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Characterization and Analysis of Bioethanol Blended Fuel as an Alternative Transportation Fuel in Bangladesh

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Abstract: In Bangladesh, the demand for petroleum products has been increasing over the years. Transportation sector is the principal consumer of petroleum products in this country. At present, diesel, petrol (80 RON gasoline), and octane (95 RON gasoline) are the petroleum-based transportation fuels commonly used in Bangladesh. Domestically produced petrol from crude oil and condensate is adequate to meet the local demand; however, Bangladesh has to import most of the octane. Besides, petroleum derivatives contribute significantly to the GHG emission load of the country. To ensure energy security, to reduce expenditure of foreign currency and dependence on foreign supply, and to secure the environment, Bangladesh is currently exploring renewable energy sources. Bioethanol produced from biomass can be a potential eco-friendly alternative energy source for Bangladesh. Although Bangladesh does not commercially produce bioethanol till date, there have been few initiatives at the private sector in this regard. Therefore, it is important to understand the feasibility of using bioethanol and bioethanol blends as alternative transportation fuel in Bangladesh. In this study, key fuel properties (specific & API gravity, RVP, viscosity, calorific value, sulfur content, copper corrosion, water & bottom sediment, water content, carbon residue, and ASTM distillation), and pollutant emission characteristics (carbon monoxide, carbon dioxide and hydrocarbon emission) of bioethanol blend petrol and octane were analyzed at various blending ratios. Physicochemical properties of bioethanol blended petrol and octane were found up to standard. Results show that, when blended with petrol and octane at low ratios, locally produced bioethanol causes less than 1 psi increase in RVP, around 10 percent decrease in calorific value, up to 5 percent reduction in sulfur content, and warrants minimum or no modification of conventional spark ignition engines. Experimental data from emission analysis indicates that using bioethanol blends is favorable from environmental viewpoint due to lesser pollutant emission. Impact on food cycle analysis shows that producing bioethanol locally, to replace up to 10 percent of the combined use of petrol and octane, will have minimum impact on the food security of the country. This study will provide the feasibility analysis of local production of bioethanol and the baseline properties of bioethanol blends as alternative transportation fuel.
Keywords: Bioethanol, transportation, fuel characteristics, economy, environment, food security.

1. Introduction

Globally the demand for energy is gradually increasing because of the limited reserve of fossil fuels, their unstable market price and detrimental impact on the environment and human life, the use of renewable energy has been gaining ground. With significant agricultural and industrial development, the demand for energy in Bangladesh is also growing consistently. In Bangladesh, transportation sector is one of the primary consumers of energy, accounting for more than half of the total demand for petroleum products in the country [1]. Currently, Compressed Natural Gas (CNG) along with petroleum derivatives, namely, diesel, petrol (80 RON gasoline), and octane (95 RON gasoline), are used as transportation fuels in Bangladesh. Even though approximately 300,000 motor-driven vehicles are using CNG as fuel in this country [2], the demand for petroleum-based transportation fuels is still growing [3]. Moreover, to preserve the limited reserve of natural gas in the country, the government has already restricted access to CNG by limiting the dispensing hours and increasing the price [4]. Such restrictions coupled with the increasing number of vehicles in the country will inevitably cause the demand for transportation fuel to rise in the upcoming years. On the other hand, exhaust emission from the rapid growth of transportation vehicles is adversely affecting the mass population. Vehicular air pollution is a major cause of respiratory distress in the urban areas of Bangladesh [5]. Therefore, for sustainable economic growth, it is essential for Bangladesh to look for renewable, alternative fuel sources to meet the growing demand for transportation fuel.

Considering the above-mentioned issues, it has become imperative for Bangladesh to explore locally available renewable energy sources to provide clean fuel [6]. Bioethanol can be a potential renewable energy source to be used either as a fuel or as a gasoline enhancer in Bangladesh. Any biomass containing sugar can be used to produce bioethanol through fermentation. Being an agricultural country, Bangladesh produces a large amount of corn and broken rice, a portion of which can easily be used as raw material for bioethanol production. Recognizing the potential, initiatives have recently been taken in the private sector to produce bioethanol from broken rice and maize.

Bioethanol, when used as a gasoline additive, increases the octane number of gasoline and improves engine performance [7,8,9]. Plants and biomass, the raw materials of bioethanol, consumes carbon dioxide produced during the combustion of bioethanol, hence, bioethanol is carbon neutral. Several studies have shown that sugarcane-based ethanol may reduce GHG emissions up to 90 percent [10]. Moreover, bioethanol, unlike gasoline, is an oxygenated fuel that contains 35 percent oxygen, which reduces particulate matter, carbon monoxide (CO) and NOx emission [11]. Compared to common gasoline additives, such as MTBE (Methyl Tertiary Butyl Ether) and benzene, bioethanol has greater octane booster properties [12]. The auto-ignition temperature and flash point of alcohol are higher than those of gasoline, which makes

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it safer for transportation and storage [13]. Furthermore, the latent heat of evaporation of alcohol is 3–5 times higher than that of gasoline, which makes the temperature of the intake manifold lower, and increases the volumetric efficiency [14]. Using bioethanol as a gasoline supplement has numerous advantages; however, one of the major concerns about commercial production of bioethanol is the potential impact on food security. Bioethanol production process converts only the starch content of the raw material while the protein and other contents of raw materials remain the same. Hence, the by-product of the process, dry distillers grain solubles (DDGS), containing a high amount of protein, can be used as poultry and cattle feed, which is the main use of broken rice and other raw materials used for bioethanol production in Bangladesh. The cost of production and consequently, the price of bioethanol is currently higher than petrol or octane in Bangladesh. Nevertheless, the price of petroleum products is often fluctuating. Moreover, using advanced technology in bioethanol production process is bringing down the cost of production while increasing yield [15,16,17,18]. Thus, in the coming future, replacing a percentage of the current use of petrol and octane can reduce dependence on import and save foreign exchange, and thereby, lead to a more stable economy for Bangladesh [6]. Also, domestic bioethanol production will create job opportunities. According to the Renewable Fuel Association, ethanol industry jobs have proven to be stable, well paid, fulfilling, and safe [19].
It is important to evaluate the physicochemical properties of locally produced bioethanol, bioethanol blends and the potential impact on local economy and food security. In this study, key fuel properties and pollutant emission characteristics of bioethanol blend petrol and octane, and the protein content of DDGS were analyzed. Current fossil fuel consumption along with their negative effects has been critically discussed to address the necessity of bioethanol blends as transportation fuel in Bangladesh. Economic aspects attributed to the annual consumption of petrol and octane, and possible savings resulting from replacing a fraction of the fossil fuel by bioethanol has been assessed as well. Availability of raw materials required for producing bioethanol locally and possible impact on food economy have also been analyzed. Overall, this study will give a comprehensive idea about the feasibility of using bioethanol blend fuels as an alternative transportation fuel in Bangladesh.

2. Material and Methods

In this study, key fuel properties of bioethanol, petrol, and octane samples along with bioethanol blend petrol and octane samples containing 5, 10, 15 and 20 percent bioethanol were assessed. The pollutant emission of a Spark Ignition (SI) engine was also investigated using petrol, octane, and bioethanol blend petrol and octane samples containing 5 and 10 percent bioethanol. The protein content of broken rice, maize, and DDGS was determined to evaluate the use of DDGS as animal feed as well.

2.1 Sample Collection and Preparation

Fuel-grade bioethanol sample was collected from Sunypun Organics Limited, Bangladesh. The collected bioethanol sample was produced from multi-feedstock, which was converted to monomeric sugars via enzymatic hydrolysis. The sugars were fermented using yeast to produce bioethanol. The produced bioethanol was purified in a multi-pressure distillation column with integrated evaporator operating under vacuum at low temperature and then dehydrated to obtain the final product (Figure 1).

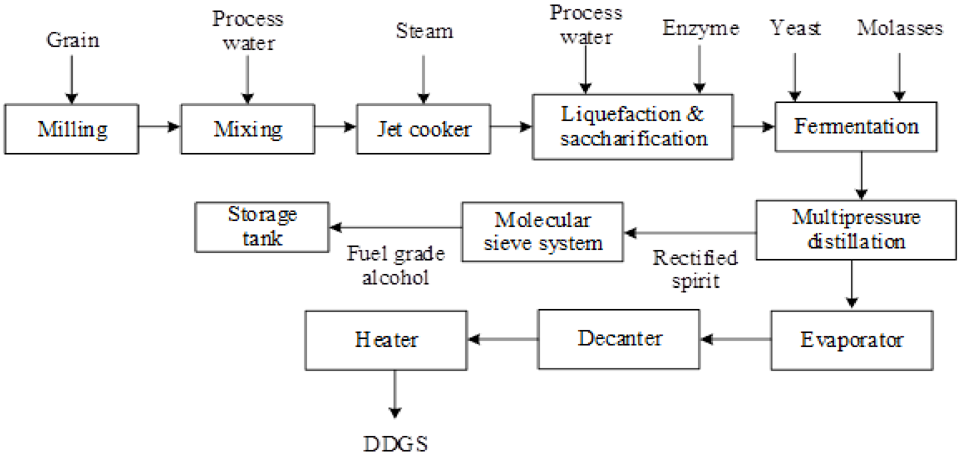


Figure 1: Simplified block diagram of bioethanol production process.

Petrol and octane were purchased from local fuel station (Nilkhet, Dhaka). The bioethanolblend petrol and octane samples containing 5, 10, 15 and 20 percent bioethanol were prepared in the laboratory using the collected bioethanol sample, petrol, and octane. For further discussion, the samples will be referred to by their individual sample ID (Table 1).

Table 1: Sample identification

Sample	Sample ID
Bioethanol	E100
Petrol	P-E0
5 per cent bioethanol blended with petrol	P-E5
10 per cent bioethanol blended with petrol	P-E10
15 per cent bioethanol blended with petrol	P-E15
20 per cent bioethanol blended with petrol	P-E20
Octane	O-E0
5 per cent bioethanol blended with octane	O-E5
10 per cent bioethanol blended with octane	O-E10
15 per cent bioethanol blended with octane	O-E15
20 per cent bioethanol blended with octane	O-E20

2.2 Methodology

2.2.1 Fuel properties

For this study, several fuel properties were tested according to ASTM specification. These test methods are listed in Table 2.

Table 2: List of test methods.

Parameter tested	ASTM test method
Specific gravity	ASTM D 1298-99
Reid vapor pressure	ASTM D 323-99a
Viscosity	ASTM D 88-94
Calorific value	ASTM D 2014-96
Sulfur content	ASTM D 3177-89
Copper corrosion	ASTM D 130-04
Water & bottom sedimentation	ASTM D 1796-97
Water content	ASTM D 95-70
ASTM distillation	ASTM D 86-04b

Carbon residue of all samples was tested by gravimetric method. The water content of bioethanol was additionally calculated using the specific gravity of the sample, which was measured by hygrometer, and data from Table 2-110 of section 2 from Perry's Chemical Engineers' Handbook [20]. The water in the samples containing various concentrations of bioethanol was calculated using material balance.
Each test was carried out minimum three times (n=3) and the average results were used for further analysis.

2.2.2 Emission analysis

Pollutant emission upon combustion, namely, carbon monoxide (CO), carbon dioxide (CO_2), and hydrocarbon (HC) emissions, was analyzed for the P-E0, P-E5, P-E10, O-E0, O-E5, and O-E10 blends. Two separate engines of the same model (1MZ-FE, 1496 cc, manufacturer: Toyota Motor Corporation) were used for the bioethanol blend petrol and octane samples. Both engines were run at two different engine speeds: 750 rpm and 3000 rpm. The exhaust gas samples were analyzed with an emission analyzer (Analizzatore gas model 810) to detect CO, CO_2 and HC levels.

2.2.3 Protein Analysis

The raw materials (corn and broken rice) and the by-product (DDGS) of the bioethanol production process were analyzed by Kjeldahl method [21] to determine their individual protein contents.

3. Results

3.1 Fuel Properties

The key fuel properties of bioethanol blend petrol and octane samples have been summarized in Tables 3, 4 and 5. Table 3 shows the variation of specific gravity, API gravity, Reid Vapor Pressure (RVP), viscosity, calorific value and sulfur content as a function of blend rate. Table 4 contains results for copper strip corrosion test and carbon residue content for various blends. Table 5 represents the water content of all samples obtained according to three separate methods: ASTM D 1796-97, ASTM D 95-70 (toluene distillation), and calculated values using specific gravity data recorded at 20ºC. During the ASTM distillation test, Initial Boiling Point (IBP), Final Boiling Point (FBP), percent loss and total recovery data were recorded, which are shown in Table 6.

Table 3: Experimental results of specific gravity, API gravity, vapor pressure, viscosity, calorific value, and sulfur content.

Sample ID	Specific gravity at 20°C	API Gravity	RVP (kPa at 37.8ºC)	Viscosity (cSt)	Calorific value (MJ/kg)	Sulfur content (wt%)
E100	0.785	49.0	14.25	1.03	27.33	0.036
P-E0	0.757	56.5	45.75	0.55	40.72	0.0480
P-E5	0.761	56.0	43	0.56	40.44	0.0474
P-E10	0.762	55.5	43	0.57	39.38	0.0467
P-E15	0.764	55.0	50	0.57	38.69	0.0461
P-E20	0.764	54.8	45.5	0.59	37.11	0.0454
O-E0	0.777	51.8	50	0.55	40.59	0.0500
O-E5	0.781	51.5	48	0.57	40.07	0.0493
O-E10	0.784	50.8	51.5	0.58	40.08	0.0486
O-E15	0.787	49.3	45	0.58	38.34	0.0478
O-E20	0.788	49.0	45.5	0.61	36.06	0.0471

Table 4: Experimental results of copper strip corrosion and carbon residue content.

Sample ID	Copper strip corrosion		Carbon residue (wt%)
	50ºC	100ºC	
E100	**1a**	**1a**	**0.011**
P-E0	1a	1a	0.014
P-E5	1a	1a	0.023
P-E10	1a	3a	0.008
P-E15	1a	3a	0.024
P-E20	1a	3a	0.031
O-E0	1a	1a	0.036
O-E5	1a	1a	0.038
O-E10	1a	3a	0.008
O-E15	1a	3a	0.004
O-E20	1a	3a	0.007

Table 5: Experimental results of water content

Sample ID	Water content (%)		
	ASTM D 1796	Toluene distillation	Calculated (using specific gravity & material balance)
E100	Nil	Nil	0.01
P-E0	Nil	Nil	0.01
P-E5	Nil	Nil	0.01
P-E10	Nil	Nil	0.01
P-E15	Nil	Nil	0.01
P-E20	Nil	Nil	0.01
O-E0	Nil	Nil	0.01
O-E5	Nil	Nil	0.01
O-E10	Nil	Nil	0.01
O-E15	Nil	Nil	0.01
O-E20	Nil	Nil	0.01

Table 6: Experimental results of ASTM Distillation of petrol, octane and bioethanol blend fuel.

Sample ID	ASTM distillation			
	IBP (ºC)	FBP (ºC)	Percent loss (%)	Total recovery (%)
E100	81.0	83.0	0.50	99.50
P-E0	54.2	266.4	0.95	99.05
P-E5	60.3	286.5	0.95	99.05
P-E10	49.9	239.8	2.07	97.93
P-E15	49.9	187.9	2.05	97.95
P-E20	45.0	200.0	2.50	97.50
O-E0	46.2	224.4	2.77	97.23
O-E5	48.9	223.9	2.90	97.10
O-E10	48.25	248.41	2.76	97.24
O-E15	48.92	191.9	2.47	97.53
O-E20	52.0	204.0	3.0	97.0

3.2 Emission Analysis

Table 7 contains CO, CO_2 and HC emissions in the exhaust gas from an SI engine for the following samples: petrol, octane, and bioethanol blend petrol and octane samples containing 5 and 10 percent bioethanol.

Table 7: Experimental results of CO, CO_2 and HC emission.

Sample ID	CO emission (%)		CO_2 emission (%)		HC emission (%)	
	750 rpm	3000 rpm	750 rpm	3000 rpm	750 rpm	3000 rpm
P-E0	0.01	0.04	13.3	13.3	3	8
P-E5	0.01	0.02	13.2	13.3	2	1
P-E10	0.01	0.01	13	13	3	1
O-E0	0.02	0.06	13.5	13.4	6	12
O-E5	0.01	0.01	13.5	13.4	5	1
O-E10	0.01	0.01	13.5	13.4	1	1

3.3 Protein Analysis

The protein and moisture content of both the raw materials (corn, broken rice) and the by-product (DDGS) of the bioethanol production process are given in Table 8.

Table 8: Protein and moisture content of corn, broken rice and DDGS.

Sample	Protein content (wt%)	Moisture content (wt%)
Broken rice	7.08	8.32
Maize	7.88	9.69
DDGS	23.67	8.01

4. Discussions

4.1 Fuel Properties

4.1.1 Specific Gravity

Specific gravity is an indicator of fuel economy, power, deposits, wear, and exhaust smoke [22]. Generally, an increase in density increases the overall performance of engines [23]. Bioethanol has a slightly higher molecular weight than both petrol and octane, and consequently, addition of bioethanol caused increase in the specific gravity of the blends (up to 2.3 percent for bioethanol blend petrol and 1.4 percent for bioethanol blend octane), as demonstrated in Figure 2.

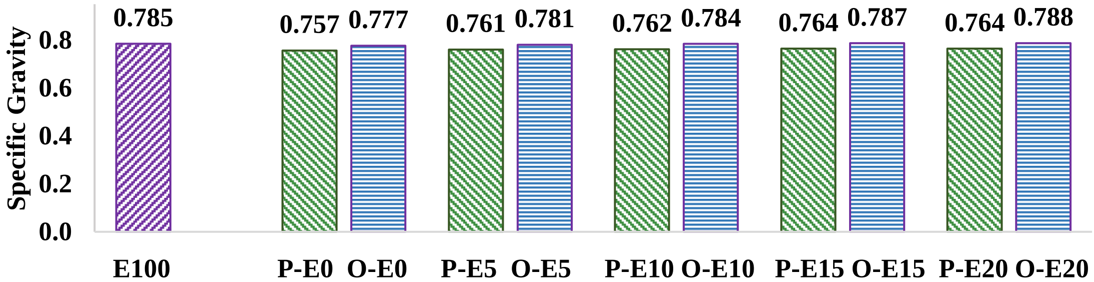


Figure 2: Effect of blending bioethanol on the specific gravity of petrol and octane.

4.1.2 API Gravity

The American Petroleum Institute gravity, or API gravity, is used to compare densities of petroleum liquids to magnify small differences in density. Figure 3 shows the effect of blending bioethanol on the API gravity of petrol and octane. For both bioethanol blend petrol and octane, API gravity decreased with increasing percentage of bioethanol; up to 3 percent and 5.4 percent reductions were observed for P-E20 and O-E20 respectively, which calls for no special modification of the traditional combustion engines [24].

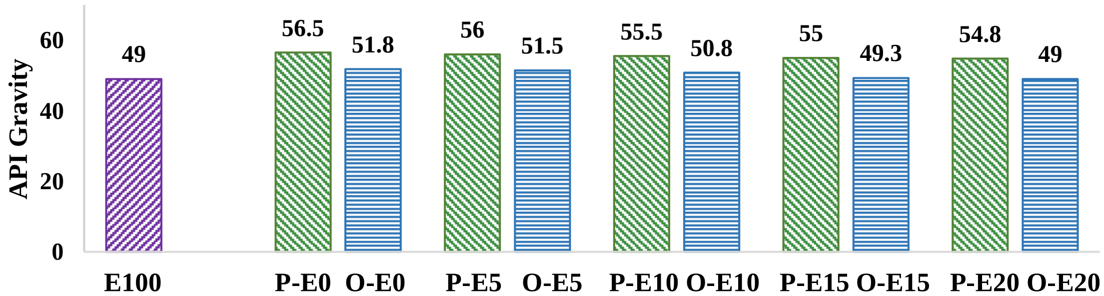


Figure 3: Effect of blending bioethanol on the API gravity of petrol and octane.

4.1.3 Reid Vapor Pressure

RVP is frequently used as an indication of the volatility of liquid hydrocarbons [25]. Petrol and octane are manufactured as liquids but they are consumed in the vapor phase. Consequently, their volatility must be high enough to assure acceptable engine start-up, warm-up, acceleration and throttle-response under normal driving conditions. On the other hand, the maximum volatility of petrol or octane must be restricted to avoid vapor lock, vaporization losses, unsafe storage and handling, and evaporative emissions of smog-forming hydrocarbons, which are undesirable from the environmental viewpoint.

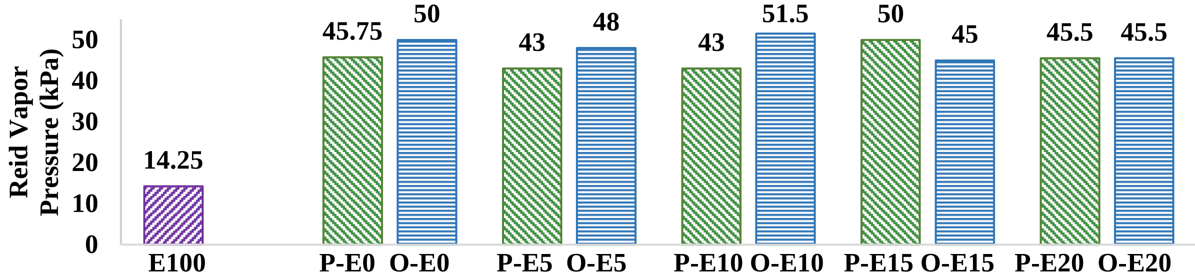


Figure 4: Effect of blending bioethanol on the Reid vapor pressure of petrol and octane.

According to RFA guidelines, unless other more volatile blending components are being used, the addition of ethanol should not create a vapor pressure increase above 1.0 psi (6.89 kPa) in conventional gasoline [26]. The experimental measurements as demonstrated in Figure 4 shows that blending of bioethanol caused an increase in RVP lower than 6.89 kPa for all bioethanol blend petrol and octane samples. Among the bioethanol blend octane samples, the blend containing 10 percent bioethanol showed the highest RVP, which is similar to the findings of other research groups [27].

4.1.4 Viscosity

Viscosity affects heat generation in bearings, cylinders, and gear sets related to an oil's internal friction. It governs the sealing effect of oils and the rate of oil consumption, as well as determining the ease with which machines may be started or operated under varying temperature conditions, particularly in cold climates.

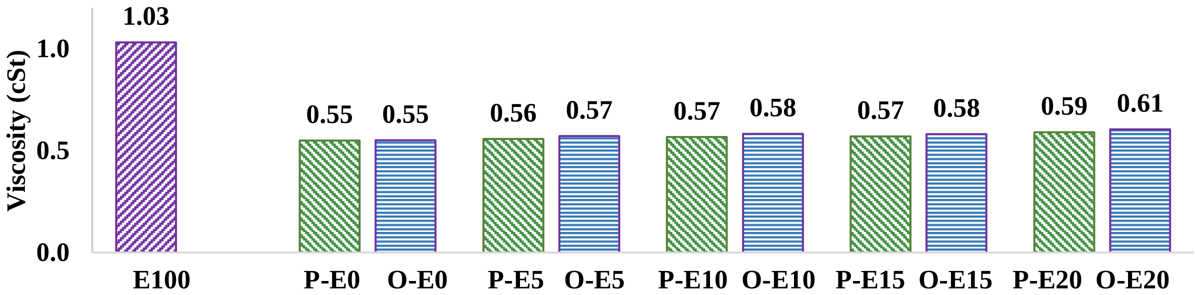


Figure 5: Effect of blending bioethanol on the viscosity of petrol and octane.

Figure 5 shows that blending of bioethanol up to 20 percent volume content caused a small increase in viscosity (maximum 7 percent increase and 10 percent increase for bioethanol blend petrol and octane samples were observed).

4.1.5 Gross Calorific Value

The Gross Calorific Value (GCV) is used to compute the total calorific content of fuel in order to determine if the fuel meets regulatory requirements for industrial fields. The combustion rate of a fuel is proportional to its calorific value.

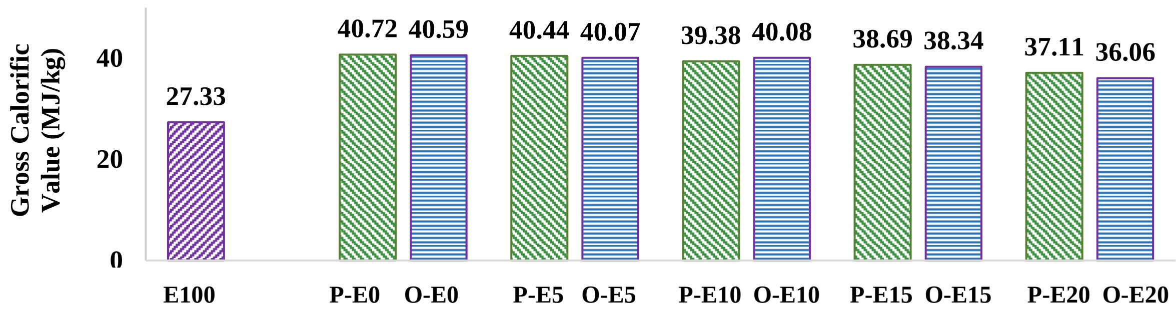


Figure 6: Effect of blending bioethanol on the gross calorific value of petrol and octane.

The GCV of bioethanol is lower than that of both petrol and octane, and accordingly, the GCV of the blends were found to be lower than the pure fuel samples; maximum 9% decrease for bioethanol blend petrol and 11% decrease for bioethanol blend octane (Figure 6) were observed. This indicates that to produce the same amount of energy, more bioethanol is needed than either petrol or octane. Generally, 1.5 gallons of fuel grade bioethanol has the same energy content as 1 gallon of petrol or octane [6]. Based on the results of this study, 1.45 gallons of bioethanol was found to have the same energy content as 1 gallon of gasoline. Since the locally produced bioethanol performed almost similar to fuel grade ethanol under test conditions, it is deemed suitable for use as a gasoline supplement.

4.1.6 Sulfur Content

Sulfur and its compounds are present in most of the petroleum products and lubricants. Sulfur in fuel is undesirable because it damages the engines through abrasive wear of the piston rings and cylindrical walls, and pollutes the environment by causing acid rain and particulate emission [29-31].

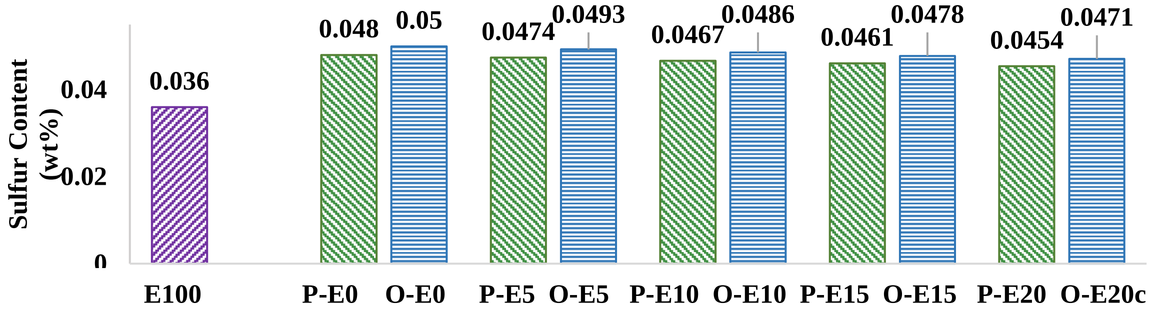


Figure 7: Effect of blending bioethanol on the sulfur content of petrol and octane.

From Figure 7, it is evident that blending of bioethanol resulted in a decreased amount of sulfur in the blends (up to 5 percent and 6 percent decrease for bioethanol petrol and octane respectively) since the sulfur content of bioethanol is lower than fossil fuels.

4.1.7 Copper Strip Corrosion

The copper strip corrosion test assesses the relative degree of corrosivity of a petroleum product. As recorded in Table 4, all samples under test showed the same degree of corrosivity, causing a slight tarnish (1a) in the color of the copper strip, at the prescribed test temperature (50ºC according to ASTM 130-04). However, for the purpose of this study, additional tests were carried out at a higher temperature (100ºC).

At the higher temperature, samples containing higher than 5 percent bioethanol caused a dark tarnish (3a) in the copper strip, representing a higher degree of corrosion. Therefore, additional protective measures, such as corrosion inhibitors, may be required to prevent corrosion of engine, fuel tank, and fuel transmission system etc., when fuel blends containing more than 5 percent bioethanol are used. In different developed countries including USA, Australia, and in several European countries, corrosion protective chemicals are used along with bioethanol blends containing more than 10 percent bioethanol [30,32,33].

4.1.8 Carbon Residue

The carbon residue value serves as an approximation of the tendency of petroleum products to form carbonaceous deposits under similar degradation conditions. Figure 8 shows the carbon residue of all samples, which were found to be sufficiently low.

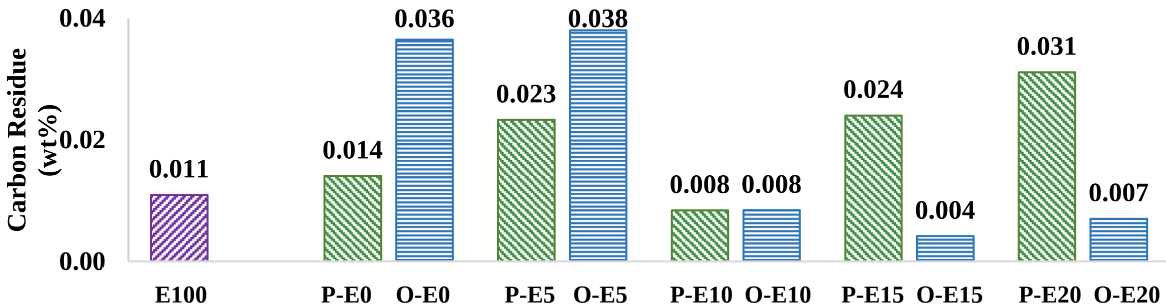


Figure 8: Effect of blending bioethanol on the carbon residue of petrol and octane.

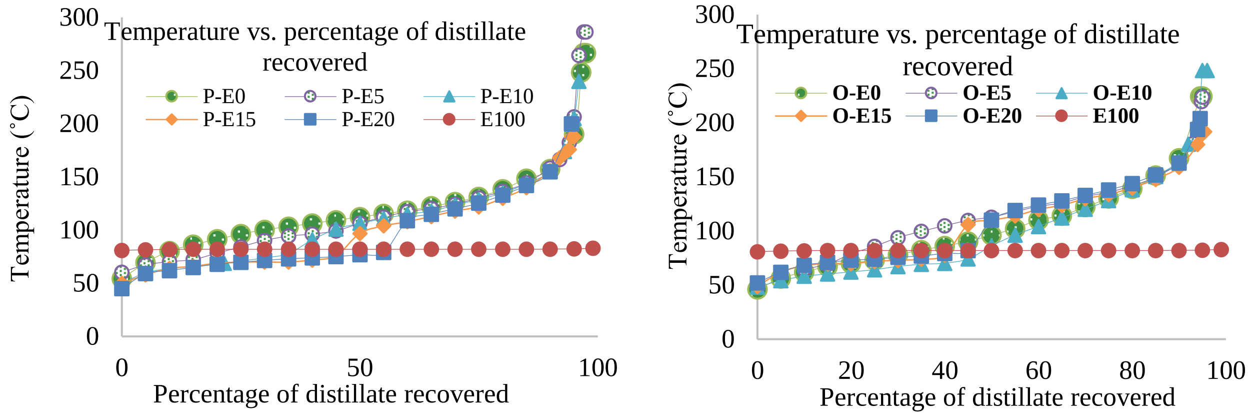
4.1.9 Water Content

Determining the water content of fuels and biofuels is important for quality control, meeting trade specifications, protecting financial value, enhancing process optimization, and for taking necessary steps to reduce risks from corrosion, safety problems, and infrastructure damage [34]. The moisture content of petrol, octane, and bioethanol samples, tested according to ASTM D 1796-97 and ASTM D 95-62 (Toluene Distillation Method), were found to be below the detection limit of the equipment used for the tests (Table 5).

However, for the purpose of this study, the water content of all samples was also calculated as described in section 2.2.1. Since the collected petrol and octane samples were refined, it was assumed that those samples contained minimum amount of water (0.01 vol%). The water content of bioethanol calculated using specific gravity was also found to be 0.01 percent (vol%), and consequently, the water content of the blends, calculated using material balance, were found to be very low (Table 5).

4.1.10 ASTM Distillation

Figure 9 (a) and 9 (b) shows the effect of blending bioethanol on the distillation curves of petrol and octane respectively. For efficient combustion, the curve should be smooth. A fluctuating curve implies an oil that may give erratic operation due to non-uniform conditions. The curve also graphically shows the degree of spread between the initial boiling point and the end point, which is important in judging the ignition properties of oil.



(a) (b)

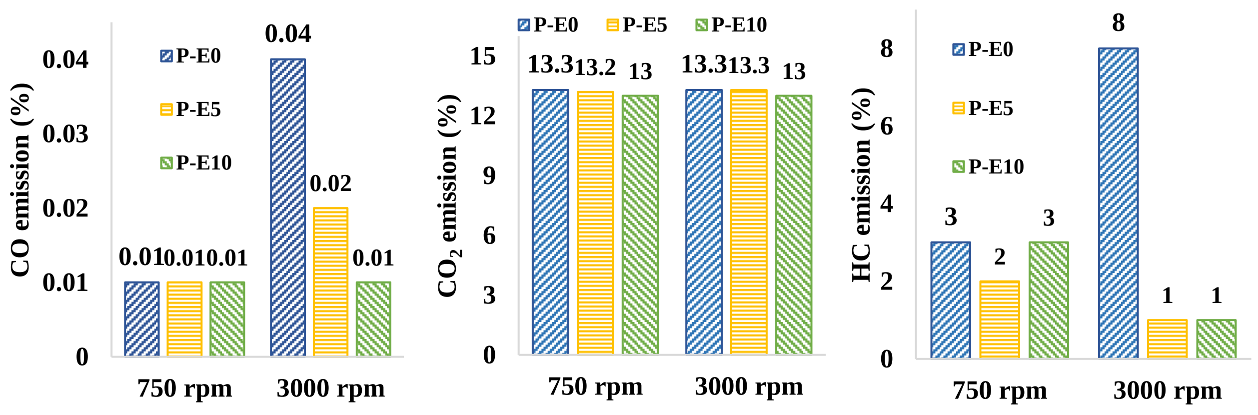
Figure 9: Effect of blending bioethanol on the boiling point of (a) petrol and (b) octane.

The boiling point range for petrol was found to be 54.2-266.4ºC and for octane, it was 46.2-224.4ºC (Figure 9). Bioethanol evaporated at an almost constant temperature of around 82ºC. Petrol and octane are generally mixtures of hydrocarbons whereas bioethanol consists of almost pure C_2H_5OH. This contributed to the difference in the boiling behavior of pure bioethanol from those of pure petrol and octane.

The temperatures at which 10, 50, and 90 volume percent of petroleum products evaporate (T10, T50, and T90 respectively) are often used to characterize the volatility of gasoline [35]. As can be seen from Figure 9, blending bioethanol did not have significant effect on the T90 temperatures. For the bioethanol blend petrol samples, the T10 and T50 temperatures were lower than those of petrol were. For the bioethanol blend octane samples, the T10 temperatures remained almost the same. However, the T50 temperatures were slightly elevated for all bioethanol blend octane samples, except O-E10, for which the T10 was lower. It is evident from Figure 9 that addition of bioethanol generally lowered the boiling point, which indicates a lower tendency to form solid deposits during combustion [36].

4.2 Emission Analysis

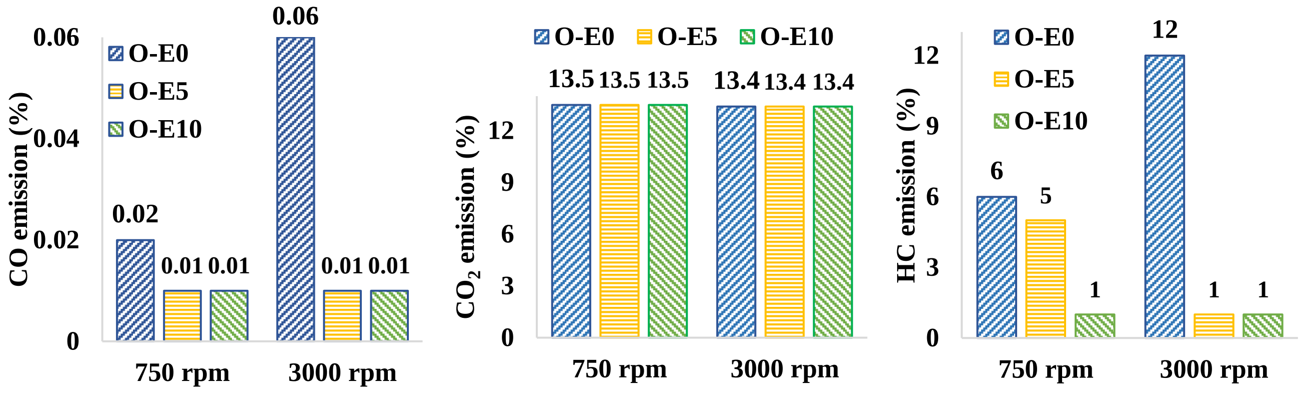
Several studies on fuel tanks and fuel system components have examined and concluded that blending bioethanol with gasoline below 10 percent does not increase corrosion in everyday operation [37,38]. The experimental results of this study also support this. However, for fuel blends containing 10 percent bioethanol, corrosion inhibitor can be used to avoid any undesired corrosion [39,40,41]. Vehicles using higher bioethanol blend fuel may clog fuel filters, fuel pumps, and carburetors [42]. Hence, for this study, the exhaust gas from an SI engine using bioethanol blends, containing up to 10 percent alcohol as fuel, were collected at two different engine speed for analysis. The pollutant concentrations were generally higher at 3000 rpm due to shorter combustion time at a higher engine speed.



(a) (b) (c)

Figure 10: Effect of blending bioethanol on (a) CO (b) CO_2 and (c) HC emission by combustion of petrol.

As can be seen from Figures 10 (a) and 11 (a), for all samples, the addition of bioethanol had minimal or no effect on CO emission at the lower speed (750 rpm). At high engine speed (3000 rpm), CO emission was found to be lower for the bioethanol blends than pure petrol and octane. This indicates that the engine tends to operate in leaner and closer to stoichiometric burning conditions with increasing bioethanol content. Since the combustion process is more complete when it is closer to stoichiometric burning, CO emission decreases. Up to 75 percent and 83 percent reduction in CO emission were observed for the P-E10 and O-E10 blends respectively.



(a) (b) (c)

Figure 11: Effect of blending bioethanol on (a) CO (b) CO_2 and (c) HC emission by combustion of octane.

For all samples, CO_2 emission was not affected much by the presence of bioethanol at either speed (Figures 10 (b) and 11 (b)). However, bioethanol is considered carbon neutral, *i.e.* the amount of CO_2 released in the bioethanol production process would be consumed during photosynthesis of the crops and biomass. Therefore, the net annual CO_2 emission associated with the use of bioethanol blends is less than that associated with the use of petroleum fuels.

HC concentration in the exhaust was found to decrease with increasing bioethanol content (Figures 10 (c) and 11 (c)), which indicates that addition of bioethanol increases combustion efficiency. HC emission was reduced by as high as 88 percent and 92 percent for bioethanol blend petrol and octane samples respectively.

4.3 Use of By-Products: Dry Distillers Grain Solubles (DDGS)

Locally available materials, which can potentially be used to produce bioethanol (such as, broken rice, maize etc.), are currently used as animal feed in Bangladesh. Protein, fiber, ash content, fat, and lipid contents are few of the key ingredients of cattle, poultry and fish feeds [43,44,45,46]. Milled rice and maize contains 70-75 percent and 60-65 percent (weight basis) starch respectively [47]. Bioethanol production process converts the starch content of these grains to sugar through enzymatic reactions followed by fermentation, while the protein content remains almost unchanged, and is accumulated in the major byproduct of the process, DDGS. About 320 kg of DDGS can be recovered from 1 ton of grain (broken rice or maize) (ref: Moji Engineering Systems Ltd. and Sunypun Organics Ltd.). To assess the feasibility of using DDGS as alternative animal feed, the protein contents of broken rice, maize and DDGS were experimentally determined, and are shown in Figure 12.

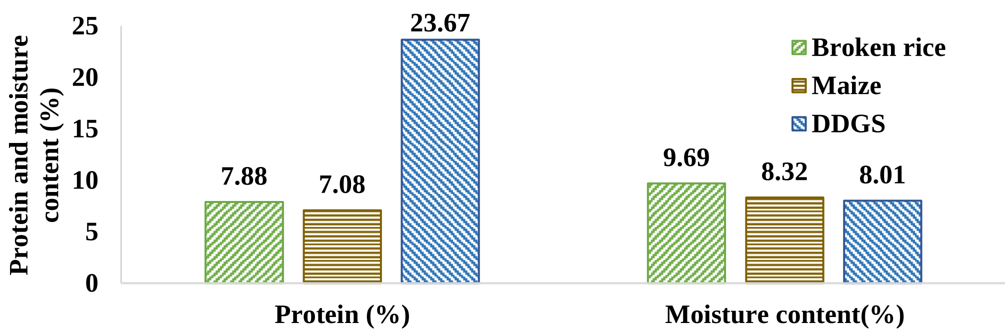


Figure 12: Protein content of corn, broken rice, and DDGS.

In Bangladesh, protein content in cattle feed and animal feed varies from 12 percent to 22 percent (Table 9). Protein content of DDGS was found to be around 24 percent, and therefore, DDGS is suitable for use as animal feed in the country. Table 9 compares the key nutritional requirements of fish feed, poultry feed, and cattle feed with the nutritional content of DDGS. DDGS contains non-fermentable solids from the grain, and it has high energy, high protein content (up to 30 percent), crude fiber (5-14 percent), crude fat (3 to 12 percent), ash (4 to 6 percent), minerals (>2.5 percent), (neutral/acid) detergent fibers, and moisture [48,49], which make it a useful additive or supplement for cattle, poultry and fish feeds [50].

Table 9: Key nutritional composition of fish feed, poultry feed and cattle feed [4,44,48,45,46]

Nutritional Parameters	Cattle Feed	Poultry Feed	Fish Feed	DDGS
Protein (wt %)	12-19	18-22	45-70	~ 30
Fiber (wt %)	17-22	7-20	-	5-14
Ether Extract (wt %)	3-4	5-9	-	~2.5
Fat and Lipid (wt %)	3-4	4-6	9-10	3-12
Ash (wt %)	-	6-11	10-12	4-6
Others	Others contain minerals (calcium, phosphorus, magnesium, sulfur, sodium, chlorine, manganese, copper, zinc, iron, cobalt, iodine, vitamins, etc.), carbohydrates, moisture, etc.			

5. Feasibility of Bioethanol Production Plant in Bangladesh

5.1. Global Scenario in Fuel Ethanol Production

In Brazil, as of 1984, approximately 7.9 million tons of ethanol was produced by fermentation of sugarcane sucrose, and as a result, petroleum imports were reduced [51]. The USA is also substantially increasing its fuel alcohol production, originally because of the fluctuation of petroleum costs, and the subsequent need for developing alternative energy sources [51]. Currently, Brazil has more than 300 ethanol plants, producing more than 7000 million gallons per year and supplying 3 million cars with pure ethanol [52]. In the USA, there are more than 80 plants producing over 15,000 million gallons of ethanol per year. In the year 2016, China, India, and Canada produced 845, 225 and 436 million gallons of ethanol respectively [52]. In the same year, approximately 1400 million gallons of ethanol were produced in the European Union. Bangladesh has the opportunity to follow the global trend of ethanol production.

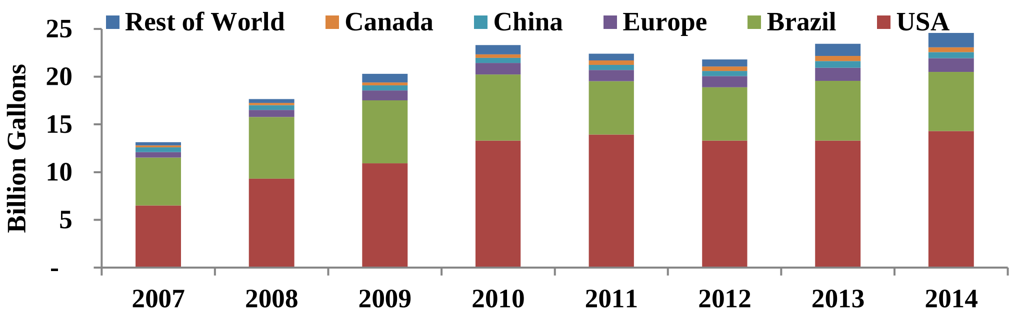


Figure 13: World Fuel Ethanol Production by country or region [52].

5.2 Current Energy Scenario: Prospect of Bioethanol in Bangladesh

In Bangladesh, the annual demand of petroleum products for the 2016-2017 fiscal year was about 5.88 million metric tons (MMT) [3]. This demand is met primarily by importing refined petroleum products, and to a lesser extent, by refining imported crude oil, which is processed along with domestic condensate and a small quantity of oil from local source: Haripur Gas Field at Sylhet, Bangladesh [53]. Considering the depletion of global fossil fuel reserves, the amount of foreign currency required to import the petroleum products, and the concern regarding environmental problems, it is essential for Bangladesh to look for alternative renewable fuel. Recently, Bangladesh Government has decided to use E5 (or, any other concentration permitted by the Government) as a transportation fuel. In this regard, the government has published a gazette about the setup of bioethanol plants on 12 December, 2017 [54].

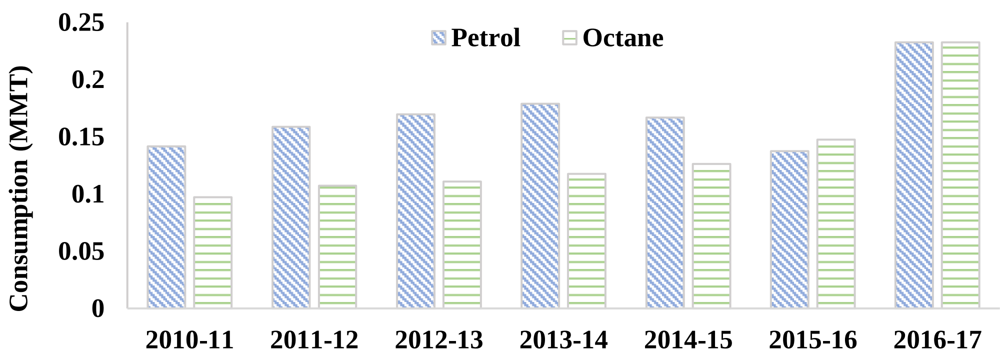


Figure 14: Annual consumption of petrol and octane in Bangladesh (in last seven fiscal years) [1]

In the fiscal year 2016-17, 232,359 metric tons (MT) petrol and 186,911 MT octane were consumed in Bangladesh (Figure 14) [1]. Replacement of 10 percent of the current petrol and octane consumption using bioethanol will reduce the annual consumption of these petroleum products up to 30.73 million liters and 24.72 million liters respectively. Estimating the cost of import for petrol and/or octane at BDT 35.0 per liter[1] [55,56], using fuel blends containing 5 percent bioethanol will save about 970 million BDT annually (equivalent to about $11.80 million USD per year) and using blends containing 10 percent bioethanol will save about 1.94 billion BDT annually (equivalent to about $23.67 million USD per year). Table 10 enlists the annual consumption (2016-17) of petrol and octane and the possible savings of foreign exchange.

Table 10: Annual consumption (2016-17) of Petrol and Octane and possible savings for bioethanol blending.

	Unit	Petrol	Octane
Annual consumption in 2016-20117	Metric Tons	232,359	186,911
Using E5 will reduce annual petrol and octane consumption	Metric Tons	11,620	9,345
	Million Liters	15.37	12.36
Using E5 will save foreign currency per year	BDT	970 million	
	USD	11.80 million	
Using E10 will reduce annual petrol and octane consumption	Metric Tons	23,235	18,690
	Million Liters	30.73	24.72
Using E10 will save foreign currency per year	BDT	1.94 billion BDT	
	USD	23.67 million	

Considering the current crude oil price, the production cost of bioethanol (85 BDT per liter; ref: Sunypun Organics Limited) will be higher than the production cost of either petrol or octane. However, the price of petroleum fuel is not immutable since the global oil market is always fluctuating and causing the fuel price to be constantly in a flux [15]. Factors such as global political conditions and demand for oil might affect the fuel price. On the other hand, adoption of newer technologies will inevitably reduce the cost of bioethanol production. Since 2001, energy requirement in bioethanol production process has decreased by 28 percent, electricity requirement by 30 percent while bioethanol yield has increased by 5.3 percent [16]. Moreover, gasoline production is more energy-intensive than bioethanol. One unit of fossil energy used in the corn ethanol production process results in 2.3 units of energy in the form of ethanol while it takes 1.23 units of fossil energy to produce one unit of energy in the form of gasoline [57][16]. Moreover, the use of bioethanol blend petrol and octane result in improved engine performance than with only petrol or octane [7].

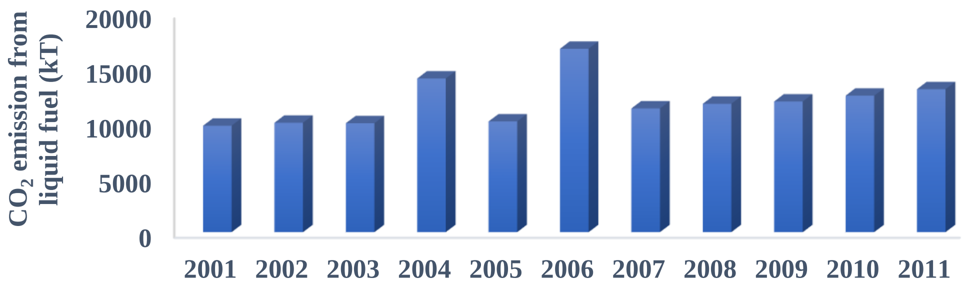


Figure 15: CO_2 emission from liquid fuel in Bangladesh [58].

The current CO2 emission in Bangladesh from the combustion of liquid fuels is alarming from the environmental viewpoint (Figure 15). In 2016, Bangladesh Government signed the Paris Agreement, agreeing to mitigate CO2 emission by way of using renewable sources using national and international support [59]. The use of bioethanol blends may reduce GHG, CO, NOX and particulate emission [7]. Also, bioethanol production plant can provide employment to a wide range of workers in a variety of occupations (Renewable Fuels Association). Thus, bioethanol, produced from locally available biomass, can serve as a potential alternative fuel source and contribute to the sustainable development of Bangladesh.

5.3 Availability of Raw Materials: Impact on Food Cycle in Bangladesh

To replace 10 percent of the combined annual consumption of petrol and octane, about 80 million liters of bioethanol will be required annually. A plant capacity of 245,000 liters per day, operating 330 days per year, will meet the required demand. Locally available raw materials under consideration are corn, broken rice, and molasses. Figure 16 shows a comparison between the requirement and availability of the raw materials for bioethanol production in Bangladesh for a plant capacity of 245,000 liters per day.

[1] FOB Price of premium gasoline = 560 $/t and Freight Cost (Middle east – east Asia) = 10 $/t
$1 = BDT 82 and Density of Petrol & Octane = ~ 0.756

***Maize*:** Annual maize production in Bangladesh was 2.45 MMT in 2015-16 [60]. Generally, maize/corn contains around 16 percent moisture (Rana), which indicates that annual dry maize production is around 2.06 MMT. 1 ton of dry corn grain yields 124.4 gal or 470 liters of ethanol [61]. Therefore, for a plant producing 245,000 liters of bioethanol each day, 205,000 tons of corn is required per year. Even though Bangladesh grows more than enough maize for bioethanol production (only around 8 percent of the produced maize is required), in accordance with government regulation, bioethanol plants must use imported maize as raw material [54].

Broken rice: In 2015, annual paddy production was of Bangladesh 52,505,000 tons and milled rice production was 35,000,000 tons in 2015 [62]. Upon milling of Asian rice or paddy rice, around 8 percent to 16 percent of broken rice is produced [63][64][65]. Making a rather conservative assumption that 5 percent of the total rice produced yields broken rice during milling, annual broken rice production in Bangladesh is around 2.63 MMT (year 2015).
15 lb (6.8 kg) of starch yields about 1 gallon (3.79 liter) of fuel ethanol [66]. Since rice contains around 51% starch [67], to run a plant producing 245,000 liters bioethanol per day, 285,000 tons of broken rice is needed annually. In Bangladesh, broken rice is currently used primarily for making rice flour, and as poultry feed. Low-income people in Bangladesh also consume broken rice to some extent. However, even if broken rice was used as the sole raw material for producing bioethanol, less than 11 percent of the total broken rice produced in Bangladesh would be required, which is highly unlikely to affect the food security of the country.

Molasses: In Bangladesh, average annual molasses production is around 100,000 tons [68]. 1 ton of molasses yields 72 to 88 gallons of ethanol [69]. Using molasses as the only raw material for producing bioethanol in a plant with a daily production capacity of 245,000 liters is not possible since it will require at least 240,000 tons of molasses, which is much higher than the current molasses production of Bangladesh. Therefore, production of bioethanol using molasses exclusively as the raw material will warrant import of molasses from overseas. However, using all potential raw materials for bioethanol production that are available in Bangladesh in an alternating fashion and in a ratio based on their availability might prove to be a more cost-effective solution.

Figure 16: Raw material for bioethanol production: available vs. required.

6. Conclusion

Bioethanol blend petrol and octane are in the early stages of development in Bangladesh. On an energy basis, bioethanol has lower calorific value than petrol and octane; hence, relatively higher amount of bioethanol blends is required to get the same performance as octane or petrol. However, as seen from the experimental results, if fuel blends with low percentages of bioethanol (up to 20 percent) are used, calorific value is not significantly affected. Also, at low blend ratios, changes in fuel properties do not warrant any engine modification. However, corrosion protective measures (corrosion inhibitor etc.) are recommended when bioethanol blends at 10 percent or higher blend ratios are used. The current cost of production of bioethanol is greater than that of both petrol and octane. As a result, the cost of using bioethanol as a substitute for either petrol or octane is higher than the current cost of fuel. However, application of new and improved technologies can bring down the cost of production of bioethanol. Furthermore, bioethanol blends can significantly reduce greenhouse gas emissions over their entire life cycle. Thus, using bioethanol to replace petrol and octane is favorable from the environmental viewpoint. According to this study, using bioethanol blends at low blend ratios (up to 10 percent) is unlikely to affect the food security of the country since, compared to the country's production, the raw material requirement is very low. Also, as analyzed in the study, bioethanol blend fuels will reduce dependence on imported petroleum products and save foreign currency. In addition, bioethanol production facilities will create job opportunities for local people. Thus, locally produced bioethanol can have a significant impact on reducing the country's dependence on foreign resources while securing a better environment for future generation.

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