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Green Initiatives: A Review of Ethanol as an Alternate Automobile Fuel

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ABSTRACT

Bio-fuels are important because they replace petroleum fuels. A number of environmental and economic benefits are claimed for bio-fuels. Bio-ethanol is by far the most widely used bio-fuel for transportation worldwide. Production of bio-ethanol from biomass is one way to reduce both consumption of crude oil and environmental pollution. Using bio-ethanol blended gasoline fuel for automobiles can significantly reduce petroleum use and exhaust greenhouse gas emission. Bio-ethanol can be produced from different kinds of raw materials. This paper reviews the current status of the technology for ethanol production. The effect of the fuel on engine performance, durability and emissions is also considered. Ethanol is an attractive alternative fuel because it is a renewable bio-based resource and it is oxygenated, thereby providing the potential to reduce particulate emissions in spark–ignition engines. This paper reviews the existing procedures for ethanol production, atmospheric aspect of ethanol fuel, ethanol as fuel and performance evaluation of ethanol. About 71 published studies (1980-2015) are reviewed in this paper. It is marked from the literature survey articles that ethanol blends performance is the most frequently studied as an alternative fuel.

Keywords:
Ethanol, Alternative Fuel, Renewable, Environment, Bio fuel

1. Introduction

The increased concern for the security of the oil supply and the negative impact of fossil fuels on the environment, particularly greenhouse gas emissions, has put pressure on society to find renewable fuel alternatives[1]. A challenge that humanity must take seriously is to limit and decrease the greenhouse effect caused by various human activities[2]. A 1999 study in France, Austria and Switzerland, revealed that emissions from road transport alone caused 21,000 premature deaths a year while direct road accidents accounted for 9947 deaths over the same period in these three countries[3]. A major contributor to the greenhouse effect is the transport sector due to the heavy, and increasing, traffic levels[4]. In spite of on-going activity to promote efficiency, the sector is still generating significant increases in CO^2 and other hazardous emissions. Emissions of carbon dioxide from the combustion of fossil fuels, which contribute to long-term climate change[5]. CO^2 levels are

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predicted to increase over the next century from 369 parts per million, to between 540 and 970 parts per million[6]. This translates to an increase in globally averaged temperatures of between 1.4 and 5.8 °C[7], in turn leading to an increase in extreme weather events and a rise in sea levels. Figure 1 shows projected emissions of carbon dioxide.

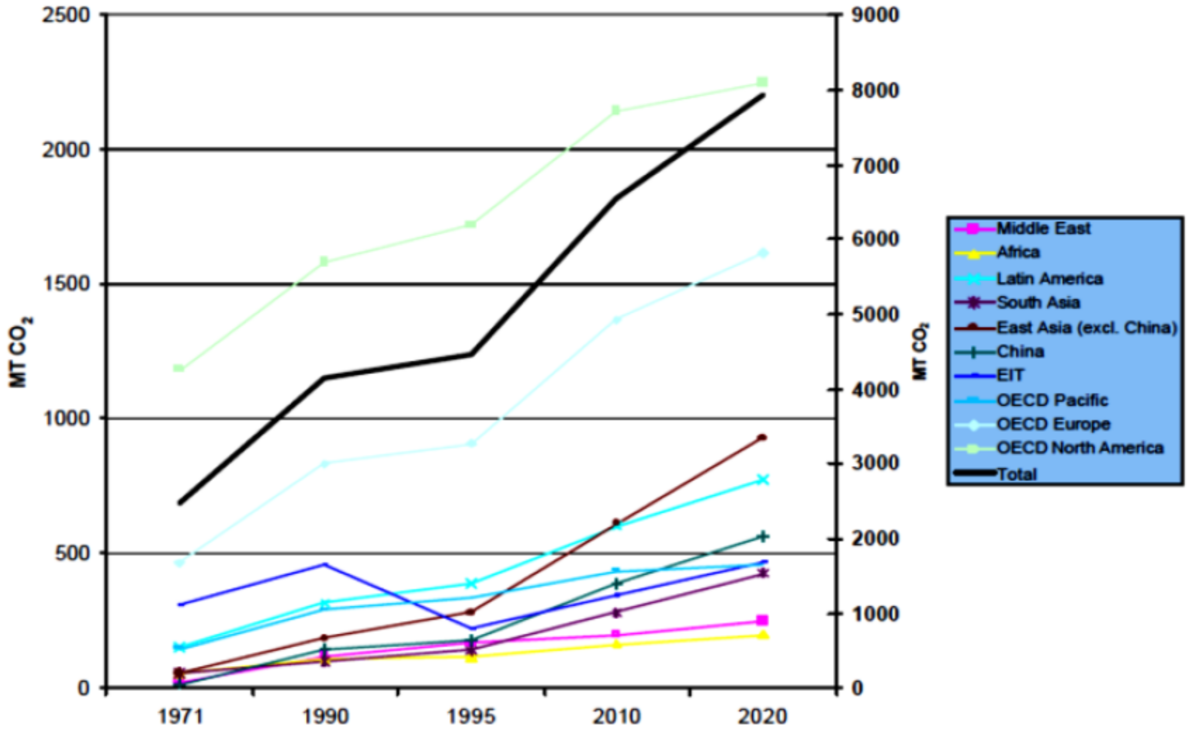

Fig. 1. Past and projected emissions of carbon dioxide[8]

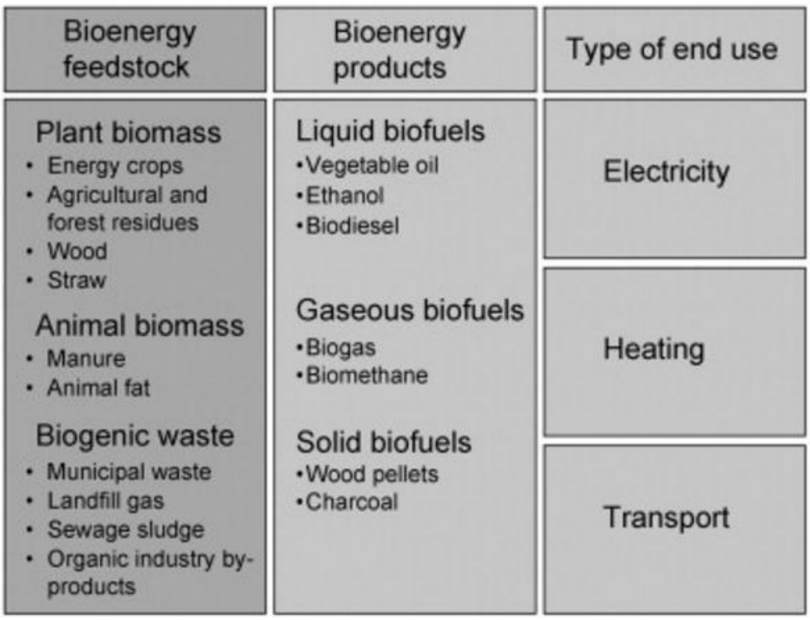

Fig. 2. Typology of bioenergy feedstock, products and end users [11-13]

Growing scientific evidence on the negative implications of global climate change induces business and governments to take measures to reduce global carbon emissions [9], forced the search for alternative, sustainable, renewable, efficient and cost-effective energy sources with lesser greenhouse gas emissions [10].The use of bioenergy, i.e. of energy generated from organic matter such as energy crops, agricultural and forest residues, wood, manure and other biogenic material (Fig. 2), can serve as a strategy to mitigate climate change.

Ethanol and ethanol–gasoline blends have a long history as automotive fuels [14-16]. In 1896, Henry Ford designed his first car, the 'Quadricycle' to run on pure ethanol [16]. Then In 1908, ford motor company's first car, the model T, used ethanol corn alcohol as fuel energy [15,16]. Ethanol has been used as fuel in the United States since at least 1908. Although early efforts to sustain ethanol program failed, oil supply disruptions and environmental concerns over the use of lead as a gasoline octane booster renewed interest in ethanol in the late 1970s[17]. Ethanol is now found at most public gas stations in some countries due to the laws and recommendations the Alternative Motor Fuels Act (AMFA) (1988)[18], Clean Air Act (1990), Energy Policy Act (2005) and most importantly The Renewable Fuel Standard Program September 2006. Ethanol is the world's most popular biofuel for use with existing spark-ignition (SI) engines[19]. The increase in ethanol use has been promoted by several legislative measures, including the Energy Independence and Security Act (EISA 2007) and the Renewable Fuel Standard (RFS), which was initiated in 2005 and expanded in 2007[20].

Ethanol has already been introduced on a large scale in Brazil, the US and some European countries[21,22]. Any material that is capable of being fermented by enzymes can serve as a source for Ethanol production. Lignocellulose waste materials obtained from energy crops, wood and agricultural residues, represent the most abundant global source of renewable biomass[23]. Among the agricultural residues, wheat straw and rice straw are the largest biomass feedstock in Europe [24]. About 21% of the world's food depends on the wheat crop and its global production needs to be increased to satisfy the growing demand of human consumption consequently, wheat straw would serve as a great potential feedstock for production of ethanol in 21st century[25].

Gasoline and diesel fuel additives that help reduce exhaust gas pollutants have also been investigated. Exhaust emissions were significantly lowered in the range 45 to 93% for a fleet of 50 1986—1987 models designed for unleaded gasoline when compared with a corresponding fleet of leaded fuel cars of on-average1980 models [26]. A synthetic fuel (made of soybean oil or animal fat hydrolyzed to glycerol) was tailored to match petroleum diesel fuel and blended with ethanol [27].

All kind of internal combustion engines i.e. Spark Ignition (SI) and Compression Ignition (CI) are equally responsible for the emission of gaseous such as nitrogen oxide (NOx), carbon monoxide (CO), carbon dioxide (CO2), hydrocarbon (HC) and smoke opacity. Some of the gaseous emitted would have direct hazardous effect. They are also polluting the surrounding atmosphere and cause acid rain, global warming, greenhouse effect and other hazardous effects. The purpose of this work is to review the recent advances for ethanol production as well as to analyze the environmental aspects, liability of ethanol as a fuel and comparative study of ethanol with gasoline.

2. Production of Ethanol

The most attractive properties of ethanol as an SI engine fuel are that it can be produced from renewable energy sources such as sugar, cane, cassava, many types of waste biomass materials, corn and barley[28-34]. Fuel ethanol can be formed by numerous methods. The first step in the conversion of biomass to ethanol is size reduction and pretreatment. Only the enzymatic process (Figure 3) will be discussed because it is considered to be the most promising technology [35,36].

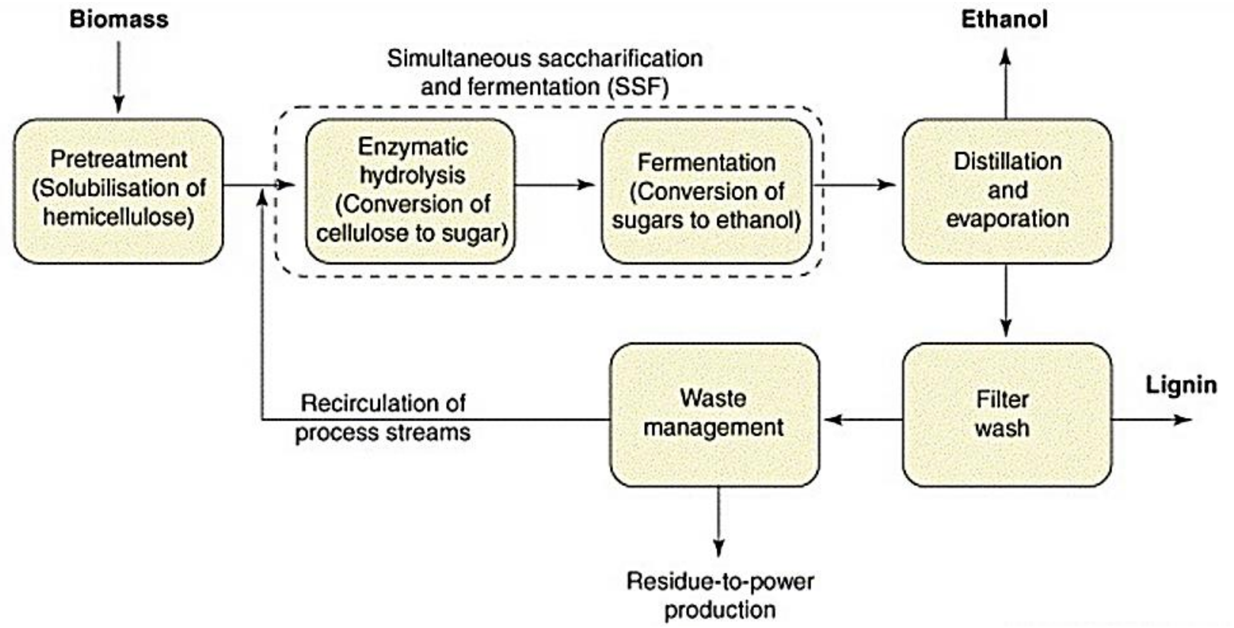

Fig. 3. Schematic flow sheet for the conversion of biomass to ethanol[21]

The most common is the dry mill process that accounts for 75% of existing production. Dry mill plants usually yield ethanol as the primary product with animal feed (called Dried Distiller's Grains with Soluble, DDGS) and carbon dioxide as co-products. In dry milling the entire corn kernel is ground and used as the feed stock for ethanol production [37,38]. Process layout is shown in figure 3.In wet milling, the corn is first separated into its components: starch, fiber, gluten and germ[37]. These plants produce ethanol as one of several food industry products including corn oil, corn syrup, and corn sugar. After fermentation the alcohol is distilled to 190 proof to reduce the water content. Afterward, molecular sieve technology is used to remove the remaining water [39]. The main difference between dry milling and wet milling is that the entire grain is milled to a median diameter of approximately 1 mm and the different components of the cereal grain are not fractionated before the water and enzyme are added; the slurry is processed as in wet milling. In both systems, the sugar-containing juice that leaves the processor (mash or wort) is essentially sterile, and this is a crucial point in the subsequent successful downstream processing [40].

Ethanol is produced from the fermentation of sugar by enzymes produced from specific varieties of yeast. The five major sugars are the five-carbon xylose and arabinose and the six-carbon glucose, galactose, and mannose [42]. The conversion of cellulosic biomass to ethanol parallels the corn conversion process. The cellulose must first be converted to sugars by hydrolysis and then fermented to produce ethanol (Figure 4). Cellulosic feedstock (composed of cellulose and hemicellulose) are more difficult to convert to sugar than are carbohydrates. Two common methods for converting cellulose to sugar are dilute acid hydrolysis and concentrated acid hydrolysis, both of which use sulfuric acid [17].

The first major fuel-ethanol program (ProAlcool) started in Brazil in 1975, followed by programs in the USA in 1978 and, more recently, in Canada (figure 6) [40]. Although many other countries produce ethanol for fuel and other purposes, major production has only occurred in those countries with especially favorable agricultural and economic conditions.

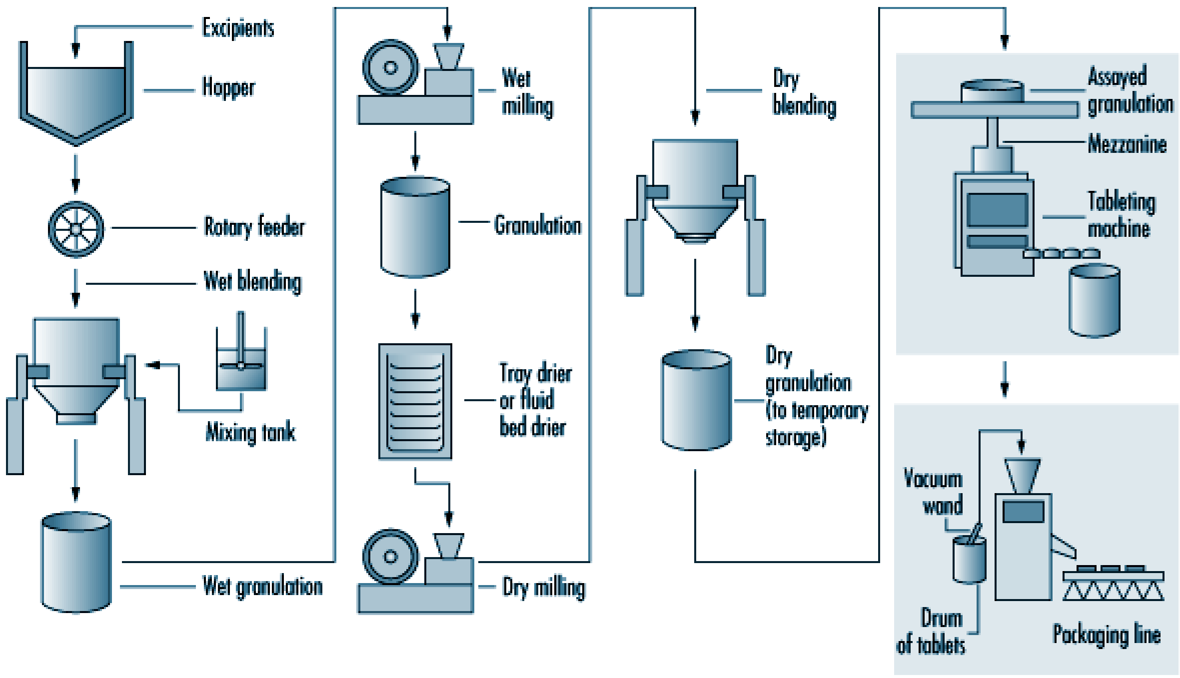

Fig. 4. Dry mill process layout [41]

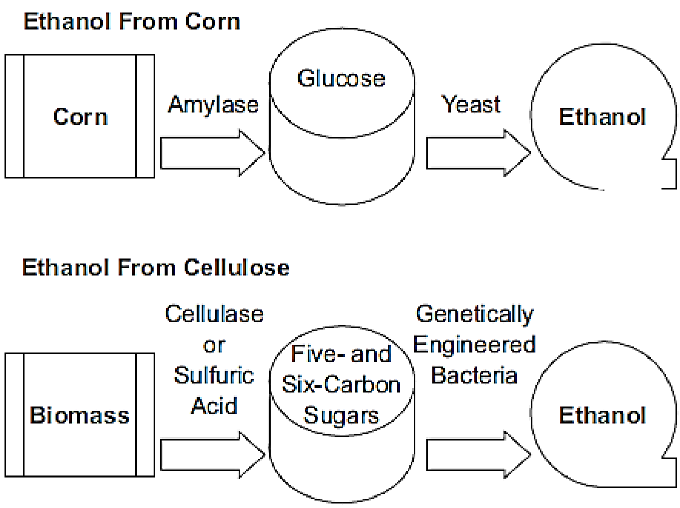

Fig. 5. Ethanol Production from Corn and Cellulose [42]

Country	Crop	Fuel-ethanol production (10^9 litres)
Brazil	Sugar-cane (juice and molasses)	10.5 hydrous
		6.5 anhydrous (in 1999)
USA	Maize (95%) plus some wheat and barley	5.3 anhydrous (in 1998)
Canada	Maize plus 15% wheat	0.24 anhydrous (in 1998)

Fig. 6. Major fuel-ethanol producers[40]

3. Environmental Aspects of Ethanol Fuel

Exhaust emissions from engines are dependent on fuel composition[43], air/fuel equivalence ratio[44], driving conditions, oxygen content and the chemical structure of additive [45].Ethanol increasingly promoted as alternate transport fuel consequent in less greenhouse gas (GHG) emissions as compared to the gasoline, economical and consider antiknock fuel[23,46,47]. The significant environmental advantage of ethanol is that, unlike gasoline and diesel, its consumption does not significantly raise atmospheric intensity of CO^2 [48]. This is because “CO2” is counter-balanced by the environment through photosynthesis [49]. On a life cycle basis, ethanol produced today roughly reduces 20% GHG emissions, and in terms of fossil energy, it delivers one third or more energy [50,51]. This GHG emission reduction could be increase by producing ethanol from more abundant cellulosic biomass sources [52]. Greenhouse gas reductions with respect to their source is shown in figure 7.

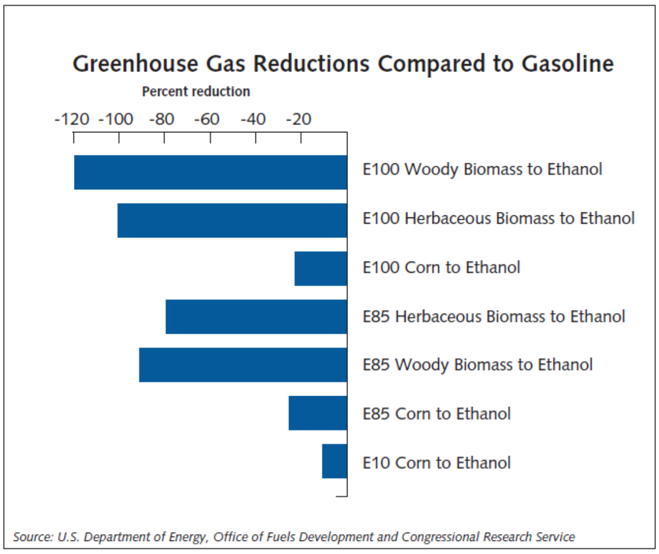

Fig. 7. Greenhouse gas reductions compared to gasoline

Discharge of “NOx” through exhaust decreased by approximately 50% as the ethanol blending increase from E_0 to E_{30}-E_{40}, while no further decrease reported by increasing blending ratio with E_{55} [53]. By adding ethanol to the fuel CO and HC emissions concentrations in the engine exhaust decrease dramatically [29,54-56]. Moreover, the specific fuel consumption, CO, CO2, HC and NOx emissions were reduced by about 3%, 53%, 10%, 12% and 19%, respectively[57,58].

4. Ethanol as a Fuel

Biofuels have the potential to leapfrog traditional barriers to entry because they are liquid fuels compatible with current vehicles and bendable with current fuels. Ethanol blends have been approved for use by every automobile manufacturer that does business in the United States. A primary advantage of ethanol for engine performance is octane enhancement: a 10% blend of ethanol in gasoline raises the octane number by 2.5 points. Some critics say that ethanol contains less energy per unit volume than unblended gasoline[59]. This is true—a 10% ethanol blend minimally reduces miles per gallon compared to pure gasoline. To overcome this deficiency, engines are being designed that take advantage of the high-octane benefits of ethanol while increasing fuel efficiency [60].

Alcohol and gasoline, despite the fact that they are from different chemical classes, are remarkably similar. One of the most important properties of a fuel is the amount of energy obtained from it when it is burned [61]. Ethanol (C_2H_5OH) is becoming a popular fuel because it burns cleaner and cheaper to manufacture. Ethanol was used as a fuel at high compression ratio to improve performance and to reduce emissions in a small gasoline engine with low efficiency[58,62].

The combustion of ethanol with a stoichiometric amount of air proceeds as follows

$$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O + Q \quad (1)$$

This combustion reaction is exothermic and liberates 28 MJ/kg (11,990 BTU/lb) of vaporized ethanol or 1.27 GJ/kg mol (548,000 BTU/mol)[63].

The world's top ethanol fuel producers in 2011 were the United States with 52.6 billion liters and Brazil with 21.1 billion liters, accounting together for 87.1% of world production of 84.6 billion liters[64]. Strong incentives, coupled with other industry development initiatives, are giving rise to fledgling ethanol industries in countries such as Germany, Spain, France, Sweden, China, Thailand, Canada, Colombia, India, Australia, and some Central American countries. Figure 8 shows the top 10 ethanol fuel producers between years 2007-2011.

Annual Fuel Ethanol Production by Country (2007–2011)
Top 10 countries/regional blocks
(Millions of U.S. liquid gallons per year)

World rank	Country/Region	2011	2010	2009	2008	2007
1	United States	13,900	13,231	10,938	9,235	6,485
2	Brazil	5,573.24	6,921.54	6,577.89	6,472.2	5,019.2
3	European Union	1,199.31	1,176.88	1,039.52	733.60	570.30
4	China	554.76	541.55	541.55	501.90	486.00
5	Thailand			435.20	89.80	79.20
6	Canada	462.3	356.63	290.59	237.70	211.30
7	India			91.67	66.00	52.80
8	Colombia			83.21	79.30	74.90
9	Australia	87.2	66.04	56.80	26.40	26.40
10	Other			247.27		
	World Total	22,356.09	22,946.87	19,534.993	17,335.20	13,101.7

Fig. 8. Top 10 Ethanol fuel producers between years 2007-2011

Ethanol is really good at pulling water out of the air around it due to –OH group present in ethanol. The water condenses in the fuel tank or storage tank and will pull the ethanol out of suspension with the gasoline in a process called Phase Separation. It decreases the octane out of the gasoline, which leaves a layer of octane-poor gasoline (often three numbers lower than before) on top and a water-ethanol layer mixture on the bottom. If the water-alcohol gets sucked into the combustion chamber, there will be great potential for engine damage[65].

5. Performance Evaluation of Ethanol

Low value ethanol blends (E5 and E10) are used in conventional gasoline engines without any modification and increases the octane number of fuel [66]. Another very common ethanol blend which is used for vehicles is E85 and Brazil is the biggest user of it. As ethanol has high octane number but low calorific value, on the other hand gasoline has low octane number but high calorific value. So, the purpose of using ethanol blend is to reach at an optimum point where both octane number and calorific value give best performance. Comparison of physical and chemical properties of both fuels are shown in table 1.

Table 1
Chemical and Physical Properties of Fuels

PROPERTY	METHOD	ETHANOL	GASOLINE
Formula		C_2H_5OH	C_4-C_{12}
Molecular Weight		46.07	100–105
Specific heat (kJ/kg K)		2.4	2.0
Viscosity (mPa s) at 20 °C		1.19	0.37–0.44
Lower heating value (MJ/m^3)		21.1	30–33
Flash point (°C)		13	–43
Auto-ignition temperature (°C)		423	257
Specific heat (kJ/kg K)		2.4	2.0
Viscosity (mPa) at 20 °C		1.19	0.37–0.44
Research Octane number (RON)	ASTM D 2699	120-135	95.5
Motor Octane number (MON)	ASTM D 2700	100-106	85
density (15 °C), g/mL	ASTM D 4052	0.79	0.739
lower heating value, MJ/kg	SS 155138	26.7	43.8

Values are given for pure fuels, without addition of oil "All properties content from Automotive Fuels Reference Book[67,68]

Engine torque and brake specific fuel consumption variations at 2000 rpm engine speed are seen in Figure 9. The engine torque increased with increasing compression ratio up to 11:1, the increasing ratio is about 8% when compared with 8:1 compression ratio. However, from 11:1 to 13:1 compressions ratio, increments are about 0.95% with E0. The highest increasing ratio of engine torque was obtained at 13:1 compression ratio with E40 and E60 fuels, the increment is about 14% when compared with 8:1 compression ratio. Minimum brake specific fuel consumption (BSFC) was obtained at 11:1 compression ratio with E0 fuel [69].

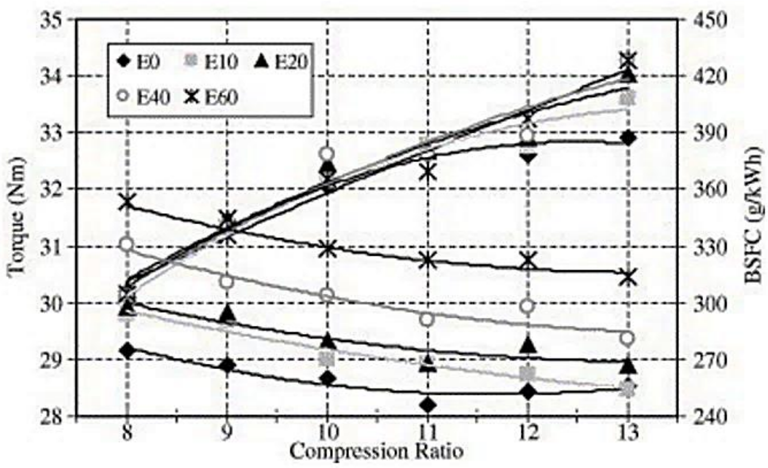

Fig. 9. Variation of BSFC and engine torque versus compression ratio (engine speed: 2000 rpm)[69]

Figure 10 shows an increase in the volumetric efficiency as the percentage of ethanol in the fuel blends increases. This is due to the decrease of the charge temperature at the end of the induction process (Ta). This decrease is attributed to the increase in the charge temperature by an amount T_h as a result of the heat transfer from the hot engine parts and the residual gases in the charge.

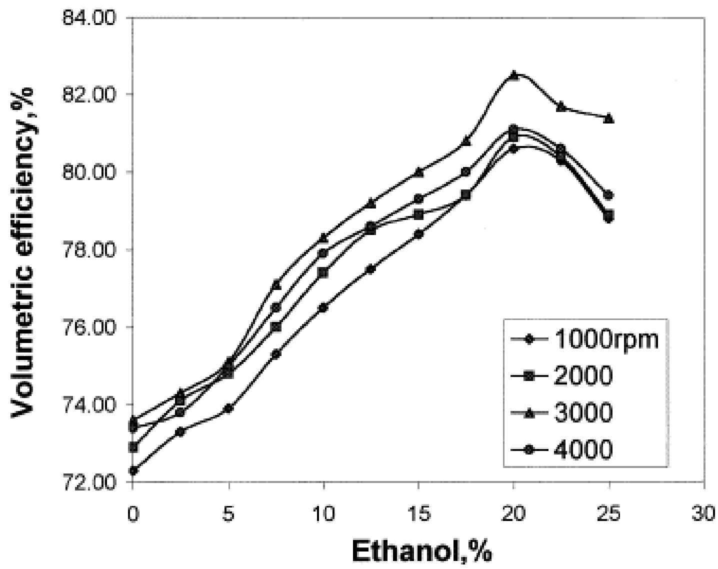

Fig. 10. The effect of ethanol addition on the volumetric efficiency[29]

The ratios of fuel consumption and CO_2 emissions for real-world measurement and dynamometer tests were close to the theoretical ratios. However, the ratios of CO, NOx and THC emissions varied by vehicle model. Results are shown in table 2.

Table 2
Average Fuel Consumption and Emission Rates based upon FTP75 Dynamometer Test

Vehicle Model	Fuel Type	No. of Vehicle Tests	Mileage Accumulation (miles)	Fuel Economy (mpg)	Fuel Consumption (gallon/mile)	Emission Rate (g/mile)			
						CO	CO_2	NO_x	THC
Taurus	E85	12	0-5000	15.4	0.065	1.13	405	0.100	0.107
		11	5000-10000	15.4	0.065	1.35	402	0.117	0.135
		5	10000-15000	15.4	0.065	1.28	397	0.119	0.153
	Gasoline	15	0-5000	20.0	0.050	1.15	431	0.100	0.103
		10	5000-10000	20.0	0.050	1.46	429	0.120	0.116
		12	10000-15000	20.4	0.049	1.17	423	0.168	0.096
Lumina	E85	15	10000-15000	13.9	0.072	2.46	448	0.184	0.125
		6	15000-20000	14.1	0.071	2.50	438	0.254	0.132
		6	20000-25000	13.9	0.072	3.27	443	0.192	0.135
		4	25000-30000	14.3	0.070	2.88	429	0.212	0.142
	Gasoline	12	10000-15000	19.6	0.051	4.26	447	0.645	0.258
		8	15000-20000	19.6	0.051	4.72	445	0.635	0.263
		4	20000-25000	18.9	0.053	5.58	461	0.641	0.285
		2	25000-30000	19.2	0.052	6.86	446	0.590	0.288

Notes: Different vehicles were tested for each fuel for a given vehicle model, fuel type, and mileage accumulation. The E85 tests were with Flexible Fuel Vehicles (FFVs) and the gasoline tests were with conventional vehicles [70,71].

6. CONCLUSION

Alcohols have been used as a fuel for engines since 19th century. Among the various alcohols, ethanol is known as the most suited renewable, bio-based and ecofriendly fuel for spark-ignition (SI) engines. The most attractive properties of ethanol as an SI engine fuel are that it can be produced from renewable energy sources such as sugar, cane, cassava, many types of waste biomass materials, corn and barley. In addition, ethanol has higher evaporation heat, octane number and flammability temperature therefore it has positive influence on engine performance.

This study examines the ethanol enrichment of unleaded gasoline, with specific attention to the following environmental impacts: (1) air pollutant emissions; (2) greenhouse gas emissions; (3) Ethanol as a fuel (4) Performance evaluation of ethanol. Based on detailed literature reviews, it is found that:

- Food crops and nonfood crops play an important role in ethanol production.
- Ethanol is a renewable resource that yields a positive energy balance.
- Provide a viable alternative produced domestically, thereby reducing dependence on fossil fuel.
- Ethanol significantly reduces engine emissions that endanger the environment.
- Ethanol is a proven performer in internal combustion engines.
- The addition of ethanol to gasoline fuel enhances octane number of the blended fuels.
- Higher compression ratios improved engine performance.
- It becomes clear that using and producing ethanol for transportation is good for country's economy, environment, and energy future.

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