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PRODUCTION PROCESS OPTIMIZATION, AND PERFORMANCE TESTING OF MMSU HYDROUS BIOETHANOL II AS RENEWABLE ENGINE FUEL

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ABSTRACT

Preliminary studies on the utility of 95% Azeotrope Ethanol (*MMSU 95 hBE*) as oxygenate and gasohol fuel in mobile and stationary engines paved the way for the Department of Energy (DOE)-funded project, Village Scale Production of MMSU Hydrous Ethanol as Feedstock for R&D in Biofuel Trials and Anhydrous Ethanol Production. Two components of the project are reported here: (1) the scaled-up production and optimization trials of *MMSU 95 hBE* and (2) the performance evaluation of hydrous bioethanol as oxygenate and gasohol blend in spark ignition engines. The first component focused on the bulk production of hydrous ethanol, including experimental trials to improve the fermentation and distillation efficiencies under scaled-up conditions. Integrated studies of the first component included: 1) yeast activation period; 2) sugar concentration; and 3) energy and water-cost efficient reflux distillation system. Previous lab scale fermentation experiments used 4-6hr aerobic activation periods before yeasts were pitched into anaerobic fermentation vessels. Under ambient conditions, the set-up gave 72-76% ethanol conversion efficiency in as short as 18-24 hrs. Succeeding experiments lowered the activation period to 1hr, which improved fermentation efficiency to 85.9%. Optimum conversion efficiency for maximum ethanol yield was observed at 30% sugar concentration. Fuel wood input during distillation was reduced by half when an insulator was used to cover the distiller. Ethanol recovery by the reflux distillation system was 95-100%. Further, we were able to reduce the water consumption by 95% using a recycling system to condense the distillate. The second component of this project focused on the performance evaluation of MMSU hydrous bioethanol both as alternative oxygenate to anhydrous ethanol and as a significant component of gasohol blends. Comparison data were obtained to highlight properties of the blends as well as document performance in spark ignition engines of cars, motorcycles and water pumps. Results of these studies demonstrate the feasibility of using hydrous ethanol instead of anhydrous both as oxygenate and as significant component of gasohol blends up to a concentration of 30% hydrous ethanol. Our studies confirmed that hydrous ethanol can be effectively splash-blended with gasoline without phase separation or other problems. The studies were able to demonstrate the benefits of oxygenation and comparable engine performance, capitalizing on the change in chemical and physical properties which occur as a result of combining water, ethanol, and gasoline to optimize the efficiency at which internal combustion engines operate. While there is a slight reduction in fuel economy due to the lower energy content of hydrous ethanol, it is counteracted by increasing engine performance due to higher octane and higher heat of vaporization of ethanol and water in comparison with gasoline and anhydrous blends.

Keywords: *bioethanol, biofuel, hydrous bioethanol fuel, hydrous ethanol*

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INTRODUCTION

The Philippine government considers the use of biofuels as one of the key ways to reduce carbon dioxide emissions and lessen the country's dependence on oil importation. Republic Act 9637 (2006 Philippine Biofuels Act), mandates the use of 5% ethanol in gasoline by the year 2009 and 10% by 2011. Under the Act, the Philippine National Standards (PNS) specified that the ethanol used in blending should be 99.6% anhydrous. However, the technical requirements to produce anhydrous ethanol effectively cut out the participation of village-scale industries – the very sector that the legislation purportedly wants to benefit.

Hydrous ethanol (also known as azeotropic ethanol) is the most concentrated grade of ethanol that can be produced by simple distillation, without further dehydration steps necessary to produce anhydrous (or dry) ethanol. Both Hydrous and Anhydrous ethanol have been used as fuel (Wagner et al., 2009). Hydrous ethanol azeotrope exists as 95% ethanol-5% water and can be used as pure ("neat") fuel in engines while anhydrous ethanol is currently used in fuel blends ranging from E-5 to E-85 (Karpov, 2007). As the process of dehydration is costly and energy-consuming, studies have noted that hydrous ethanol is up to 30% less expensive than anhydrous ethanol (Domingo, Ignacio, Ariano and Yadao, 2013). Hydrous ethanol is easier to produce and to handle, and it offers a better life cycle emissions profile than anhydrous ethanol (Karpov, 2007).

The use of hydrous ethanol at temperatures lower than 15.6^{0}C (60^{0}F), however, poses technical problems, primarily because the mixture can exhibit phase separation, rendering such blends unsuitable for fuel use (Mills & Ecklund, 1987). This explains why in countries where temperature varies widely from summer to winter, (e.g. in North American and European countries), only anhydrous ethanol is used as oxygenate. If ever hydrous ethanol is used, additives and dispersants are necessary to prevent phase separation. Coupled with reformulations that are mandated during summer and winter months, the use of hydrous ethanol is rendered impractical in most countries with cold climates.

Such is not the case in the Philippines. With an average annual temperature of 26.7^{0}C (80^{0}F), even the coolest months in Baguio City do not register temperatures below 18.3^{0}C. Previous studies have established that water tolerance of ethanol-gasoline mixtures improves with increasing temperature (Korotney, 1995), suggesting the possibility that hydrous ethanol-gasoline blends can be used without the need for dispersants and additives. If so, hydrous ethanol can be splash-blended in gasoline formulations successfully and economically in the Philippines.

Cognizant of the added cost of producing anhydrous ethanol, and in order to develop adaptable and adoptable technologies at the village level, the MMSU Biofuels Group have been investigating the potential use of hydrous ethanol as substitute for anhydrous ethanol. At current demand, 30% reduction in the cost of hydrous ethanol is worth over Php6 billion in savings per year for the industry. Aside from these savings, blending hydrous bioethanol with gasoline results in a substantial total volume of gasoline substitution despite relatively small percentage additions Fermentation and distillation technologies developed by the MMSU Biofuels group make it possible for ordinary ethanol feedstock growers to participate in the nascent bioethanol industry. Included in this group are sugarcane and sweet sorghum growers, nipa and coconut sap harvesters, and the like.

The overall objective of the project is to develop technologies to mass produce *MMSU 95 hBE* and study its utility as substitute to anhydrous ethanol as oxygenate and gasohol fuel blend for spark ignition engines. Specifically, it aims to: (1) optimize fermentation and distillation technologies under scaled-up conditions; (2) compare the Octane Rating of various hydrous ethanol gasoline blends with commercially available E-10 gasoline; (3) compare the performance of various hydrous ethanol blends with commercially available fuel in an engine dynamometer using an SI engine; and (4) compare the performance as regards mileage and/or Heat Rate of 20% hydrous ethanol blend (*MMSU hBE-20*) with Unleaded E-10 to various gasoline engines.

METHODOLOGY

Optimization trials on the production of *MMSU 95 hBE*

Fermentation efficiency of yeast in different activation periods under scaled-up conditions

Previous lab experiments have shown that 30-60 min activation gives the highest fermentation efficiency and thus used in this trial. Known amount of yeast was activated in a specific volume of prepared sugar feedstock for fermentation. The separate container with the propagating yeast was continuously stirred at room temperature for 30 and 60 min before they were pitched into the separate fermentation vessel. The fermentation vessel was installed with a breather and a provision for mechanical stirring to maintain anaerobic conditions. The experiment was conducted twice.

Re-fermentation trials of sugar residues after distillation

One of the drawbacks of using commercial Baker's yeast is its high sugar requirement for optimum activity. A preliminary lab scale experiment showed optimum activity occurs at 30% sugar concentration, giving ethanol yield of 12-14% (v/v) which is close to the maximum ethanol tolerable limit (15%v/v) for yeast viability. Concentrations below 30% resulted in longer fermentation periods and lower ethanol yields. It was found out that after distillation, there is still a large amount of residual sugar in the hydrolysate. The objective of this experiment was to evaluate the ethanol conversion efficiency of the sugar residue after distillation.

Two trials were evaluated. Trial 1 involved the addition of fresh sugar to the sugar residue to attain an initial 30% concentration. Trial 2 involved concentrating the sugar residue to 30% by boiling off excess water. Both sugar feedstocks were separately added with known amount of yeast using the fermentation protocol followed in the previous trials.

Zero-water loss distillation protocol

Like any distillation system, water supply is the life of the condensation process. In conventional systems, water is continuously lost during distillation, which is costly, wasteful and sometimes harmful to the environment. The objective of this experiment was to improve the design of the cooling and water recycling system to attain a zero-water loss distillation protocol.

Performance Evaluation of *MMSU 95 hBE-20* as Oxygenate and Fuel in Stationary and Spark Ignition Engine

Research Octane Number (RON) of selected MMSU 95 hBE blends.

RON rating of fuel describes the auto-ignition property of fuel: the lower the RON, the lower the auto-ignition temperature of fuel. Hence, the RON of *MMSU 95 hBE* blends must be determined to prevent engine knocking. Three selected blends were formulated to observe the effect of hydrous and anhydrous blends in two commercially available gasoline fuels (Unleaded E-10 and XCS E-10). Formulations are as follows: (1) *hBE-20* in UnE-10c, (2) *hBE-20* in XCS E-10c, and (3) 20% anhydrous ETOH in UnE-10c. The fuel blends were tested at SGS (Subic Bay Freeport, Philippines) Inc. using ASTM D2699-2012.

Performance of hBE blends in stationary engine

To test the performance of hBE blends, seven treatments of fuels were prepared, using two commercially available E-10 fuel (UnE-10c and XCS E-10c) and neat (i.e. "pure") gasoline as the base fuels for hBE blends. The performance of hBE blends and other treatment fuels were tested in an engine dynamometer using a 1.6-L Toyota Altis engine at the Vehicles Research and Testing Laboratory (VRTL) of the College of Engineering, Mechanical Engineering Department, University of the Philippines, Diliman. The AVL Systems Technology Engine Dynamometer used in these tests is compliant with SAE 1349J standard and can measure up to 300KW output electrical power absorber. It must be noted that the intention of the engine dynamometer test is to compare the engine performance using different fuel treatments and not to determine the maximum performance of the Toyota Altis engine. The following fuels were evaluated: (1) Neat Gasoline, (2) *hBE-10* in Neat Gasoline, (3) *hBE-20* in Neat Gasoline, (4) Extra Unleaded E-10c (UnE-10c), (5) *hBE 20* in UnE-10c, (6) XCS E-10c, and (7) *hBE-20* in XCS E-10c.

Performance of hBE blends in Chassis Dynamometer

The performance of various blends as regards maximum power, mileage and combined fuel economy were also evaluated in road tests of a brand new Kia Rio (1.3 MPI engine) using the Japanese 10-15 mode standard cycle. The 10 mode simulates city driving while the 15 mode simulates long distance drive. The blends used in these tests were as follows: (1) Neat Gasoline, (2) *hBE-10* in Neat Gasoline, (3) *hBE-20* in Neat Gasoline, (4) Unleaded E-10, and (5) *hBE-20* in UnE-10c. The tests were also conducted at VRTL in UP-Diliman.

Performance of hBE blends in motorcycles

Actual mileage runs of motorcycles in MMSU using *hBE-20* and Unleaded E-10c were determined through actual road tests. Short-campus cycle and long-distance cycle ride protocols were established to minimize errors in accounting for the actual mileage of the two brand-new 155 TMX motorcycles utilizing separate and exclusive fuels. During the mileage runs, the two motorcycles were ridden simultaneously.

Performance of hBE blends in 16HP Engine

The performance of UnE-10c was compared to *hBE-20* using a 16HP Briggs and Stratton engine on a Test Rig of Agricultural Machinery Testing and Evaluation Center (AMTEC) in UP-Los Baños, Laguna. The procedures used to determine the power, fuel economy and temperatures were as specified in the Philippine Agriculture Engineering Standard (PAES 117:2000, Agricultural Machinery - Small Engine - Methods of Test).

RESULTS AND DISCUSSION

Bulk Processing of *MMSU 95 hBE* and Production Protocol Optimization Trials

Fermentation efficiency of a 30-60 min-activated S. cerevisiae at scale-up conditions

To start the fermentation process, the yeast must first be activated – i.e., the yeast is introduced to a favorable liquid medium to encourage rapid activation prior to adding to the hydrolysate. Once the yeast culture has been rapidly propagated to a desired density, it is pitched into the hydrolysate to start the anaerobic fermentation process.

This method is preferable to adding the yeast directly, for several reasons. First, it results in a more rapid fermentation, as the yeasts have already grown and multiplied and now ready for anaerobic fermentation. The sooner the yeast can get to work, the better the resulting fermentation will be. Activating the yeast can save considerable time to complete the entire fermentation process as well as increase the ethanol concentration.

Secondly, it ensures viability of the yeast. By making a starter solution before pitching, one can discover whether yeast is viable or non-viable.

Thirdly, a starter, when properly made, will acclimate the yeast to its destined environment. When the starter is acclimated, it will do its work once it is added to the primary, with much more efficiency .

Activation takes valuable time, however; and in a commercial situation, it is important to identify the minimum time required to get satisfactory fermentation results. The experiments have indicated that an activation period of as little time as 1hr is effective enough to give 83.47% efficiency; reducing this time further to 30 mins results in a reduction of fermentation efficiency (79.57%) as shown in Table 1.

Re-fermentation trials of sugar residues after distillation

Even under optimum conditions, there are considerable sugars that remain after fermentation and distillation. Attempts to utilize these residual sugars by simply adding yeast gave very poor results. The experiments (Table 2) centered on adjusting the residual sugar concentration to the optimum 30% by either adding fresh sugar or concentrating the sugar by boiling out the water in the hydrolysate. Results indicate that the addition of fresh sugar is more effective than simply boiling out the water to achieve the optimum sugar concentration. After second cycle fermentation, virtually all of the added sugar in Trial 1 was converted into ethanol (97.43%) whereas only half of the remaining sugars in the re-concentrated are converted to ethanol (47.93%). This is likely due to anti-yeast nutritive factors that are produced in the initial fermentation process, or that some of the remaining sugars have simply become non-fermentable. At any rate, the findings indicate that there is still value in the residual sugars for a second fermentation as the addition of fresh sugar can result in much higher fermentation efficiency than the theoretical 50%.

Table 1. Average fermentation efficiency (%) of *S. cerevisiae* at two different activation periods under laboratory and scale-up condition

Activation Period, hr	Laboratory Scale, 10L	Scale-up, 149L
30	85.85	79.57
60	85.17	83.47

Lab scale - 10L; Sugar conc, 32%; Theoretical ETOH, 1.632L (reported 2011-2012)

Fig. 1. Fermentation set up at laboratory (a) and Scale-up condition (b)

Table 2. Ethanol potential of residual sugar after fermentation and distillation of a 10L volume sugar feedstock at 31% sugar concentration

Experimental Trials	Brix of Sugar Residue in Hydrolysate after Distillation, %	Final vol. of sugar feedstock for fermentation, L	Computed 95% ETOH yield, L	Actual ETOH yield, L	ETOH Conversion Efficiency, %
Trial 1-fresh sugar added to sugar residue to make 30% Brix	15	12	1.93	1.89	97.93
Trial 2-sugar residue concentrated to make 30% Brix	16	12.5	1.98	0.95	47.93

Energy-efficient, Zero–Water Reflux distillation system

Distillation is the most widely used separation technique in bioethanol production. One disadvantage of the distillation process is the large energy requirement, accounting for around 25-40% of the total energy usage. In distillation, a great deal of energy is consumed to evaporate the liquid, and large amounts of cool water are consumed to condense the vapor back to liquid (Enweremadu, 2012)..

Clearly, the energy requirements for ethanol production must be reduced markedly to make it a competitive fuel. This can only be done by a variety of technology and plant design improvements. Distillation columns are used for about 95% of liquid separations and the energy use from this process accounts for an estimated 3% of the world energy consumption (Hewitt et al, 1999). With rising energy awareness and growing environmental concerns there is a need to improve the design and operation of distillation systems to reduce overall plant energy consumption and operating costs.

The group has succeeded in designing and improving a distillation system that utilizes a much smaller amount of energy and water. Design A (Fig 2) represents the upscale prototype of a reflux distiller according to manufacturer's specifications. It required 2 hrs to allow a first drip of ethanol to drop and spent 8hrs to finally collect all the ethanol in the system (Table 2). According to calculations done by Balik-Scientist Dr. Sergio Capareda in 2011, ten hours of distillation operation consumed firewood with energy equivalent of 504 MJ, and required4.13m^3 of fresh water to cool the system throughout the operation. Water cooling usually starts at least 30 min before the first drip of ethanol (ETOH) and this is signaled at 50^{0}C. The data obtained in Design 1 served as benchmark information for the succeeding design improvement. Design B (Fig. 3) is Design A covered with an insulator. The energy requirement was reduced to 403.2 MJ and water was reduced to 3.26 m^3 because the distillation time was reduced by 1hr. Design C (Fig. 4) is Design A with modified and improved cooling system. Although Design C required the same energy input as Design A, the water requirement was reduced by 95%.

These studies indicate that the energy needed to produce a liter of ethanol can be decreased simply by insulating the distillation vessel and using wood waste materials to supply the heat required to boil the hydrolysate. Considering all the above trials, Fig 5 will exemplify a cost-effective design for optimum ethanol yield and savings on energy and water input (Table 3).

Table 3. Design improvement of the reflux distillation system for a more efficient and zero-water loss distillation system

Designs*	No. of hrs ETOH to drip	No. of hrs to finish the distillation	Energy Equivalent of fuel wood used, MJ (7MJ/ kg wood)	*Vol. H_2O used, m^3	Difference in Energy input, MJ	Difference in water input, L
A	2	8	504.0	4.13		
B	1	7	403.2	3.26	100.8<A & C	0.87<A
C	2	8	504.0	0.20		3.93<A
D	**1**	**7**	**403.2**	**0.20**	**100.8<A & C**	**3.93<A**

*Volume of fermented beer for distillation: 185L; *See Figs. Below.*

Fig. 2. Design A. 241L capacity equipped with unmodified cooling system from manufacturer's design.

Fig. 3. Design B. 241L Capacity equipped with unmodified cooling system with insulator.

Figures 4 and 5 show a system to recycle water to cool the condenser, thus reducing the water needed to condense ethanol at the head of the distillation column. In the process of distillation vapors passing through the condenser are cooled and condensed by water flowing through condenser tube. In the previous setup, the water used for cooling the condenser comes from the water supply tap. This fresh water, after circulating through the condenser, channels as wastewater into the drain. This is a big loss of precious potable water. To overcome this problem, the group developed a technique in which water from the outlet tube of the condenser unit is collected, cooled, and re-circulated again in the condenser unit.

The advantages of condenser water recycling are obvious. First, it prevents waste of a precious natural resource particularly in places where natural water supply is scarce and drinking water is not even enough to meet the human demand. Second, this system is not dependent on tap water supply for cooling the condenser unit as, in the case of MMSU and many areas in the Philippines, tap water supply may not be available regularly. Lastly, during summer months, water coming from the tap can be very hot and may fail to effectively cool the condenser and reduce the speed of distillation .

These optimization trials and studies have resulted in significant recommendations

Fig. 4. Design C.1. 241L Capacity equipped with modified cooling system (at CRL). C.2 .3-in-1 distillation system (at CAS).

Fig. 5. Design D. 241L Capacity equipped with insulator and modified cooling system (*proposed optimized design*).

in the up-scaled production of hydrous bioethanol that can be implemented under village conditions. However, continuing efforts will be done to attain more efficient and more cost-effective fermentation and distillation procedures.

Performance Evaluation of *MMSU 95 hBE-20* as Oxygenate and Fuel in Stationary and Spark Ignition Engine

*Research Octane Number (RON) of selected MMSU 95 hBE blends***.**

Table 4 shows the RON of selected hBE blends compared to commercially available gasoline fuels. The results are congruent with the findings of Yasmin et al. (2006) that RON of gasoline blends with ethanol increases RON. Blending of hydrous ethanol to commercially available E-10 gasoline from Petron increases the octane rating of the hBE blends. Commercially available UnE-10 and XCS have RON of 93+ and 95 respectively while the RON of *hBE-20* in UnE-10c and hBE-20 in XCSc are 98.5 and 98.3 respectively. This proves that hBE fuel blends are free from engine fuel knock. Using anhydrous ethanol to make 20% gasohol blends gave 98.9% RON which is 0.4% higher than the *hBE-20* in UnE-10c.

It is significant to note that the use of hydrous ethanol, either as oxygenate or gasohol component, improves the RON of the gasohol blends just as effectively as the anhydrous. It is a common observation that high octane rating decreases the tendency of engines to “knock. “Knocking (also called knock, detonation, spark knock, pinging or pinking) in spark-ignition internal combustion engines occurs when combustion of the air/ fuel mixture in the cylinder starts off correctly in response to ignition by the spark plug, but one or more pockets of air/fuel mixture explode outside the envelope of the normal combustion front. The fuel-air charge is meant to be ignited by the spark plug only, and at a precise time in the piston's stroke cycle. Knock occurs when the peak of the combustion process no longer occurs at the optimum moment for the four-stroke cycle. The shock wave creates the characteristic metallic "pinging" sound, and cylinder pressure increases dramatically. Effects of engine knocking range from inconsequential to completely destructive. The results indicate that the hBE blends are safe to use as fuel as it does not cause premature auto ignition of the fuel in the combustion chamber that leads to engine damage .

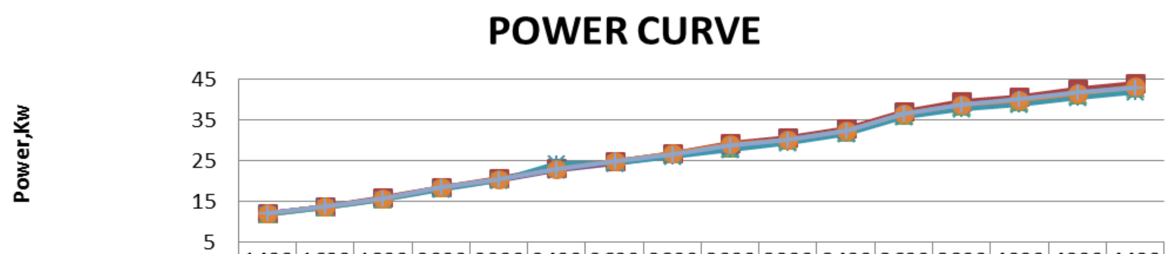
Performance of hBE blends in stationary engine

Table 5 shows the performance of various hBE blends compared to commercially available gasoline E-10 fuels in an Engine Dynamometer Test. Although~~,~~ the difference is minimal, it supports the claim by Domingo et al. (2013) that *hBE-20* is more powerful compared to UnE-10c at 4400 RPM in this test. It also shown that of all the blends, *hBE-20* is the most powerful at 44.13KW at 4400 RPM.

Table 4. Research Octane Number of selected hBE Blends

Gasoline Fuel and hBE blends				
UnE-10c	**XCS E-10**	***hBE-20* in UnE**	***hBE-20* in**	**20% anhydrous**
93+	95	98.5	98.3	98.9

Table 5. Performance of various fuels and blends in terms of Brake Power



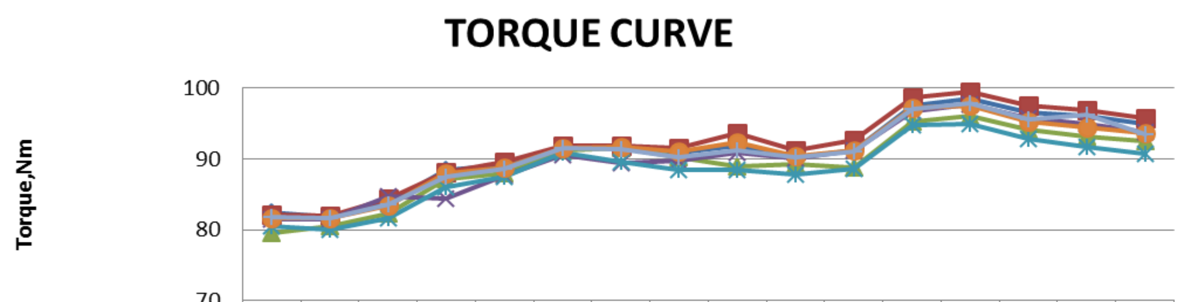
	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3600	3800	4000	4200	4400
20%hBE(XCS)	12.08	13.72	15.77	18.5	20.54	22.97	25	26.63	28.84	30.41	32.59	36.75	39.19	40.47	42.27	43.79
20%hbeU	12.04	13.75	15.92	18.45	20.64	23.1	25	26.83	29.37	30.73	32.99	37.18	39.58	40.84	42.6	44.13
neat	11.68	13.49	15.51	18.25	20.29	22.9	24.92	26.44	27.89	30.01	31.82	35.91	38.2	39.45	40.95	42.65
UnE10	11.96	13.64	15.58	18.11	20.21	22.76	24.31	26.31	28.53	30.34	32.46	36.47	38.91	40.15	41.76	43.21
10% hBE(Un-N)	11.8	13.42	15.4	18	20.16	24.39	24.39	25.95	27.77	29.42	31.55	35.75	37.75	38.88	40.34	41.8
20% hBE (Un-N)	11.98	13.69	15.72	18.43	20.46	23.02	24.95	26.68	29	30.25	32.46	36.66	38.82	39.93	41.49	43.17
XCS E10-C	11.96	13.68	15.75	18.33	20.4	23.01	24.89	26.46	28.64	30.23	32.41	36.59	38.9	40.04	41.85	43.06

Table 6 shows the torque performance of hBE blends. Results indicate that the various hBE blends are comparable, if not superior, to anhydrous blends. The results support the claim of Domingo et al. (2012) that the torque is stronger using *hBE-20* compared to other blends, including commercially available gasoline fuel UnE-10c and XCS E-10c.

Performance indicators of various fuels and blends in terms of economy are shown in Table 7 where 40L of each sample blend (non-repeated run) is fed in the dynamometer. The results show slightly lower fuel efficiency when hydrous ethanol is used as oxygenate or blending fuel.

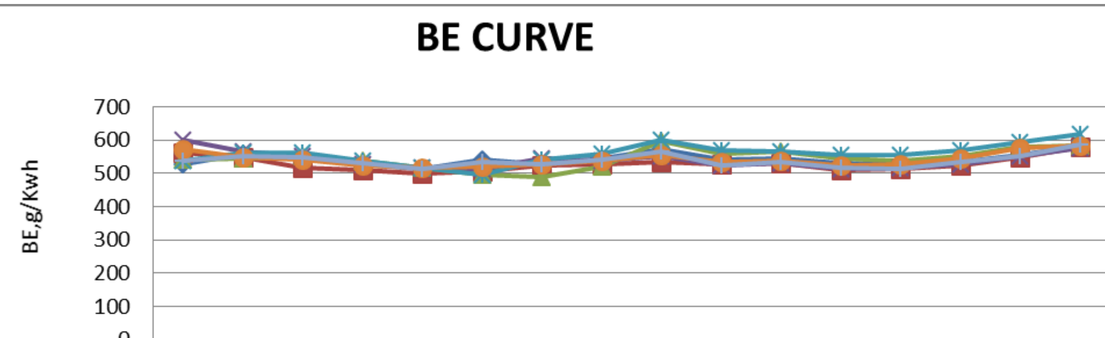
Based on the results of the engine dynamometer testing, blending of either anhydrous or hydrous ethanol increases engine torque and power. However, the said fuel blends decrease the efficiency of the engine. Of the various gasoline blends, *hBE-20* in UnE-10c followed by *hBE-20* in XCSc provides the higher torque of 99.47 kg-m and 98.47 kg-m respectively. UnE-10c and XCS E -10c give only 97.75 kg-m and 97.76 kg-m respectively. For the efficiency of the various blends, there is almost no significant difference enabling us to conclude that *hBE-20* fuel in UnE-10c is the best blend in the said test procedure. This suggests that *hBE-20* is the "optimal gasohol blend level" that could give the optimum performance. According to an article published in 2009 , when gasoline is appropriately combined in mid-level ethanol blends, the chemical reactions of these compounds optimize the efficiency at which internal combustion engines operate. For hydrous ethanol blends, this is accomplished primarily through the total heat of vaporization resulting from combining ethanol and water. Essentially, the lower energy content of hydrous ethanol is counteracted by increasing engine performance due to higher heat of vaporization of ethanol and water in comparison with gasoline and anhydrous blends. Furthermore, hydrous ethanol blends (oxygenated hydrocarbons) lower engine operating temperatures due to cooling of intake fuel mixture with 3-6% more water and increasing heat of vaporization when compared to anhydrous ethanol. The result is more efficient combustion, cooler running engines, lower exhaust temperatures, and increased longevity of engine life. This explains the better performance observed in *hBE-20* blends.

Table 6. Performance of various fuels and blends in terms of Torque



	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3600	3800	4000	4200	4400
20%hBE(XCS)	82.43	81.83	83.67	88.37	89.17	91.37	91.83	90.83	91.9	90.17	91.13	97.47	98.47	96.6	96.1	95
20%hbeU	82.1	82.03	84.47	88.07	89.6	91.9	91.87	91.5	93.57	91.27	92.67	98.6	99.47	97.5	96.83	95.77
neat	79.6	80.53	82.27	87.17	88.03	91.13	91.53	90.17	88.93	89.33	88.7	95.27	96	94.17	93.07	92.57
UnE10	81.5	81.45	84.65	84.45	87.65	90.55	89.35	89.7	90.9	90.1	91.2	96.7	97.75	95.8	94.95	93.75
10% hBE(Un-N)	80.53	80.03	81.7	85.93	87.5	90.9	89.57	88.5	88.5	87.83	88.6	94.8	94.87	92.8	91.7	90.67
20% hBE (Un-N)	81.7	81.7	83.37	87.97	88.8	91.57	91.67	91	92.37	90.31	91.17	97.23	97.53	95.3	94.37	93.67
XCS E10-C	81.8	81.67	83.57	87.53	88.57	91.53	91.43	90.23	91.17	90.23	91.03	97.07	97.76	95.6	96.16	93.47

Table 7. Brake Fuel Economy of the different Fuel Blends



	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3600	3800	4000	4200	4400
20%hBE(XCS)	526.5	559	549.5	527.3	515.2	540.9	528	544.9	572.2	540.4	546.9	529.8	527.5	536.5	556.2	582.3
20%hbeU	563.2	547	518.1	510.4	498.8	508.2	523.2	529.1	533.3	527.2	532.1	512	515.1	523.3	548.2	578.4
neat	542.9	545.7	553.8	537	515.5	495.4	490.8	520.3	598.9	560	566.7	543.9	537.7	553.7	580	583.7
UnE10	600.6	566.8	551	528.1	516.6	513.4	545.5	538	553.5	523.9	531.1	513.6	516	526.5	553.2	576.5
10% hBE(Un-N)	536.6	564	564.3	539.8	518.5	495.1	541.3	558.5	601.6	570.1	567.6	554.7	557.2	570.5	594.8	617.9
20% hBE (Un-N)	572.7	547.1	543.1	525.4	518.3	519.5	527.8	537.1	557.4	533.8	538.2	524.3	528.1	543.7	575.1	583.1
XCS E10-C	539.4	552.3	548.3	531	515.1	535.4	527.5	543.1	566	525.3	536.3	515.6	512.8	536.1	553	585.9

Performance of hBE blends in Chassis Dynamometer

The performance of a brand-new Kia Rio car fueled by various ethanol blends were evaluated using the AVL Systems Technology chassis dynamometer of VRTL. Table 8 shows that hBE blends provide more power compared to anhydrous ethanol gasoline blend UnE-10c and Neat gasoline. In terms of mileage using the Japanese standard cycle 10-15 mode, the performance of hBE blends are also comparable with UnE-10c although *hBE-20* gives a lesser mileage economy. For the CFE which was derived from the combination of drive cycle test and constant velocity test, it appears that when neat gasoline was blended with ethanol, either hydrous or anhydrous, the CFE is lessened.

The reduced fuel efficiency observed in Table 7 (stationary engine) and Table 8 (chassis dynamometer) was expected since water does not provide calorific content. However, a report shows that there is an "optimal blend level" of ethanol and gasoline – most likely E-20 or E-30 – at which cars will get better mileage than predicted based strictly on the fuel's per-gallon BTU content. The 2007 flex-fuel Chevrolet Impala utilized in midlevel blends testing revealed a 15% increase in fuel efficiency using the Highway Fuel Economy Test (HWFET) for E-20 in comparison with unleaded regular gasoline. For the same vehicle, the highway fuel economy was greater than calculated for all tested blends, with an especially high peak at E-20. The study, co-sponsored by the U.S. Department of Energy (DOE) and the American Coalition for Ethanol (ACE) also found that mid-range ethanol blends reduce harmful tailpipe emissions. According to Baylor University, "as far as safety and performance is concerned, hydrous ethanol is a slightly better fuel (than anhydrous ethanol) in every respect. This report gives encouraging information that since *hBE-20* seemed to be the optimal blend, it may be too early to conclude that it is slightly inferior in terms of fuel efficiency. Like in the test stated above, the test cars in this project are presently undergoing mileage test runs for *hBE-20* in city and highway driving to monitor engine fuel efficiency, among other parameters.

Performance of hBE blends in Motorcycles

Table 9 shows the performance of *hBE-20* compared to Unleaded E-10 in both short and long-distance cycle routes of TMX motorcycles. Results (from average runs) indicate that mileage economy is better for *hBE-20* in relatively short distances and frequent stop-and-go conditions. For long-distance cycle drives, the TMX motorcycles have almost the same fuel economy at 46.43km and 45.18 km of UnE-10c and *hBE-20* per liter respectively.

Table 8. Performance of hydrous ethanol blends in Kia Rio (1.3 MPI SI engine) using chasis dynamometer

PERFORMANCE INDICATORS	VARIOUS FUEL BLENDS				
	UnE-10c	***hBE-20* in UnE-10c**	**Neat**	***hBE-10* in Neat**	***hBE-20* in Neat**
Maximum Power, KW	46.72	47.38	45.27	47.21	47.76
Mileage, km.lit	13.24	13.05	14.15	13.43	13.55
Combined Fuel Economy (CFE), km/lit	16.64	16.09	17.15	15.52	15.61

Table 9. Comparative performance of UnE-10c and *hBE-20* in TMX Motorcycles

METHOD	FUEL USED	
	Unleaded E-10	***hBE-20***
MMSU Campus Cycle Route	33.22	37.74
Batac-Laoag Long Distance Cycle Route	46.43	45.18

E-20. Normally, if the power is higher it will consequently provide lesser efficiency as described by its fuel economy. In this test, UnE-10c provides more power and better efficiency compared to *hBE-20*. The possibility of the Briggs not being put into higher number of burning hours (break-in period) might cause the lesser performance of the *hBE-20*. The UnE-10c was the last fuel used in the testing after *hBE-20*.

Performance of hBE blends in 16HP Engine

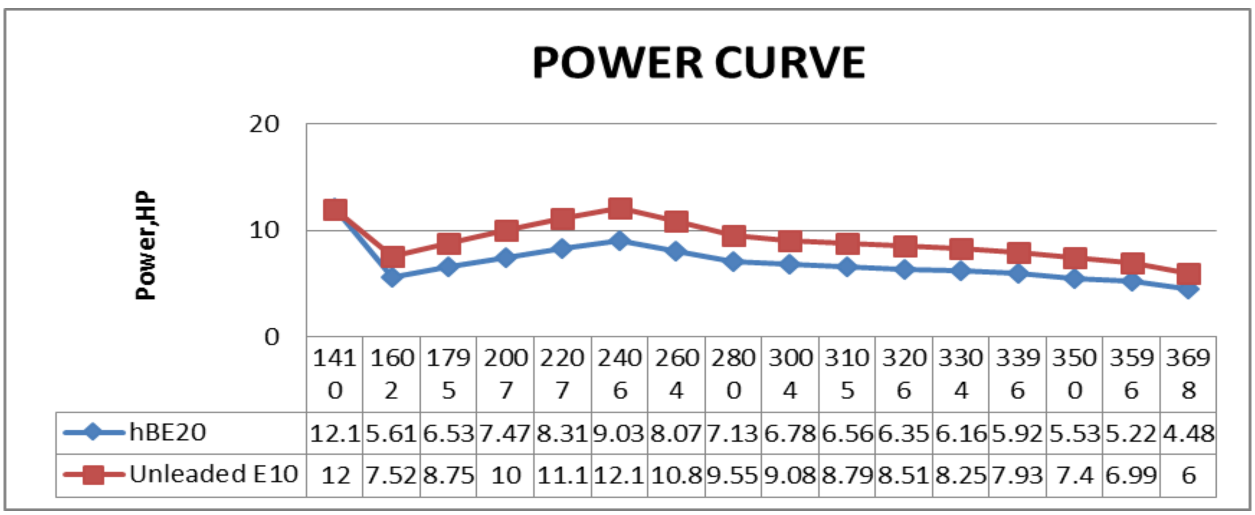
The performance of UnE-10c and *hBE-20* fuel was also evaluated using a 16HP Briggs and Stratton engine. As revealed in Table 10, results indicate that UnE-10c provides more power in the engine compared to *hBE-20*.

Table 11 shows the Brake Fuel Economy of *hBE-20* vs. Unleaded E-10 when used in the 16 HP Briggs and Stratton engine. Data indicates that UnE-10c performs better when compared to *hBE-20.*

CONCLUSION

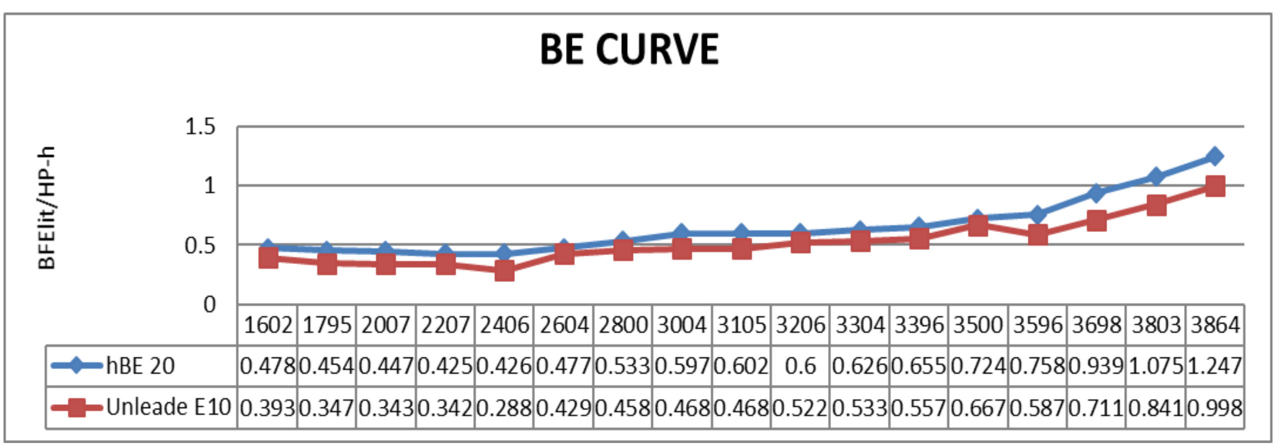
The present conditions used in the bulk production of *MMSU 95 hBE* and optimization trials warrant the different trials to be considered cost-effective protocol.

Table 10. Brake power comparison of hBE20 and UnE10c in a 16HP Briggs and Stratton Engine



	1410	1602	1795	2007	2207	2406	2604	2800	3004	3105	3206	3304	3396	3500	3596	3698
hBE20	12.1	5.61	6.53	7.47	8.31	9.03	8.07	7.13	6.78	6.56	6.35	6.16	5.92	5.53	5.22	4.48
Unleaded E10	12	7.52	8.75	10	11.1	12.1	10.8	9.55	9.08	8.79	8.51	8.25	7.93	7.4	6.99	6

Table 11. Brake Fuel Economy of 16HP Briggs and Stratton Engine



	1602	1795	2007	2207	2406	2604	2800	3004	3105	3206	3304	3396	3500	3596	3698	3803	3864
hBE 20	0.478	0.454	0.447	0.425	0.426	0.477	0.533	0.597	0.602	0.6	0.626	0.655	0.724	0.758	0.939	1.075	1.247
Unleade E10	0.393	0.347	0.343	0.342	0.288	0.429	0.458	0.468	0.468	0.522	0.533	0.557	0.667	0.587	0.711	0.841	0.998

However, continuing efforts will be done to attain more efficient and more cost-effective fermentation and distillation procedures.

Performance evaluation of the different gasohol blends generally shows the net advantage of using hydrous ethanol in gasoline blends. Using a brand-new Kia Rio, hBE blends provide more power compared to anhydrous ethanol gasoline blend UnE-10c, as well as compared to neat gasoline. In terms of mileage using the Japanese standard cycle 10-15 mode, the performance of hBE blends are also comparable with UnE-10c although *hBE-20* provides lesser mileage economy. For the CFE which was derived from the combination of drive cycle test and constant velocity test, it appears that when neat gasoline was blended with ethanol, either hydrous or anhydrous, it lessens the CFE.

Under campus cycle drive runs, it obtained better fuel economy for *hBE-20* compared to UnE-10c fuel at 37.74 and 33.22kmL^{-1}, respectively; while for long-distance cycle drives, the mileage of TMX motorcycles have almost the same mileage at 46.43km and 45.18km of UnE-10c and *hBE-20* per liter, respectively.

In Brake Fuel Economy, of the two fuels used in the 16HP Briggs and Stratton Engine, UnE-10c performed better compared to *hBE-20*. Normally, if the power is higher, it will consequently provide lesser efficiency as described by its fuel economy. In this test, UnE-10c provides more power and better efficiency compared to *hBE-20*. There is a possibility that the Briggs and Stratton engine had lesser performance when fueled with *hBE-20* because it had not been subjected to a proper break-in period. The UnE-10c was the last fuel used in the testing after *hBE-20*.

Based on these studies, the study concludes that hydrous ethanol is a satisfactory substitute to anhydrous ethanol both as oxygenate and as gasohol fuel. Considering the production cost difference, a case can be made that the Philippines should consider transitioning to hydrous ethanol as oxygenate and fuel in the future.

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