 to 15 percent worldwide. In several countries, including the United States and Brazil, it is possible to utilize a high-level ethanol fuel mix that includes between 50 and 85% of ethanol (Jesus et al. 2021, Butt et al. 2021). Ethanol has lower production costs than fossil fuels due to its ease of production. Burning ethanol as fuel produces only carbon dioxide and water as by-products. The released carbon dioxide does not significantly contribute to the problem of pollution.

On the other hand, it is believed that the combustion of ethanol generated from biomass such as maize and sugarcane results in "atmospheric carbon neutrality." This is because as the biomass grows, it takes in carbon dioxide, which has the potential to counteract the amount of carbon dioxide that is emitted when ethanol is burned. The three primary areas of concentration in the circular economy are the feedstock, the manufacturing process, and the distribution of the end product. The product's afterlife never received the consideration it deserved from the company. It has not been considered how the product will be maintained once it has reached the end of its useful service life (Leong et al. 2021, Venkatesh et al. 2018, Xu et al. 2022).

The percentage of ethanol mixed with gasoline in India reached 10.16 percent in 2022, significantly higher than the country's goal. Additionally, the nation has committed to reaching a blending rate of twenty percent by the year 2025. The successful E20 ethanol blending project in India may save the government $4 billion each year in 2020-21 when the country's net petroleum imports will be 185 Mt at $551 billion (Doğan et al. 2017, Stein et al. 2013)ethanol which has high octane rating, low exhaust emission, and which is easily obtained from agricultural products has been used in fuels prepared by blending it with gasoline in various ratios (E0, E10, E20, and E30. Traditional fuels tend to be more expensive, but ethanol is more environmentally friendly since it generates less pollution. This type of mixed fuel is both a requirement and an opportunity due to the large amount of cropland that is now accessible, the expanding production of food grain and sugarcane, and the technological prowess to convert vehicles to operate on E20. Compared to four-wheeled cars, two-wheeled vehicles showed a reduction in CO emissions of up to half, while four-wheeled vehicles saw a reduction of up to thirty percent. In addition, the combination of ethanol and gasoline can cut hydrocarbon emissions by around 20% (Tibaquirá et al. 2018)increasing gasoline octane rating and reducing dependence on petroleum products. However, recently environmental authorities in large urban centers have expressed their concerns on the true effect of using ethanol blends of up to 20% v/v in in-use vehicles without any modification in the setup of the engine control unit (ECU.

The primary goal of this study is to reduce harmful emissions from a small gasoline-powered generator. Carbon monoxide is hazardous to human health because it affects the blood's capacity to deliver oxygen to and from tissues. Specifically, hemoglobin is rapidly oxidized to carboxyhemoglobin upon contact with carbon monoxide in the blood. When carbon monoxide is found in the lungs, hemoglobin does not achieve a saturation level of 100% oxygen. This hydrocarbon has also been demonstrated to decrease the synthesis of white blood cells, suppress the immune system, and make white blood cells more susceptible to infection. Another consideration is that pollutant phototoxicity changes as plants progress through their life cycles (Sambandam et al. 2022, Padmanabhan et al. 2022).

CONCLUSION

Much of the energy used today, especially in transportation, comes from the fossil fuel sector. Experts' focus has shifted to renewable energy sources like ethanol on flex-fuel due to the depletion of fossil fuels and the discharge of harmful pollutants. To increase the engine's performance, minimize harmful emissions on environmental sustainability, and fulfill circular bio-economy standards, an experimental inquiry was undertaken on a light-duty power generator fueled by an ethanol-gasoline blend. When ethanol is added to the mixture, the engine's specific fuel consumption drops by 6% to 28% across the blends. The maximum thermal efficiency of ethanol rises to 26% at full load. The percentage reductions in unburned hydrocarbon volume ranged from 3% to 11%. Ethanol blends that increase combustion and improve lean-running engine performance can reduce carbon monoxide by 6% to 23%. This study gives an overview of ethanol as a possible alternative fuel for flex-powered power generators to meet the goals of the circular bio-economy.

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