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PRODUCTION, CHARACTERIZATION, TESTING, AND EVALUATION OF THE MMSU HYDROUS BIO-ETHANOL POTENTIALS AS A VILLAGE-SCALE ENTERPRISE

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Abstract

This inquiry produced cost efficient protocols of 95% fuel-grade hydrous bioethanol sweet sorghum syrup and evaluated the physico-chemical properties and mechanical performance of biofuels from various hydrous gasohol blends. Consequently, it improved the efficiency of previous processes, including that of reducing the yeast activation period from 4-6hr to 1hr and improved the sugar conversion efficiency of ethanol from 70-76% to as high as high as 85%.

Specifically, fuel grade hydrous azeotrope ethanol was produced from various feedstock sources such as sugar cane jaggery and sweet sorghum syrup using *Saccharomyces cerevisiae* for fermentation and reflux distillation system to purify the ethanol. The formulated hydrous gasohol blend, which is the *MMSU hBE-20 (*consisting of 20% azeotrophic bioethanol and 80% anhydrous E-10 gasoline) was tested to run a stationary 4-stroke engine. At loads of 4, 6, and 8kg, *MMSU hBE-20* was as efficient as the commercial XCS E-10. Gasohol blends containing hydrous ethanol up to 40% generally showed comparable performance with *MMSU hBE-20* and XCS E10 in terms of physical, chemical, and mechanical properties. Higher blends (50-90% hydrous ethanol) can still run the stationary 4-stroke test engine without discernible mechanical problems but with slightly reduced performance and efficiency. Expanded mixtures of the gasohol blends that were as high as 90% hydrous ethanol; 20% XCS E-10 showed no phase separation at room temperature.

As such, producing *MMSU 95-hBE* at the village level can be highly profitable whether marketed for fuel or for bioethanol-based consumer products.

Keywords: *hydrous ethanol, azeotrope, MMSU 95-hBE, MMSU hBE-20, reflux distillation, biofuel*

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Introduction

Results of experiments previously conducted informed the framework of this research. Since 2009, integrated studies including: a) fermentation of sugar cane juice, sweet sorghum jiggery, and molasses; b) reflux distillation using fermented hydrolysates from different feedstocks to produce the Mariano Marcos State University hydrous bio-ethanol (*MMSU 95-hBE)*; and c) formulation, characterization, and testing of hydrous gasohol blends using *MMSU 95-hBE and Petron XCS-10* have been conducted. In these subsequent studies, fermentation conditions have been optimized for more cost effective and efficient processes. New biofuel formulations have also been developed, characterized, and tested.

Previous fermentation experiments (Agrupis, et al, 2009) used ordinary baker's yeast that was activated under aerobic conditions for 4-6hr before pitching into separate anaerobic fermentation vessels containing four different first generation feedstocks (sugarcane molasses, sweet sorghum syrup and jaggery, and Ilocos *basi* from sugarcane). Those processes yielded 71-76 % ethanol conversion efficiency in 18-24hr, giving ethanol yields of 12-14% (v/v), which is close to the maximum ethanol tolerable limit (15%v/v) of yeast.

In purifying ethanol, reflux distillation processes were developed using different column packing materials that gave 95-100% ethanol recovery with 90-95% ethanol purity. Ethanol collected with less than 95% purity was redistilled to attain azeotrope hydrous ethanol purity. Initial tests on the chemical, physical, and mechanical properties of the hydrous ethanol and resulting gasohol biofuel formulations showed high potential of the azeotropic product. The hydrous ethanol was named *MMSU 95-hBE,* while the blend of 20% Ethanol and 80% XCS-10 gasohol biofuel was labelled as *MMSU hBE-20.*

In an attempt to comply with the Philippine National Standards (PNS) as prescribed in the Biofuels Act of 2006, several trials were done to produce anhydrous ethanol at 99.6% purity. Specifically, benzene was used to create a ternary azeotrope that can be distilled off to leave pure ethanol. Calcium oxide and Zeolite were also tried as desiccants to remove water from the hydrous ethanol. Purity that was obtained was at most 96-97%.

Further dehydration of 95% azeotrope ethanol unnecessarily increases the cost of producing gasohol. If hydrous ethanol can substitute for anhydrous in biofuel formulations, a substantial saving can be achieved while alleviating the negative environmental impact of further removing the last 5% of water from the azeotrope. This realization formulated the *MMSU 95-hBE* as oxygenate for gasoline and successfully tested to run farm and fishery engine-driven implement, generators, and motor vehicles.

Sweet sorghum was chosen for this study as feedstock over other first generation feedstock since it is a national priority biofuel crop that is grown experimentally in multiple sites in the country, with MMSU as lead institution.

In order to develop village-adaptable and adoptable technologies for village-level bioethanol industry, the study produced, characterized, and tested the hydrous ethanol fuels using sweet sorghum syrup as feedstock.

Specifically, it a) optimized fermentation and distillation protocols under laboratory and scaled up conditions; b) expanded and characterized gasohol blend formulations using *MMSU 95-hBE*; and c) evaluated the economic profitability of producing hydrous bioethanol for biofuel at the village level.

Methodology

Fermentation Efficiency of S*accharomyces cerevisiae* at Different Activation Periods

Results of concept experiments served as anchor in using 4-6hr–activated yeast before it was pitched into the fermentation vessels containing the sweet wort at 30 Brix° (Agrupis, et al, 2013) using sweet sorghum syrup adjunct. 'Sweet wort' in this experiment is the starting sugar solution reconstituted from sweet sorghum syrup, while 'adjunct' is the fermentable sugar. Other terms used in this paper include 'fermenting wort' (sweet wort added with yeast), and 'beer' (fermented wort). Sugar concentration of 30 Brix° was based on the works of D'Amore et al (1989).

The study shortened the activation time without negatively affecting the yeast fermentation efficiency. Doing so would lead to significant process efficiencies; the least of which decreased the cycle time from fermentation to distillation.

Four yeast activation periods were evaluated: 1, 2, 4, and 16hr. Yeast activation refers to the growing of yeast under aerobic condition to propagate yeast cells before pitching them into the fermenting vessel. Activation is essentially done in a smaller container. Here, known amount of yeast at 0.3% concentration based on the 10L previously prepared 30 Brix° sweet wort was weighed and grown in a 1L volumetric flask containing 0.5L sweet wort. The flask containing the propagating yeast was continuously stirred over a moderately heated hot plate at 50°C for 30min. The temperature condition was based on the work of Banat, et al (1998). The flask was set to rest at room temperature to correspond to the different activation periods before they were pitched into the 13L fermentation vessel.

Fermentation Efficiency of S*accharomyces cerevisiae* at Different Sugar Concentrations

Previous experiments used 30-31 Brix° sweet wort from sugar cane or sweet sorghum syrup (Agrupis, et al, 2013). However, after fermentation and distillation, waste effluent still contained high residual sugar. Hence, the present study evaluated different sugar concentrations from 15 to 30% in 13L and 220L fermentation vessel. The activation time that registered the highest fermentation efficiency as noted in the previous section was followed, while other fermentation conditions such as hot plate temperature and volume of the sweet wort were the same as in the previous experiment. Likewise, active dry yeast (Y1) performance and its combination with instant dry yeast (Y2) were also evaluated.

Scaled-up Reflux Distillation System

In the previous experiments, the ethanol present in beer with concentrations ranging from 13 to 15% v/v was recovered at 90-104% efficiency using a 13L capacity reflux distiller. The recovery efficiency considered the 5-7% water that was retained in the 93-95% hydrous ethanol collected from the system; hence, efficiency over 100% was possible.

In these subsequent studies, the laboratory scale distiller was set to 241L. The efficiency was tested at half and full capacity. The amount of wood fuel used and the time required to finish the process were recorded. The efficiency of the distiller with and without heat insulator was also evaluated in terms of net energy input/output.

Formulation, Characterization and Testing of the *MMSU 95-hBE* Gasohol Blends

The ethanol azeotrope (95% ethanol) collected and purified from fermentation and distillation of sweet sorghum syrup was used to formulate different gasohol blends. The blends contained 20, 30, 40, 50, 60, 70, 80, and 90% *MMSU 95-hBE* combined with *XCS E10.* Pure 95% hydrous ethanol and XCS *E10* served as controls. The gasohol blends were tested for the different chemical, physical, and mechanical tests using a 4-stroke stationary test engine.

Chemical, Physical and Mechanical Testing Protocols

Fermentable sugar was determined using a hand-held refractometer (Atago Master-M). Specifically, the refractometer measures the refractive index and Brix with automatic temperature compensation. Specific glucose content was determined using the DNS method described by Miller (1959) with some modifications based on the procedure established by Nam Sung Wang of the University of Maryland.

Physical and mechanical tests of the hydrous ethanol blends were adapted from ASTM standards like D4052, D445, D 240 for density, kinematic viscosity, and heating value, respectively. Performance of hydrous biofuel blends using a 16HP Briggs and Stratton engine on a Test Rig of AMTEC at the University of the Philippines-Los Banos, Laguna followed the standards set by the Philippine Agriculture Engineering Standard (PAES 117:2000, Agricultural Machinery - Small Engine - Methods of Test). All tests were repeated several times for the statistical means. Data emanating from the average of 3-4 trials are reported.

Results and Discussion

Fermentation Efficiency of *S. cerevisiae* at Different Activation Periods

Activation period is the time spent to allow the yeast to increase in number under aerobic condition. Previous proof of concept experiments explored 4-6 hr activation period before the yeasts were pitched into the fermentation vessel with the sweet wort having 71-76% fermentation efficiency.

Table 1 shows the fermentation activity of *S. cerevisiae* under different activation periods. Specifically, a much shorter activation period is possible and it can result in improved fermentation efficiencies at the same time. The results suggest that 1-hr activation of the yeast before pitching into the fermentation vessel is sufficient to achieve 86% fermentation efficiencies and excellent alcohol production rates. Likewise, the findings strongly show the value of time in making the system cost effective. Rate of ethanol production was 1,401mL/hr and yeast deterioration activity decreased by half per hour when pitching into the fermentation vessel was delayed. A 2hr-activation period led to 695.98mL/hr and decreased by half an hour after. Decreased fermentation efficiency after 16hr confirmed the utilization of sugar for yeast cell

Table 1. Fermentation activity of *S. cerevisiae* under different activation periods

ACTIVATION PERIOD (hr)	FERMENTATION EFFICIENCY (%)	PRODUCTION RATE (mL/hr)
1	85.85	1401.00
2	85.17	694.99
4	85.78	349.98
16	51.47	52.50

Hydrolysate volume, 10L; Sugar conc, 32%; Theoretical ETOH, 1.632L production instead of alcohol under aerobic condition.

The sugar feedstock concentration in this experiment was adjusted to 30%. This is the amount of sugar that could yield the theoretical limit of 15% ethanol, which is also the maximum tolerable limit of S. *cerevisiae* in the medium (Alexandre, et al, 1994).

Fermentation efficiencies of 51-86%, however, suggest a considerable amount of unconverted sugar to ethanol. These results led to the succeeding series of experiments in order to establish the minimum sugar concentration that can give the optimum ethanol yield. Minimizing sugar wastage has the potential to save labor and time in the overall process.

Fermentation Efficiency of *S. cerevisiae* at Different Sugar Concentrations

Prior to the conduct of this experiment, an evaluation of the different sugar concentrations (5, 10, 15, 20, 25, and 30%) were carried out using a 1L-capacity fermentation vessel to determine the minimum amount of sugar that could give optimum conversion efficiency to ethanol at different fermentation periods from 24-96hr. Results showed considerable fermentation efficiency at 15-30% sugar in 24hr, but not in the lower concentrations (5 and 10%). Based on these results, the combined efficiency of using active (Y1) and instant (Y2) preparations of *S. cerevisiae* was further tested using 15-30% sugar concentrations using a scaled up 13L capacity fermentation vessel within a 24hr-observation period (Table 2). Ethanol yield and purity leveled up with the increasing sugar concentration. The findings suggest that sufficiently high concentration of sugar is needed for yeast to survive longer and to ferment sugar more efficiently. The results of this study concur with the work of D'Amore, et al (1989) . Furthermore, the combined effect of two-yeast preparations is more effective than using them singly.

The same yeast combination was tested using a scaled up 220L fermentation vessels. As shown in Table 3, fermentation efficiency and purity of the ethanol product declined due to CO_2 suffocation brought about by poor aeration in the improvised scaled up set up. Accumulation of CO_2 gas in the system decreases the pH (pH 3-4) of the beer to a level beyond the tolerable limit of the fermenting organism. *S. cerevisiae* could survive in a very narrow pH range of 4.5-5.0 (Yan, et al*, 2012).*

Table 2. Fermentation activities of *S. cerevisiae* at different concentrations of sugar feedstock in a 13L fermentation vessel

PARAMETER	**SUGAR CONCENTRATION (%)/ YEAST (Y)**					
	15		20		30	
	Y1	Y1+Y2	Y1	Y1+Y2	Y1	Y1+Y2
Actual initial sugar, %	15.5	15	20.2	20	30	31
Ethanol yield, mL	670	650	800	910	1600	1700
Ethanol yield, % (v/v)	4.9	5.0	6.2	7.0	12.1	13.0
Ethanol purity, %	86	87	88	89	92	93
Fermentation efficiency, %	63.80	64.81	60.33	68.63	80.0	85.47

Table 3. Fermentation activities of *S. cerevisiae* at different concentrations of sugar feedstock in a 220L fermentation vessel

PARAMETER	FERMENTATION TRIAL		
	1	2	3
Initial sugar, %	31	30	25.5
Actual volume of sugar feedstock, L	120	120	220
Ethanol yield, L	12.72	13.0	19.23
Ethanol yield, % (v/v)	10.6	10.83	8.74
Ethanol Purity, %	92	92	91
Fermentation efficiency, %	67.04	58.98	67.21

Table 4. Distillation trials using upscale reflux distiller with 241L capacity

PARAMETER	WITHOUT INSULATOR	WITH INSULATOR	WITH INSULATOR
Volume beer hydrolysate, L	120	120	220
Fuelwood used, kg	52.4	35	37
Energy equiv of fuelwood ,MJ (7MJ/kg wood)	366	245	259
Ethanol Yield, L	12.72	13	19.23
Energy equiv of ethanol, MJ (21 MJ/L ETOH)	266.12	273	403.83
Net energy	-99.88	+28	+144.83

Reflux Distillation Experiments

A scaled up 241L reflux distiller was designed and fabricated based on the 13L distiller. Distillation efficiency was comparable with the 13L distiller in terms of ethanol recovery (90-100%) and ethanol purity (90-93%). This suggests the feasibility of designing even higher capacity reflux distillers for village-scale enterprises to accommodate the availability of higher quantities of feedstock. The use of insulator tremendously improved net energy of the system both at half-filled and at full capacity levels.

Formulation, Characterization and Testing of Fuel Grade Gasohol Blends

Previous proof of concept experiments showed the suitability of hydrous ethanol in gasohol blends. The purity of the 95% hydrous ethanol was confirmed by DOST-ITDI via the Report Analysis No. ITDI-CHL-2010-0551. The test showed that there were no methyl alcohol and acetaldehyde in the products. Total acids were detected but negligible.

The first hydrous gasohol blend formulated was the *MMSU hBE-20*. This blend contains a ***7.5:1*** ratio of E-10 and MMSU *95hBE*. A series of phase separation studies were carried out to test the stability of the fuel under various temperature levels. Results of which are shown in Table 5. The mixture of *MMSU 95-hBE* and XCS E10 consistently passed the phase separation test up to 90%. The lack of separation persisted in most of the blends even when stored in the refrigerator set at 4^{0}C overnight. Under refrigerated conditions of 4°C, only the 80 to 90% hydrous blends (hBE-80 and hBE-90) showed phase separation. The result is in congruent with other published works (Korotney, 1995). This means that extremely high ethanol blends may pose some problems in areas where these low temperatures might prevail; however, under Philippine conditions, these are unlikely to occur. Incidentally, the phase-separation of E -80 and E-90 disappears even without agitation once the formulations were taken out of the refrigerator.

All gasohol blends from E-20 to E-90, using hydrous hBE-95 and anhydrous E-10 at 31°C showed no evidence of phase separation under ambient conditions. Hence, different gasohol blends were pursued for further tests to evaluate their chemical, physical, and mechanical properties. Pure XCS E10 and pure *MMSU 95-hBE* served as controls.

Table 6 presents the physical and chemical properties of *MMSU 95-hBE* blends. Specifically, the heating value of higher blends is lower than that of leaner blends. However, the reduction in heating value is slight and up to a blend of 50%. The decrease in heating value is less than 1%. During actual driving tests using an unmodified carburetor-type vehicle conducted on the 20% blend, no discernible effects on both mileage and performance were detected. The same table shows a dramatic reduction on the CO_2 concentration of the exhaust gases demonstrating the favorable effect of higher ethanol blends on the environment. Reduction of CO_2 during the combustion of the hydrous ethanol fuel blend is due to the increased fuel octane (Karpov, 2007).

Meanwhile, Table 7 details the mechanical properties of the *MMSU 95-hBE* blends. Gasohol blends containing hydrous ethanol up to 40% generally showed comparable performance with *MMSU hBE-20* and XCS E10. At higher blends (with 40-90% hydrous ethanol), adjustments of the carburetor were necessary. Stationary 4-stroke test engine fueled by higher ethanol blends nonetheless performed without discernible mechanical problems although at a reduced performance and efficiency.

Table 5. Phase separation results using various blends of hydrous ethanol-gasoline under ambient and refrigerated conditions

HYDROUS ETHANOL-GASOLINE BLEND	AMBIENT TEMPERATURE +31°C SEPARATION	REFRIGERATED TEMPERATURE +4°C SEPARATION
E-20	NO	NO
E-40	NO	NO
E-60	NO	NO
E-80	NO	YES
E-90	N0	YES

Table 6. Physical and chemical properties of *MMSU 95-hBE* blends in comparison with the commercial XCS E-10

MMSU 95-hBE **Blends, %**	**DENSITY (kg/m^3)**	**KINEMATIC VISCOSITY (mm^2/s)**	**HEATING VALUE (Btu/lb)**	**CO_2 CONCENTRATION (mg/L)**
XCS E-10	735.416	0.6787	20,189.087	12.089
20	738.968	0.7198	20,166.799	11.000
30	750.480	0.8020	20,104.884	11.274
40	759.148	0.9048	20,053.544	10.786
50	765.624	1.0488	20,013.191	9.526
60	780.152	1.2008	19,931.372	9.328
70	790.320	1.3665	19,872.022	8.088
80	799.028	1.5269	19,817.962	9.790
90	807.108	1.6974	19,769.394	9.030
95	817.068	1.8358	19,708.003	7.847

Table 7. Mechanical properties of *MMSU 95-hBE* in comparison with commercial XCS E-10

MMSU 95-hBE **Blends, %**	**BRAKE HORSEPOWER (HP) @ 8kg load**	**FUEL CONSUMP-TION ($^L/_{HR.}$)**	**BRAKE FUEL RATE ($^L/_{HR\text{-}HP}$)**	**BRAKE THERMAL EFFICIENCY (%)**
XCS E-10	3.92	0.480	0.1224	64.76
20	3.83	0.469	0.1225	64.47
30	3.84	0.479	0.1247	62.53
40	3.88	0.563	0.1451	53.17
50	3.86	0.524	0.1358	53.17
60	3.82	0.511	0.1338	56.74
70	3.77	0.589	0.1562	47.98
80	3.75	0.751	0.2003	37.14
90	3.78	0.602	0.1593	46.35
95	3.85	0.677	0.1758	41.48

Table 8 shows the mechanical properties of *MMSU hBE-20* and XCS E10 when tested using a 6.5HP engine at different loads of 6, 7, and 8kg. Just like in the previous tests, the performance of *MMSU hBE-20* was as efficient as the Commercial XCS E-10. The same observation was obtained when the blend was tested on a motor vehicle (Toyota FX) and on 4-stroke motorcycles. The same performance trials have been repeated ever since, which led to the same results. These trials indicate that hydrous ethanol can be used as oxygenate and gasohol blends. Furthermore, they can be used at much higher rate than what the Biofuels Act allows to be used as fuel to power motors and engines under Philippine conditions.

Table 8. Performance of a 6.5 HP engine at different loads fed with *MMSU hBE-20*

PERFORMANCE PARAMETER	FUEL TYPE	ENGINE LOAD (kg)		
		4	6	8
Fuel Consumption, (L/hr)	MMSU hBE-20	0.588	0.589	0.593
	Commercial E-10	0.577	0.634	0.608
Brake Horsepower, (BHP)	MMSU hBE-20	2.152	3.216	4.269
	Commercial E-10	2.159	3.209	4.271
Brake Fuel Rate, (L/ Bhp.hr)	MMSU hBE-20	0.273	0.183	0.139
	Commercial E-10	0.267	0.198	0.142
Heat Value, (Btu/lb)	MMSU hBE-20	20,243.804	20.242.388	20,245.219
	Commercial E-10	20,264.000	20,265.402	20,264.000
Brake Thermal Efficiency, [BTE (5%)]	MMSU hBE-20	27.784	42.896	56.664
	Commercial E-10	29.550	39.875	55.335

One negative feedback on using hydrous ethanol in gasohol fuel blends was the rust formation or corrosion in older engines and gasoline compartments. Nonetheless, newer vehicles are now manufactured with components that are rust-resistant or rust-proof; hence such feedback is addressed.

In fact, a theory is proposed to respond to rust concerns. Figure 2 shows the chemical structure of a hydrous ethanol azeotrope. In this model, water is hydrogen-bonded to six ethanol molecules. Although hydrogen bonds are not chemical in nature, they result in one of the most stable and strongest physical bonds found in nature. This explains why it is not easy to take out the remaining water in an ethanol azeotrope using ordinary distillation. This structure supports the speculation that it is not the water in the azeotrope that can cause rust in metals. The water in this azeotrope is not free to participate in oxidative reactions that bring about rust. Standard rust tests have been going on to evaluate the rusting effect of hydrous gasohol blends under laboratory conditions.

Profitability Analysis on the Production of Hydrous Ethanol

From the very beginning, the ultimate goal of production, characterization, testing, and evaluation of the MMSU hydrous bio-ethanol potential as a Village-

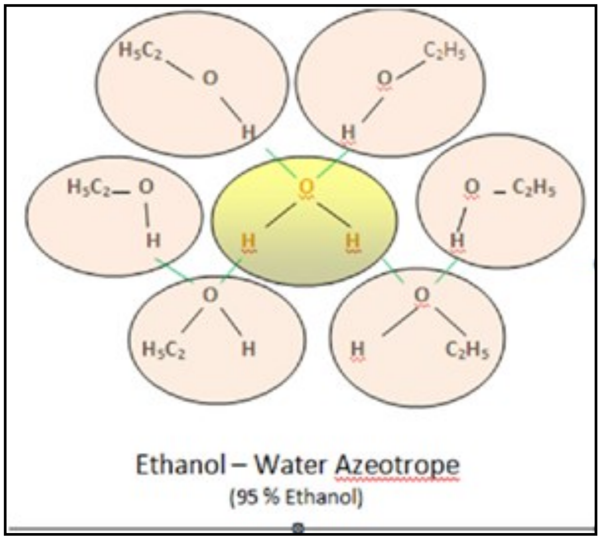

Fig. 2. A proposed chemical structure of the distilled ethanol azeotrope showing water hydrogen-bonded to six ethanol molecules

scale enterprise has been to develop technologies that are both **adaptable** and **adoptable** at the village level. The use of improvised bioreactors (plastic water containers), monitoring systems (condoms), and common strains of yeast (bakery yeasts) are examples of technologies meeting the basic criteria for a community-based technology. Techniques that were deemed complicated or expensive were immediately dismissed.

The primary reason behind prioritizing technologies for village-scale enterprise is its resistance to the vagaries of the economic cycle and requires much less capital than large-scale bioethanol models. The fact that only 25-30% of the ethanol requirement of the country can be supplied by industry behemoths like the San Carlos Biorefinery illustrates the finding difficulty for expensive installations. Village-scale model costs less than Php 150K to set up, which is within the means of an organized group of farmers. The viability of a village-scale enterprise resulted in extensive consultations with MMSU economists.

Profitability analysis on the production of hydrous bioethanol was based on a 241-L scale distiller using 5-gal ordinary water dispenser jugs as bioreactors. Among the four feedstocks evaluated in previous experiments, sweet sorghum jaggery was the least expensive source of feedstock. It was cheaper compared with the others and it required lesser amounts for each production batch. A 241-L distiller has been used at MMSU, which utilizes waste bagasses and wood scraps as fuel to fire the furnace for the distillation process. Cost and return analysis and profitability estimates for the production of hydrous ethanol are presented in Table 9. The analysis is based on a per liter production of 95% ethanol from sweet sorghum using a 241L-capacity reflux distiller, which costs Php50,000. The variable cost to produce one liter of hydrous ethanol is Php20.00. However, this could vary up to Php24 due to fluctuations in the cost of energy. The selling price of ethanol per liter is Php53.00.

Scaling up the production of hydrous ethanol to higher-capacity distiller would give a cost advantage or economies of scale. The feasibility of scaling up a 13L-reflux distiller design to a 241L reflux still has been validated. As the project expands to higher level of production, bulk buying of inputs (e.g., feedstock) through long-term contracts would further reduce cost. Additionally, the specialization or technical skills of the workers (i.e., researchers and laborers) would increase and lead to higher efficiency in the long run.

Table 9 likewise presents the profit derived from hydrous ethanol at four levels of production for comparison from a liter to

Table 9. Profitability analysis of hydrous ethanol production using sweet sorghum as feedstock

PARTICULAR	AMOUNT	AMOUNT	AMOUNT	AMOUNT
Quantity produced (liter)	1	50	100	150
Sales (Q*P), PhP	53	2650	5300	7950
Variable Cost, PhP	20	950	1805	2568.75
Return Above Variable Cost, PhP	33	1700	3495	5381.25
Fixed Cost, PhP	18.67	18.67	18.67	18.67
Profit, PhP	14.33	1681.33	3476.33	5362.58

150L. A conservative estimate of the reduction in variable cost by 5% was used. Considering a 100-L production, the profit is Php3,476.33 or Php34.76 per liter. This is about 92.58% higher than the variable cost per liter (Php18.05). If the variable cost increases to Php24.00/L, the profit for a 100L production will be Php2,881.33 or Php28.81/L, which is relatively profitable.

Conclusions and Recommendations

Hydrous bioethanol was produced using the propriety fermentation and distillation techniques developed by the MMSU Bioethanol Research Team. Process improvements reduced the yeast activation period to one hour and improved the fermentation efficiency.

Hydrous ethanol (95% ETOH) produced by MMSU was used to formulate gasohol mixtures containing 20 to 90% hydrous ethanol. The blends were tested for the absence of phase separation under ambient and refrigerated conditions. Chemical, physical, and mechanical properties of the different gasohol blends were rigorously tested using 4-stroke stationary engines. Gasohol blends up to 40% *MMSU 95-hBE* performed comparably with XCS E10 without any carburetor adjustments. At higher blends (50-90% hydrous ethanol), adjustments of the carburetor were necessary. Stationary 4-stroke test engines ran without discernible mechanical problems, although with slightly reduced performance and efficiency. Performance comparison of *MMSU hBE-20* and XCS E10 on a 6.5 HP engine at different loads showed no discernible difference.

Moreover, results indicate that the *MMSU 95-hBE* gasohol blend formulations are stable products when used under Philippine climatic conditions and are promising as engine fuel. Among the formulations, the *MMSU hBE-20* showed the highest potential for immediate use in stationary 4-stroke engines as well as moving vehicles. Suitability of the blend was used to run 4-stroke motorcycles and a Toyota FX vehicle that traveled from Batac City, Ilocos Norte to Metro Manila and Baguio City.

Further economic analysis shows a high profitability of using *MMSU 95-hBE* as feedstock for value-added products. With 60-L production daily, the profit is Php 5,957 per day for a 185% profit margin when the product is used for consumer, medical, and research purposes. A village-level bioethanol industry can realistically produce 60-L ethanol daily and can be as high as 100L when all conditions are optimized and management operations are systematized.

Commercialization of these technologies could open new opportunities for village-level ethanol production and would contribute significantly towards the implementation of several Republic Acts namely: the RA 9637- the Philippine Biofuels Act, RA 9003- Philippines' Ecological Solid Waste Management, Act RA 9513- The Philippines Renewable Energy Act, and the RA 8749- The Philippine Air Act.

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