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Article

Effect of Retention Period on Stability of Ethanol Blended Motor Gasoline Blends in Various Storage Vessels

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Abstract: Current study presents an experimental analysis on the retention behavior of ethanol-blended motor gasoline stored in vessels made of stainless steel, aluminum, glass, and epoxy-coated material. A novel approach has been applied to ascertain the stability of different prepared blends. A comparison was done among neat motor gasoline, 12%, 15% and 20% ethanol blended motor gasoline with respect to time. The selection of percentage of ethanol blending was done as per the available fuel standards. During the initial stage of the study, various test parameters of both neat motor gasoline & ethanol blended motor gasoline blends were checked. The selected test parameter was density, distillation, total sulphur, water content, ethanol content, corrosiveness to copper, solvent washed gum content including visual appearance and colour. Petroleum products testing procedures were followed during the study. Further, all the samples in respective containers were retained and all the tests were re-conducted at an interval of 60, 90 and 120 days of retention and all the tests were performed within a period of (±3) days. These studies revealed that ethanol blended motor gasoline retained up to period of 120 days, were found stable up to 120 days with respect to the tests conducted. Concluding objective of this work was to ascertain that after 120 days of retention period, EBMG blends are meeting the required specifications and fit for further use.

Keywords: ethanol blended motor gasoline; blends; quality parameter; specification; test Methods; UV-FD Sulphur analyser; density; distillation; auto titrator

1. Introduction

A significant portion of global energy consumption still relies on fossil fuels. As the prices of these fuels continue to rise, there is an increasing demand for clean, renewable energy alternatives. Consequently, various alternative fuel sources are being explored, including biogas, natural gas, vegetable oils and their esters, alcohols, and hydrogen. Among these, alcohols-particularly ethanol is considered promising candidate for use in gasoline engines, offering solutions to both energy security and environmental pollution challenges.

Ethanol (ethyl alcohol), a renewable energy source derived from biomass, has been extensively tested in internal combustion engines. Research has focused on comparing the performance characteristics of alcohol-gasoline blends, particularly for stoichiometric combustion. For example, Gravalos & team [1], tested blends of lower and higher alcohols with gasoline, ranging from 10% to 30%. Their results showed that alcohol blends, particularly those with higher alcohol content, reduced unburned hydrocarbon and carbon monoxide emissions compared to pure gasoline.

Al. Hasan [2] also investigated various ethanol-gasoline blends, finding that a 20% ethanol mixture performed well in terms of engine efficiency and emissions. Another group of researchers [3] explored the potential issues of higher ethanol blends (10%, 30%, and 70%) in a single-cylinder SI engine, showing that while performance decreased with the 70% ethanol blend, optimized operating conditions could mitigate this drop, resulting in similar performance to pure gasoline and reduced emissions. Thangavel et al. [4] tested dual fuel injection systems for ethanol-gasoline blends in a single-cylinder engine and found that a 50% ethanol blend improved efficiency and torque due to better combustion characteristics.

Ethanol is considered a viable green fuel for spark ignition engines due to its high evaporation heat, high octane rating, and increased flammability temperature, which can improve engine performance and raise the compression ratio. Ethanol's low Reid vapor pressure also allows for safer storage and transport. Moreover, its oxygen content can help reduce environmental pollution when used as an alternative to gasoline, although it does require engine modifications due to cold-start issues when used in pure form. The widely-used E85 blend, consisting of 85% ethanol and 15% gasoline, mitigates some of these challenges, while the gasohol blend (90% gasoline and 10% ethanol) is another common mixture. Ethanol's combustion characteristics differ from those of gasoline. For example, ethanol requires 60% more air for combustion, generates 66% more energy, and has a higher heat of vaporization. Its tendency to form a saturated vapor at a single boiling point and vapor pressure makes it harder to ignite, especially at temperatures below 10 °C, presenting challenges for cold starts. As ethanol content increases in blends, these issues tend to worsen [5].

Use of ethanol is also associated with corrosion which indicates that fuel system must be made using stainless steel and rubber, compatible. Ethanol is also having lower lubricants properties due to which more resistant materials should be used. Heating value of ethanol is low, and it requires an alteration in injection assembly so that fuel flow can be controlled. Therefore, a limited percentage of ethanol can be used in conventional gasoline engine [6]. The use of ethanol in gasoline has grown significantly in recent years, contributing to a rise in nitrogen oxide (NOx) emissions. However, it has been found that higher ethanol content can reduce hydrocarbon (HC) and carbon monoxide (CO) emissions. Studies have shown that the ethanol-to-gasoline ratio in blends can affect both energy efficiency and emissions, with varying impacts based on engine load conditions. Notably, several experiments found minimal changes in engine performance and emissions at low ethanol blend levels, particularly below 10% [7].

In research [8], the use of ethanol-blended fuel was shown to reduce CO emissions by 30–37% and HC emissions by 19–28% compared to regular gasoline. Additionally, adding a catalyst to the exhaust system led to further reductions in CO, HC, and NOx emissions. Another group [9] studied fuel injector characteristics and found that long-term use of ethanol blends led to injector contamination, highlighting challenges in fuel system maintenance when using alternative fuels. Ethanol blending in gasoline is associated with several challenges related to phase separation and volatility. Authors have reported a comprehensive study on the stability of blends in ethanol-gasoline engines. The study revealed that ethanol in gasoline engines leads to phase separation, which was attributed to the high affinity of ethanol for water and air humidity. This results the formation of an azeotropic mixture of the ethanol gasoline blend. It was further reported that the tendency of formation of azeotropic mixture can be reduced by using Ethyl tertiary-butyl ether and further increase the water tolerance level [10]. Ethanol-gasoline blends can also experience issues with water solubility, which is temperature-dependent. Proper handling of these blends is crucial to prevent water contamination, which can cause phase separation, freezing, corrosion, and filter blockages. The Indian Standard Specification 2796:2017 allows for up to 10% ethanol in gasoline, with potential to increase this to 20%. Despite these challenges, the blending of ethanol in gasoline remains a practical approach to modernizing fuel use in internal combustion engines.

A lot of literature is available on the effects of ethanol/gasoline fuel blends on NO_X emissions in spark-ignition engines. Another group has also reported that the ethanol blending into the fuels has dramatic impact on the production, storage, and distributions of ethanol blended fuels. It has also been concluded that the effects of ethanol on volatility properties, phase separation tendency & materials compatibility arise from the non-ideal mixing of ethanol with hydrocarbons [11].

Huang and team have reported experimental investigation of a methanol diesel reactivity-controlled compression ignition (RCCI) engine, specially they focused on combustions and emission characteristics under various methanol substitution and exhaust gas recirculation (EGR) rate at different altitudes [12]. Further the ethanol-diesel stabilized fuel was proposed with furan-derivative (a kind of renewable biomass) as co-solvent. By using a nanoparticle size analyser and a conductivity analyser, it was found that the blends of ethanol/furan-derivative/diesel were in the state of microemulsion and had good phase stability [13]. The effects of fuel injection masses (12, 24, 36 mg) and fuel injection pressures (30, 40, 50 MPa) on ethanol spray flame on an optically visualized constant volume combustion chamber have also been reported [14]. Another group [15] has tried to identify the trends and characteristics of low-carbon alcohols (LCA fuels) combustion research for the period 2000–2021 through bibliometric analysis. They used citation analysis to evaluate the influence of most productive journals, countries/regions, authors, institutions, and relevant literature, and discussed about collaborative network between various authors, countries/regions, institutions, and the co-occurrences among different keywords. They extracted a dataset of 2250 publications from the Web of Science Core database and analysed with Cite Space and Biblioshiny.

While material compatibility with E10 is documented [16–18], the kinetics of quality parameter degradation for higher blends (E12-E20) in common depot storage materials over medium-term storage remain unquantified, particularly under laboratory conditions (temperature 24 ± 2 °C, pressure 743 to 748 mmHg & percentage relative humidity 60–75). This study tests the hypothesis that EBMG blends up to E20 can be stored for 120 days in glass, SS, Aluminium & epicoated metallic containers without exceeding critical specification limits for key parameters like water content, gum formation and corrosiveness towards copper strip.

At storage locations, oil marketing companies are not much clear about the period till when EBMG product can be stored. Our aim in current study is to see the stability of these blends and till what time they can retain their quality parameters. Also, there is a need to monitor the stability of EBMG fuels retained in various mediums over the period. To address such challenges during retention period of the EBMGs, current study has been conducted. Retention relates to the storage of EBMG in tanks at petroleum supply depots. The most commonly available petroleum product storage tanks are made up of steel and sometime these are internally epi coated. Moreover, containers used to handle the petroleum products are made up of aluminum, stainless steel (SS) and glass. Thickness of used sample container was 0.9–1.0 mm & 304 type stainless steel was used in stainless sample containers. Therefore, in current study the type of containers selected for retention of blend samples are aluminium, stainless steel, glass, and epi coated. This paper covers the behavior of different EBMG blends in various mediums. The medium used in the current investigation are Aluminum, stainless steel, glass, and epi coated. Different blends of motor gasoline were prepared and to ascertain whether there is any deterioration in basic quality parameters, retained for defined period. Before blending, the key parameters of both motor gasoline and ethanol were tested individually. During certain intervals, most of the parameters of the prepared blends retained in various mediums were tested. Overall objective was to see the effect of retention period on retention of various quality control parameters. The selected time intervals were 60 days, 90 days and 120 days including the initial period. There is no specific reason for selection of greater retention period 120 days and study may be conducted beyond this period also. Throughout the study, the internal surface area-to-volume ratio was about 7:5. The internal surface area-to-volume ratio was derived according to the size & space occupied by the product inside the vessel. During the retention period, sample containers were kept in airtight conditions.

As for as previous works are concerned, a lot of works on EBMG have been reported, however none of them addressed stability of the blends with respect to the time and medium (type of vessels selected). Current work addresses stability of different blends in different medium with respect to the time.

2. Materials

Materials like motor gasoline (MG) and anhydrous ethanol used in the study were received and certified by the Indian refiners in line with existing specifications of Bureau of Indian Standards (BIS) and readily available with their respective test reports. Anhydrous Ethanol used was of Industry grade which is being used for blending with motor gasoline. It was supplied by a regular supplier M/s- DCM Shriram, India and was used in preparation of all the blends. Used Aluminium, glass and stainless steel (SS) containers are available in market for handling of petroleum products and were received from regular suppliers of the industry. However, used epoxy-coated samples containers were received from the ASTM during supply of ASTM proficiency testing program samples. Chemicals used for testing were also received from commercially available suppliers with respective certificates of analyses and used without any further purification. All the prepared blends were retained at laboratory temperature (24 ± 2 °C). Both temperature and humidity were monitored on a regular basis. During retention period, percentage relative humidity was recorded in the range of 60 to75%.

2.1. Experimental Setup and Controls:

(a) Dimensions of sample containers, cubical container (Length = 16 cm, Width = 15 cm & Thickness = 10 cm) & cylindrical containers (Height = 22 cm & Diameter = 16 cm), used material grades were commercial received from regular suppliers. Lined cap method used in sealing of containers, and headspace percentage was about 90%. Chemical resistant type epoxy coating has been used in epoxy coated sample containers.

(b) Accurately recorded temperature was (24 ± 2 °C) and relative humidity in the range of 60 to75%.

(c) There is no specific reason to select 120 days retention period. The selected period is basically at an interval of 30 days & in multiple of the same we picked one month, two months, three & finally four months which comes to 120 days. After 120 days, these observations were not made as prepared blends were consumed.

(d) Based on the performance of prepared blends, being treated as a sample, the same property is predicted for the bulk. In petroleum Industry, required test parameters are determined from a sample taken from the bulk & based on which parameters of bulk are assumed. The same hypothesis has been applied in the current work.

3. Sample Preparation

Methodology details of the current study have been summarized in Figure 1.

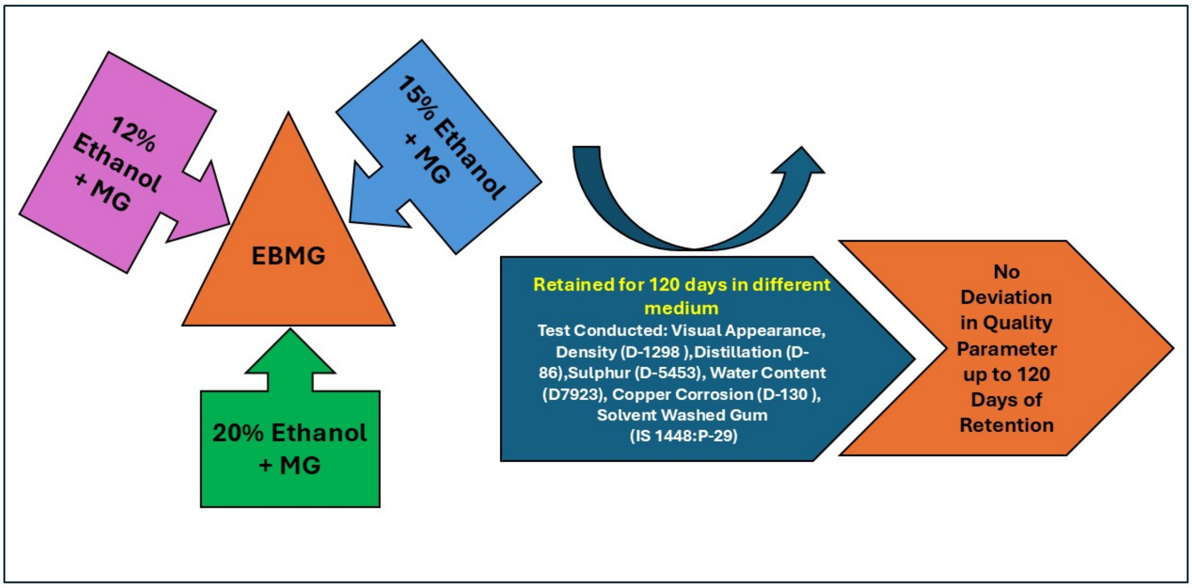


Figure 1. Methodology of the current Study.

Blends of motor gasoline and anhydrous ethanol were prepared with 12%, 15% and 20% ethanol in motor gasoline & subsequently filled in respective sample containers. All the measuring devices had valid calibration certificates from the internationally recognized agency and traceable to international standards. Further, to avoid any contamination, due care was taken while handling the sample. Testing of the samples was carried out by using lab equipment which were being maintained as per internationally recognized standard ISO/IEC 17025:2017. Neat MG retained in glass, Stainless Steel (SS), epoxy-coated & Aluminium was abbreviated as NM-Glass, NM-SS, NM-Epi and NM-Al respectively. MG with 12% ethanol blends were retained in glass, SS, epoxy-coated & Aluminium and abbreviated as E12-Glass, E12-SS, E12-Epi & E12-Al, respectively. MG with 15% ethanol blends retained in glass, SS, epoxy-coated & Aluminium and were abbreviated as E15-Glass, E15-SS, E15-Epi and E15-Al, respectively. Lastly MG with 20% ethanol blends retained in glass, SS, epoxy-coated & Aluminum was abbreviated as E20-Glass, E20-SS, E20-Epi and E20-Al, respectively.

4. Methods

Neat anhydrous ethanol was tested for relative density (Specific gravity), acidity, alkalinity, aldehyde content, ethano %, total Sulphur content and miscibility with water (Table 1).

Table 1. Test results of key parameters of neat ethanol used for blending.

S. No.	Characteristic	Test Method	Test Result
1	Appearance	Visual	Clear, bright & free from sediments
2	Relative density at 15.6/15.6 °C	IS 15464-Annexure-A	0.7946
3	Acidity (as CH3COOH), mg/kg	IS 15464-Annexure-D	27.0
4	Alkalinity, mg/kg	IS 15464-Annexure-D	0.0
5	Aldehyde Content (as CH3CHO), mg/L	IS 15464-Annexure-E	<60
6	Ethanol, % *v*/*v*	IS 15464-Annexure-B	99.8
7	Sulphur content, mg/kg	ASTM D5453	2.8
8	Miscibility with water	IS 15464-Annexure-J	Miscible in medium

All the tests pertaining to neat anhydrous ethanol were carried out by the manual test methods which involve IS/ASTM test methods underlined in the specification Indian Standard (IS) 15464. The applicable test methods are Annexure-A, Annexure-B, Annexure-D, Annexure-E and Annexure-J of IS 15464. Total Sulphur content test was performed on UV-FD based Sulphur analyzer using ASTM (American Standard for Testing Materials) D-5453 test method. In the current work, anhydrous ethanol was blended with motor gasoline in desired proportions (% by volume). For example, to prepare 12% EBMG blend, 12% ethanol & 88% motor gasoline were mixed & stirred properly so that perfect mixing is ensured. Similarly, 15% EBMG was prepared by blending 15% anhydrous ethanol & 85% motor gasoline. Likewise, 20% EBMG blends were also prepared. The number of tests conducted on all these blends are visual appearance and colour, density, distillation, total sulphur, water content, ethanol content, copper strip corrosion and washed gum content. Density was measured manually by ASTM D-1298 using hydrometer and thermometer bearing calibration certificate traceable to National Physical Laboratory (NPL) New Delhi, India. Ethanol content was determined by using the Water Extraction Method of Annexure-B, B-2 Method-1 of IS 15464 which is an alcoholometric method using hydrometer. In this method ethanol content in anhydrous ethanol is being determined using method given in IS 2302 using alcohol meter and Table 1 of IS 2302. As per the test method, measurement error of is ±0.1%.

Result is reported in percent by volume. The distillation test was conducted on an auto distillation tester (Make Tanaka, model AD-6) by using ASTM D-86 test method. The distillation tests parameters were selected as per the specification requirement of Bureau of Indian Standards (BIS) or Indian standards (IS) which is the National Standard Body of India. The recorded distillation parameters are initial boiling point (IBP), percent evaporated at 70 °C (E70/°C), percent *v*/*v*, percent evaporated at 100 °C (E100/°C), percent *v*/*v*, percent evaporated at 150 °C (E150/°C), percent *v*/*v*, Final Boiling Point (°C) and Residue (percent by volume). These recorded points are in line with IS 2796:2017, IS 17586:2021, IS 17021:2018 and are agreed by the vehicle manufacturer and fuel marketers. Distillation parameters obtained as per ASTM D86 have been recorded & verified according to repeatability of the test method. Deviation range of multiple tests were well within the limit allowed by the test method.

Total sulphur content test was conducted on a UVFD auto sulphur analyzer (make -analytikjena, model compEAct) by using ASTM D-5453 test method. Further, water content was determined on Metrohm Make Auto Titrator (Model 831KF Coulometer) using ASTM D7923 test method. Corrosiveness to copper strip was tested by using ASTM D-130 test method. Gum content (solvent washed) tests were performed by air-jet apparatus method on a solid metal block by using ISO 6246 test method and reported in g/m^3. Throughout the testing, laboratory environmental conditions were maintained as per the requirement of ISO/IEC 17025:2017. All the tested parameters are reported as per precision and bias of the respective test methods.

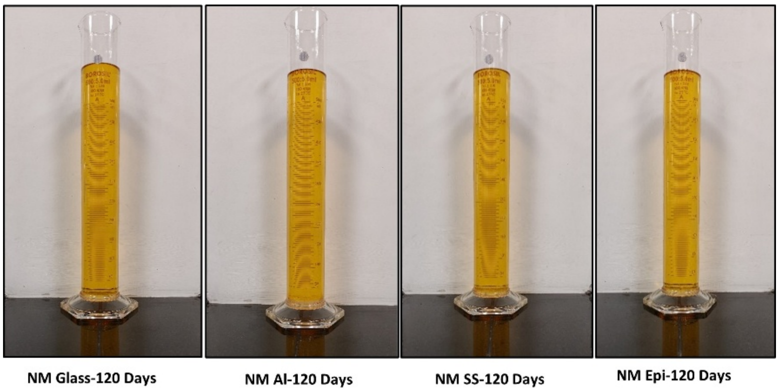
5. Results and Discussions

The test results of neat anhydrous ethanol to be used for blending are tabulated (Table 1) and all the selected parameters are within the prescribed limit of the specification IS 15464:2022. Prepared blends were retained and over the period test parameters such as visual appearance and colour were recorded. Ethanol content (Table 2) in the percent volume of prepared blends was determined by using the test method referred in Indian Standard 2302 by alcohol meter and IS 2302 (detail method described in IS 15464:2022).

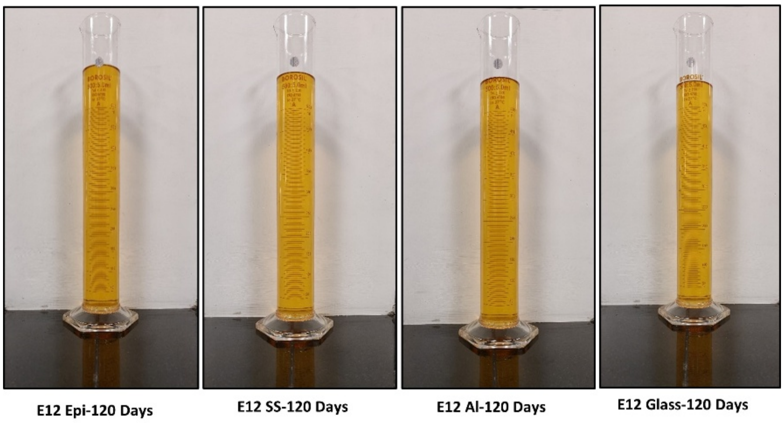
Table 2. Observed Ethanol contents of different blends.

Sample	Ethanol Content at Initial Stage	Ethanol Content after 60 Days	Ethanol Content after 90 Days	Ethanol Content after 120 Days
E12-Glass	11.5	11.5	11.5	11.5
E12-SS	12.0	11.5	12.0	11.5
E12-Epi	12.0	11.5	12.0	12.0
E12-Al	11.5	11.5	12.0	12.0
E15-Glass	14.0	14.0	14.5	14.5
E15-SS	14.0	14.0	14.5	14.5
E15-Epi	14.5	14.0	15.5	14.0
E15-Al	14.5	14.5	14.0	14.0
E20-Glass	19.5	19.0	19.0	19.0
E20-SS	19.5	19.0	19.0	19.0
E20-Epi	19.0	19.0	19.5	19.5
E20-Al	19.0	19.0	19.0	19.0

Appearance and visual colour are recorded in Figure 2a–d, which reveals that even after 120 days of retention period, EBMG samples remain stable with respect to appearance & brightness in respective medium. Clarity and brightness of all the blends are retained throughout the period. All the samples were meeting the criteria of Clear, brightness, and free from any sediments irrespective of the retention medium used (Figure 2a–d).

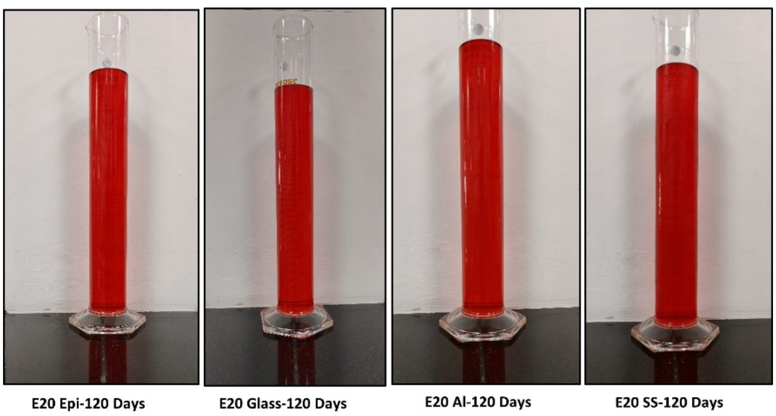


(**a**)



(**b**)

(**c**)



(**d**)

Figure 2. (**a**) Appearance of NM after retention period of 120 days. (**b**) Appearance of E12 blends after retention period of 120 days. (**c**) Appearance of E15 blends after retention period of 120 days. (**d**) Appearance of E20 blends after retention period of 120 days.

Another test parameter of the blends is density at 15 °C. As per the latest specification of MG and EBMG, required density range is 720–775 kg/m^3. It could be seen that there is an increasing trend in the densities of all blends in each medium including neat MG during the retention period. In the case of EBMG, the increase in density is due to ethanol blending as pure ethanol is having higher density as compared to neat MG. As the time increases, there may be increase in the density as lighter part of the blend may scape out. Further slight increase in density of EBMG is seen, which may be attributed to the loss of lighter components during retention period and thereby a slight increase in density (Figure 3). This seems to be a mechanism behind variation in density. These values are within the permissible limit of the referred standards [IS 2796:2017, IS 17586:2021 & IS 17021:2018].

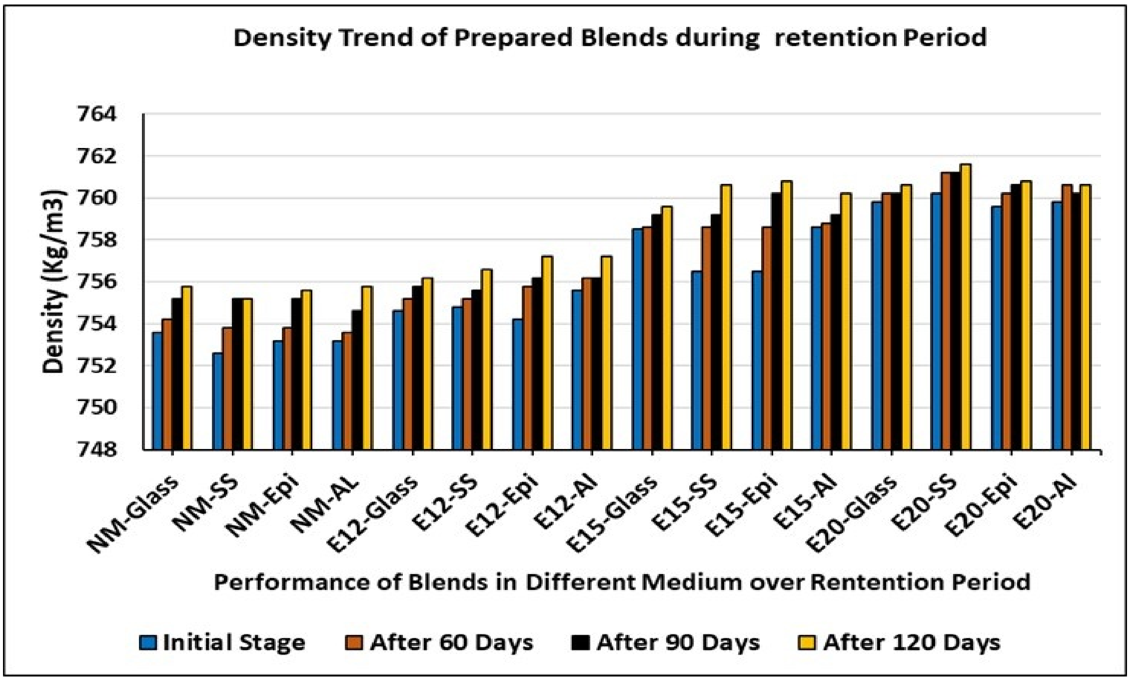


Figure 3. Density of EBMG Blends as a Function of Storage Time and Container Material.

Next parameter investigated is the distillation in which IBP is being discussed initially. If we see the trend of IBP of retained blends (Figure 4) it can be inferred that IBP for neat MG is almost constant whereas after ethanol blending, it is showing an increasing trend.

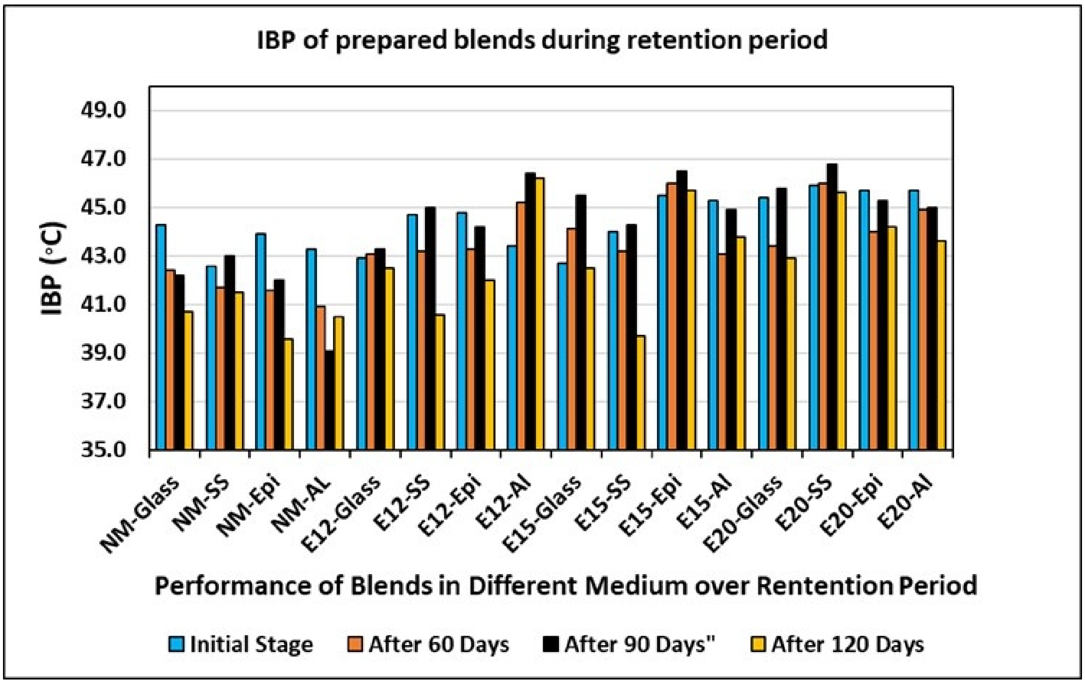


Figure 4. IBP of EBMG Blends as a Function of Storage Time and Container Material.

The increase in IBP after ethanol blending could be due to addition of ethanol as IBP of ethanol is greater than the neat MG. Hence, after ethanol blending, there is contribution of ethanol in increasing initial boiling point of EBMG blends. To ensure optimal cold start performance, it is essential that at least 20% of the fuel by volume (*v*/*v*) vaporizes below 70 °C. If this percentage is too low, starting difficulties may arise in engine, while if it is too high, fuel evaporation losses may increase, and vapor bubbles could form in the intake manifold. Consequently, the E70/°C percentage range has been defined in oil industry standards. For pure MG, the range is set between 10–45% *v*/*v* during colder months and 10–55% *v*/*v* in summer. For ethanol blends like E12, E15, and E20, the range extends from 10–55% *v*/*v* in summer and 10–58% *v*/*v* in colder months. Additionally, the E70/°C percentage has been assessed for all fuel blends in relation to their retention period. For neat MG, the E70/°C value is on the lower end and increasing when ethanol is added (Figure 5).

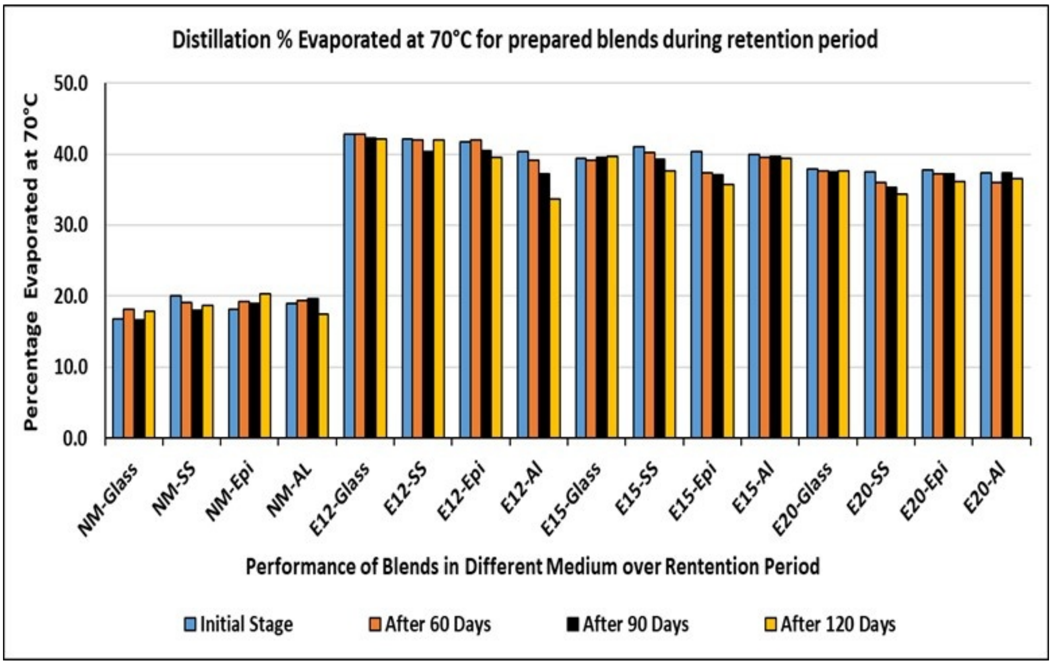


Figure 5. E70 of EBMG Blends as a Function of Storage Time and Container Material.

All the values are in the range of earlier outlined respective standards only. In case of E12, it is highest and further there is a slight drop & lowest for E20. This phenomenon was explained by some authors who have drawn the distillation curve for blends of ethanol blended MG & reported that there is significant depression in distillation curve between the points at which 10% and 50% of the fuel was distilled [19]. The increase in E70/°C could be due to the well-known fact that after the addition of ethanol to gasoline, it will increase volatility, which causes an increase in recovery. Already guidelines have been issued for blending ethanol and handling motor gasoline containing up to 10% *v*/*v* ethanol [20]. It has been addressed that ethanol also affects the distillation characteristics of the EBMS and E70 is changed most significantly. E70 increases by about 8% *v*/*v* when 5% *v*/*v* ethanol is blended into NMG. An 18% *v*/*v* increase in E70 is observed when 10% *v*/*v* ethanol is blended into base gasoline. These changes are significant and can be compared to the 28% *v*/*v* overall range of E70 that is defined in the EN228 specification for all volatility grades. Therefore, it may be concluded that over the retention period, both parameters, IBP and E70 are within the range of the specification.

Next point of observation is E100/°C for different blends with respect to the retention period. The temperature at which 100% *v*/*v* of fuel is vaporized, is a critical parameter, since if it is too low it can cause the solidification of water vapour contained in the intake air resulting in the formation of ice on elements forming the blend. For Neat MG, E12 & E15, the range of E100/°C is 40–70 (percent *v*/*v*) whereas for E20 it is 45–78 (percent *v*/*v*) as per existing specifications. Figure 6 clearly states that for all the blends there is a constant increase in E100/°C with an increase in ethanol content throughout the period. It means that after blending MG, there is an increase in volatility, which contributes to an increase in E100.

While going through the available literature, studies have shown that when ethanol molecules interact with light and medium fractions of gasoline, they form azeotropes [21]. If the temperature at which 90% of the fuel is vaporized is too high, the fuel may not completely vaporize in the cylinder. This can lead to the fuel remaining in liquid form, displacing the lubricant, and resulting in oil dilution. Furthermore, incomplete combustion can cause irregular engine performance. Additionally, the presence of high-boiling-point hydrocarbons in gasoline contributes significantly to the production of harmful emissions. The E150/°C values for all blends have been determined, with the results plotted over the time (Figure 7).

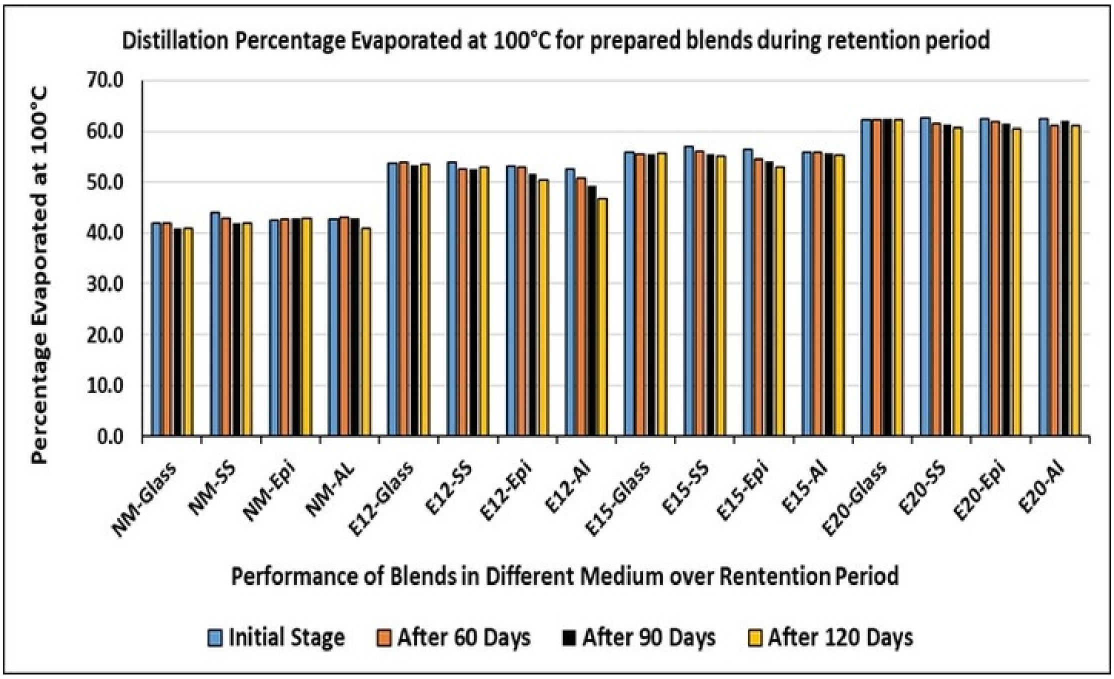


Figure 6. E100 of EBMG Blends as a Function of Storage Time and Container Material.

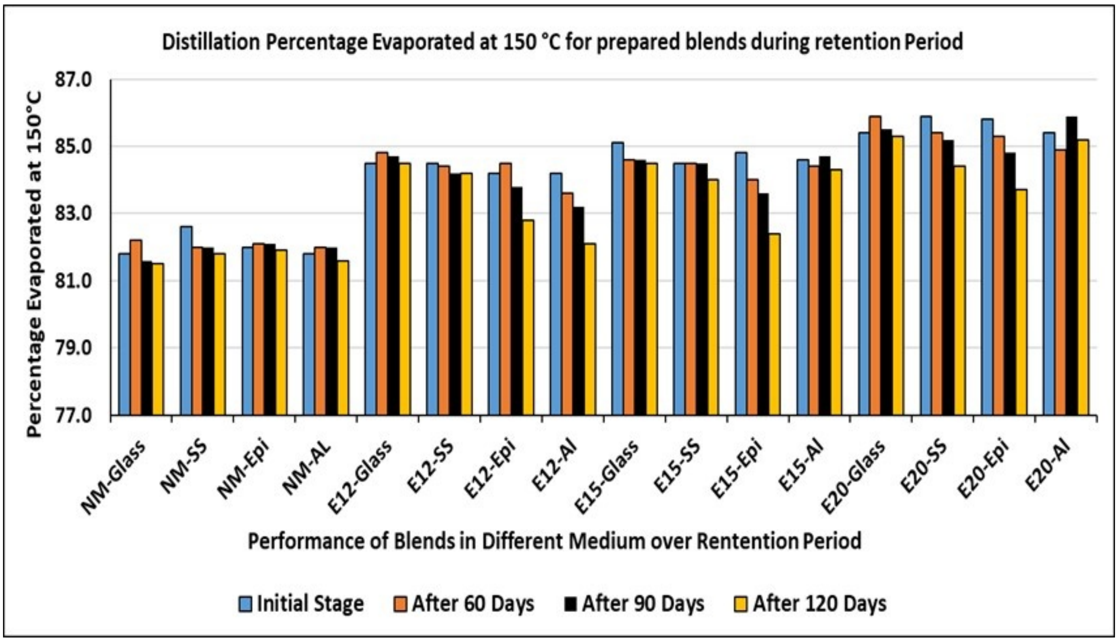


Figure 7. E150 of EBMG Blends as a Function of Storage Time and Container Material.

According to the specifications, the minimum E150/°C range (percent *v*/*v*) should be 75% for both pure MG and the E12 blend, while a minimum of 85% is required for the E20 blends. The plot revealed that the trend is increasing from neat MG to ethanol blended samples (E12) and after that it remains almost constant for all the blends (E15 and E20 both). Initial increase from MG to E12 is due to sudden change in matrix from neat MG to EBMG and from E15 to E20, the matrix remains the same. It can be inferred that after 90 and 120 days of retention period, there is a further drop which may be due to the loss of lighter components present in blends over the retention period. Another parameter is the final boiling point, which is limited to below 210 °C (maximum) as per motor gasoline specifications. The maximum temperature observed on the distillation thermometer when a standard ASTM distillation is carried out is called final boiling point (FBP), and recorded in °C. The upper limit is limited so that the engine is not damaged by heavy materials. Figure 8 clearly indicates that ethanol blending is lowering the FBP. FBP for neat MG is at higher side whereas when ethanol is blended, there is a drop in FBP from 2–3 °C.

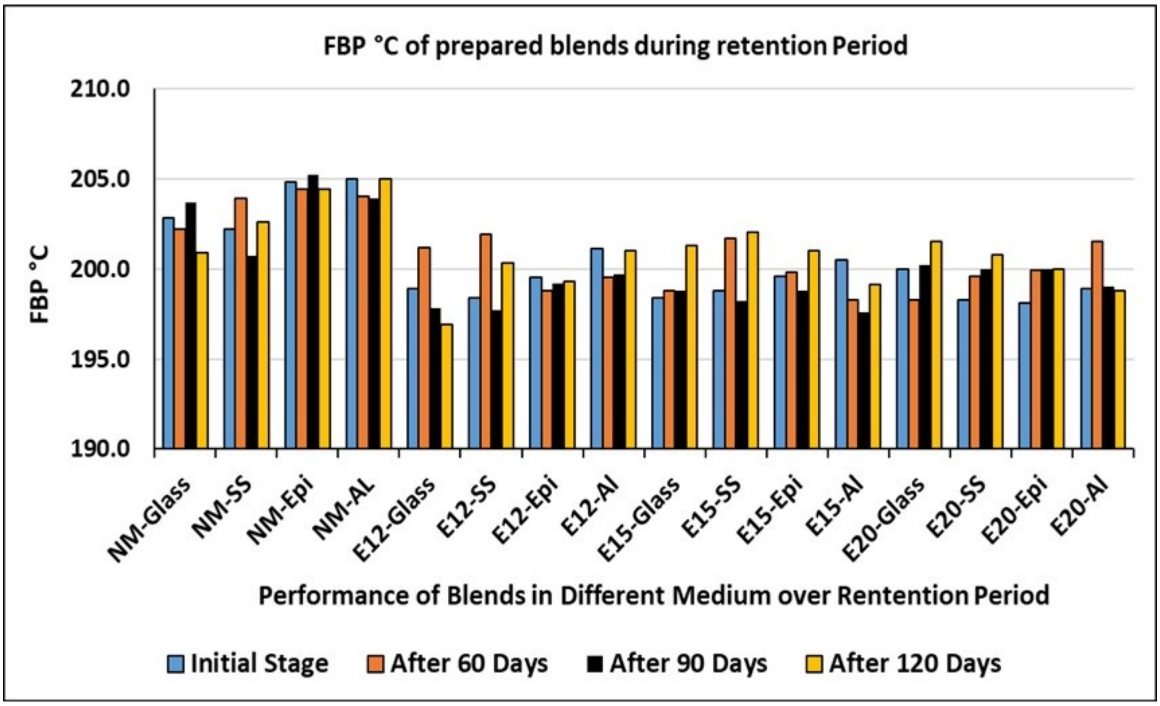


Figure 8. FBP of EBMG Blends as a Function of Storage Time and Container Material.

The value is almost constant from 12% to 20% EBMG. Drop in FBP of blends after ethanol blending is being accounted to the lower boiling point of pure ethanol. When ethanol is blended with MG, it contributes to reduction of FBP in respective EBMG blends. Above observations reveal that after 120 days retention period all the distillation parameters are in line with the respective standards only [IS 2796:2017, IS 17586:2021 & IS 17021:2018]. Hence, it can be inferred that after retention period, all the distillation test parameters are well within the range of these specification only. The presence of ethanol in gasoline can influence the combustion process and emissions. Many research aimed to understand how sulfur-containing compounds within these blends behave during combustion and their impact on regulated pollutants and carbonyl emissions. At fuel stations across the globe, only the low-Sulphur fuel that complies with Bharat Stage-VI (BS-VI)/ Euro 6 specification requirements are being handled. From emissions and air quality perspective, the most important parameter defined in the new fuel quality specifications BS-VI is the maximum Sulphur content of gasoline. In all the cases, sulphur content is limited to a maximum of 10 ppm for BS-VI regulations. The pattern of total Sulphur content of all the blends is shown in Figure 9 & it can be remarked that the value of total sulphur content is almost constant & within the permissible limit of the specification.

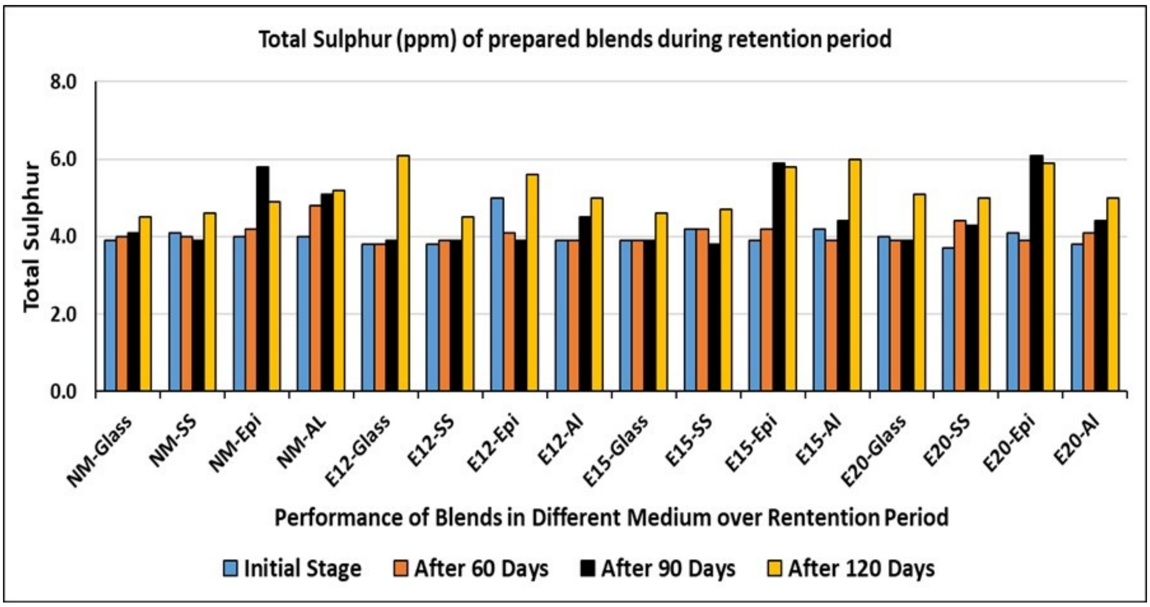


Figure 9. Total Sulphur of EBMG Blends as a Function of Storage Time and Container Material.

Further, the results obtained are also within the reporting limit of the test method used. In the case of blends retained up to 120 days, there is a slight increase in total suplphur content value which is within the range of specification & precision of the test method. Apart from this, no significant change in total Sulphur content is observed, which implies that prepared blends are stable in all the medium & will meet the specifications with respect to total sulphur even after a retention period of 120 days.

Another, the most important challenge in EBMG is the water content envisaged due to the great affinity of ethanol with moisture in surroundings and resulting in an increase in water content. Atmospheric moisture may encounter EBMG fuels and cause an increase in water content over the retention period. One of the main concerns in the supply process is that as the use of ethanol continues in ethanol containing fuels, there are chances of phase separation. Phase separation happens when water contaminates gasoline, causing ethanol to bind with the water molecules. This results in two distinct layers within the storage tank, one containing only gasoline at the top, and the other a mixture of ethanol and water at the bottom. This issue can arise at any stage of ethanol production or distribution, so it is crucial to minimize water exposure throughout the process. Ethanol contains a hydroxyl (-OH) group, which leads to strong hydrogen bonding like water. This characteristic makes ethanol hydrophilic, meaning it has a strong tendency to attract water. The turbidity point, which refers to the haziness of the fuel, is an effective indicator of when phase separation begins as the water content increases. If excess water is present, ethanol can increase the concentration of dissolved water in gasoline before phase separation (turbidity) is observed. As reported [22] at the same turbidity point, the dissolved water content of gasoline increases as the ethanol concentration in the blend increases. In current study while discussing appearance, it has been mentioned that there is no such case of turbidity point or haziness during the study.

Figure 10 depicts that after a retention period of 90 and 120 days, there is an increase in water content. The highest observed value of water content is 0.194% for 15% EBMG retained for 120 days in epicoated medium. This increase may be due to the increase in moisture in the matrix with respect to time. The water content of E15 blended gasoline in epoxy-coated containers (maximum 0.194%) was significantly higher than that in other containers. This difference may be related to the adsorption/penetration properties of the epoxy coating of the vessel. As time increases over the retention period, these blends are more susceptible to moisture, and it may cause an increase in water content.

The maximum observed value is within the acceptable range of the various specifications of EBMGs. These observations revealed that all the blends are stable and there is no further increase water content of the retained blends.

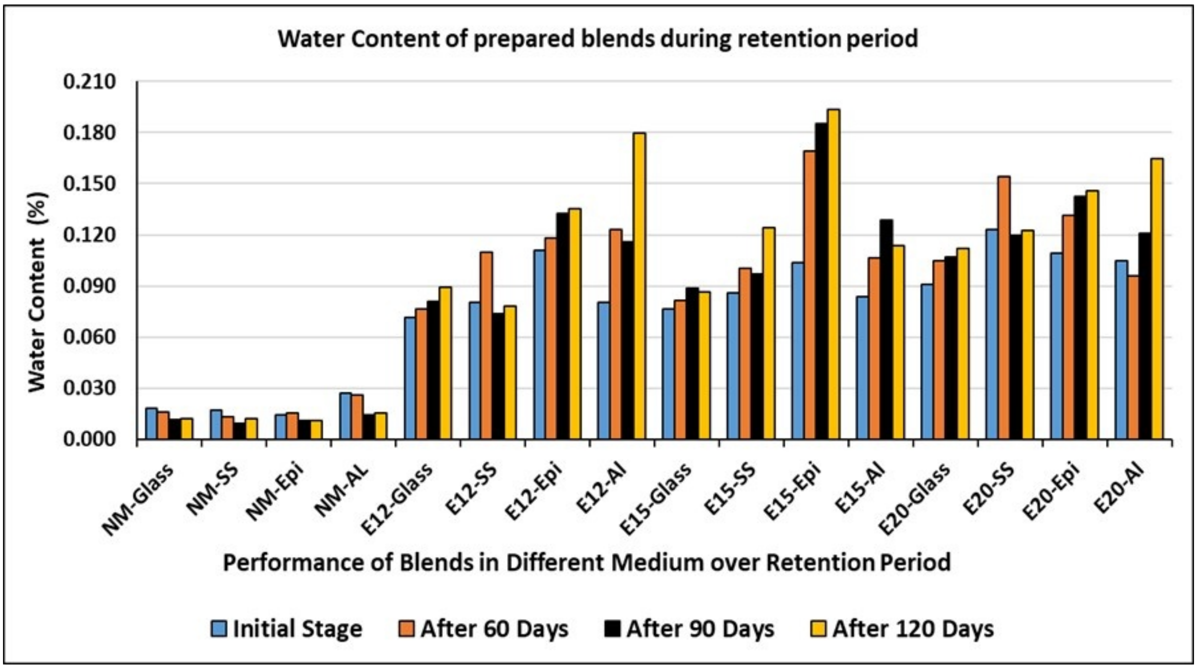


Figure 10. Water Content of EBMG Blends as a Function of Storage Time and Container Material.

Copper strip corrosion tests were conducted on different blends right from initial to the final stage of the retention period. Results revealed that there is not any significant change in copper strip corrosion ratings till the final stage. This would enable us to help get detailed insight into the transfer of EBMG through pipeline (Figure 11). Since the life and maintenance of any product pipeline is also the function of the products to be transferred, as the nature of product plays an important role with the metallurgy of the materials used for fabrication of pipeline. For existing and new emerging pipelines, EBMG are new kind of stuff to be handled and there are chances that either quality parameters of EBMG gets alter or EBMG may also affect the metallurgy of the pipeline. To overcome this situation & get detailed insight about the challenges in transferring EBMG through pipeline, both water content and copper strip corrosion tests have been conducted on EBMG.

Figure 11. Copper Strip Corrosion test results of prepared blends.

From the results discussed, it is very clear that both water content and copper strip corrosion tests results are within the acceptable range of specifications. This will enable us to plan for the feasibility of transfer of EBMG through pipelines. If pipelines are to be used for transferring EBMG, they must be completely dehydrated prior to the shipment of these blends as ethanol has affinity for residual water. Dehydrating a pipeline system is costly & a difficult task. It will require additional effort/equipment for successful completion [20].

At present in various countries, ethanol is being used as renewable fuel for SI engines as well as additive to improve the octane number of gasolines. It is reported that during storage, some hydrocarbons present in gasoline react with absorbed atmospheric oxygen and with each other, forming resinous, polymeric, and non-volatile materials with a high molar mass that are commonly called gum. The gum sticks to the metal surfaces along the vehicle-fuel system, from the tank to the combustion chamber. Accumulation of these products can cause engine wear and can have adverse effects on engine efficiency, performance, emission, and durability [20]. Thus, it is pertinent to find out the trend of gum content of prepared blends retained over the defined period (Figure 12).

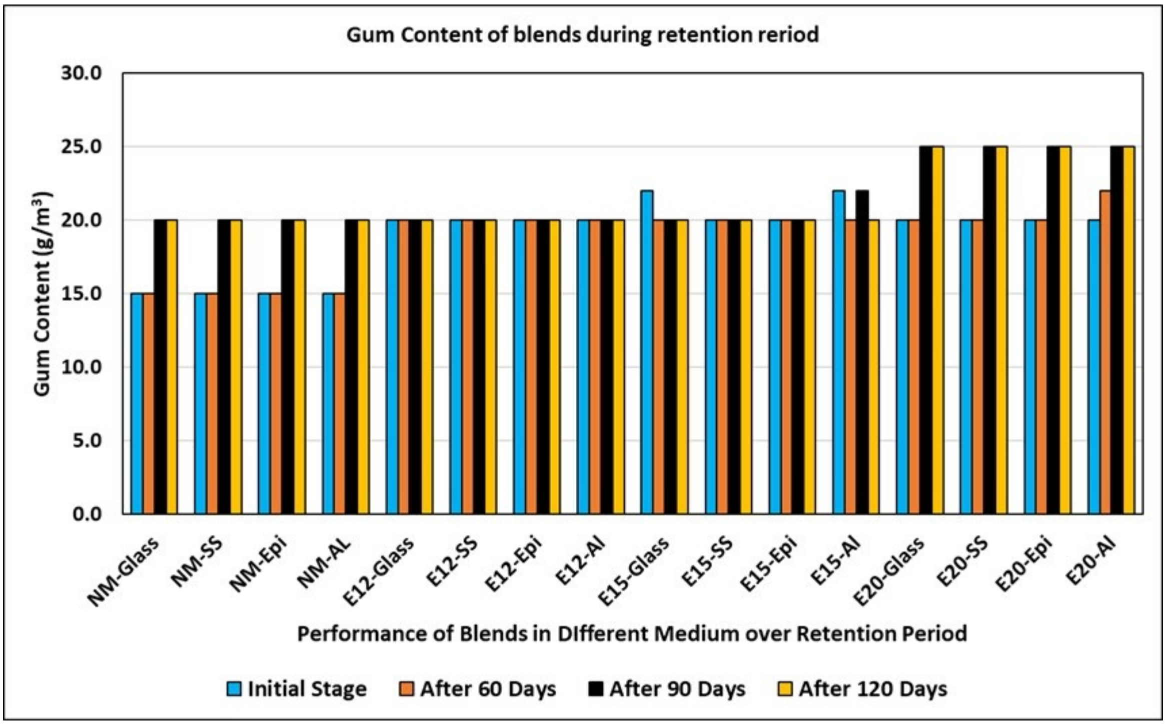


Figure 12. Gum content of EBMG Blends as a Function of Storage Time and Container Material.

Gum content test has been conducted as per test method ISO 6246. The value of solvent washed gum content test is reported as per the test method where these are ranging from 15 g/m^3 to 24 g/m^3. As per the reporting format of the test method, 18 g/m^3 is reported as 20 g/m^3 and 24 g/m^3 as 25 g/m^3. Thus, the values of gum content (solvent washed) lie in the range of 15 to 25 g/m^3. The pattern of observed gum content of various blends shows that there is increase from neat to 20% ethanol blended motor gasoline (E20) irrespective of the medium used. However, this increase is not beyond the specification range and hence it is not altering the respective specification requirement. It is observed that in case of E20 blends, which contain added red dye, the trend of gum content value was slightly increasing but during test when washing solvent is added in slightly excess quantity as permitted by the test method, these values are coming at lower side. It turns out that a slight increase in value might also be contributed by the red dye added, which gets dissolved after addition of subsequent amount of the washing solvent. No separate experiments were conducted to investigate the interference of red dye. The degree of dye influence was interpreted based on residue obtained & the same was observed while washing the gum. Lastly, it can be inferred that all the values are well within the range of the respective specifications and hence all these blends are stable with respect to gum content. Again, it could be concluded that if these EBMG product retained at any location is being transferred through pipeline, these will make any contribution in increase of water content and does not play role towards the corrosiveness to the pipeline.

Based on above observations and discussions, all the properties and their trends are summarized in Table 3.

Table 3. Summary of the fuel properties on gasoline.

S. No.	Characteristic	Test Method Used	Neat Gasoline Property	E12 Fuel Property w.r.t. Time	E15 Fuel Property w.r.t. Time	E20 Fuel Property w.r.t. Time
1	Appearance	Visual	Clear & Bright	Clear & Bright	Clear & Bright	Clear & Bright
2	Density, Kg/M^3	ASTM D-1298	Constant	Increases	Increases	Increases
3	Distillation-Initial Boiling Point (IBP)/°C	ASTM D-86	Constant	Increases	Increases	Increases
4	Distillation-% Evaporated at 70° °C	ASTM D-86	Decreases	Increases	Increases	Increases
5	Distillation-% Evaporated at 100 °C	ASTM D-86	Constant	Increases	Increases	Increases
6	Distillation-% Evaporated at 150 °C	ASTM D-86	Constant	Increases	Increases	Increases
7	Distillation-Final Boiling Point (FBP)/°C	ASTM D-86	Constant	Decreases	Decreases	Decreases
8	Total Sulphur (ppm)	ASTM D-5453	Constant	Constant	Constant	Constant
9	Water Content (%)	ASTM D7923	Constant	Increases	Increases	Increases
10	Copper Strip Corrosion	ASTM D-130	No Change	No Change	No Change	No Change
11	Gum Content (g/m^3)	ISO 6246	Constant	Constant	Constant	Increases
12	Ethanol Content (% by Volume)	Annex-B, B-2 Method-1 of IS 15464	Constant	Constant	Constant	Constant

6. Conclusions

No deterioration in visual appearance and colour of EBMG sample is seen over the retention period of three months. The same could be ascertained by respective photographs taken at defined intervals. Density & various distillation parameter such as IBP, E70, E100, E150 and Final Boiling Point were monitored and revealed that all are within the permissible limit of the applicable specifications. Total sulphur value is in the range of 4 to 6 mg/kg and are within the range of the applicable specification only. Water contents for neat motor gasoline are lowest (in the range of 0.011 to 0.027%) throughout the retention period. Further, after ethanol blending water content is increasing with respect to time. It is highest for 15% and 20% ethanol blended motor gasoline blends (maximum observed value is 0.194%). The trend of water content is indicating that till the retention period, there is no significate change. Copper strip corrosion tests results also reveal that there is not any significant change over the retention period. Solvent washed gum content is also within the permissible range of the specification (in the range of 15 to 20 g/m^3). After reviewing all the tested parameters of various blends after 120 days of retention period, it turns out that the tested parameters under study are within the limit of respective specification. Hence, it can be concluded that the prepared blends are stable and could be retained for 120 days in any type of medium highlighted in the current study. The outcome of the study provides detailed insight about various tested quality parameters and how these blends perform after retention period. This would be helpful for various oil industry locations where ethanol blended motor gasoline is being stored and handled. Further study may also be conducted to see the effect of retention period for much longer period.

Institutional Review Board Statement

This section is not applicable

Informed Consent Statement

This section is not applicable

Data Availability Statement

Above statement is accepted for further reference.

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Conflicts of Interest

The author declares no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

Nomenclature List

EBMG—Ethanol Blended Motor Gasoline
NMG—Neat Motor Gasoline
DISI—Direct injection spark-ignition gasoline engine
SS—Stainless steel
BIS—Bureau of Indian Standards
IS—Indian Standard
ASTM—American Standard for Testing Materials
NPL—National Physical Laboratory
E70—Percent evaporated at 70 °C
E100—Percent evaporated at 100 °C
E150—Percent evaporated at 150 °C
FBP—Final Boiling Point
E12—MG with 12% ethanol blends
E15—MG with 15% ethanol blends

E20—MG with 20% ethanol blends
BS—VI-Bharat Stage-VI

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