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Performance Evaluation of the ISU-Ribbon Type Mixer for Biomass Fuel Production and Energy Generation

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ABSTRACT

Agricultural waste is a potential source of fuel and briquetting is one of the methods to turn it into useful biofuel. In briquetting, different agricultural wastes are mixed and compacted to produce a more densified biofuel. However, the big challenge for briquette producers is the lack of machines to be used to turn these raw materials into briquettes. Testing and evaluation of the ISU-Ribbon Type Mixer was conducted to determine its performance in terms of mixing different biomass for briquette production. The result of the study shows that the variation of the engine speed has no significant effect on the mixing rate of the machine. However, a direct linear relationship between the two variables was observed. As the engine speed of the machine increases, the mixing rate also increases. The mixing performance of the machine was measured by gathering the data on the coefficient of variation of the rice hull content of the mixed biomass. The smallest value of coefficient of variation obtained was 14.05% operated at an average engine speed of 2,677 rpm. The trend in the value of coefficient of variation is declining as the engine speed increases. In terms of economic viability, the machine was found to be a good investment with a benefit of 1.167 times the cost of operation.

Keywords*–Ribbon-Type Mixer, Mixing Rate, Coefficient of Variation, Mixing Quality, Mixed Biomass, Mixing*

Introduction

The steady depletion of global energy resources due to increased consumption by mankind has contributed to the severe problem of exhausting all available non-renewable energy resources such as natural gas, oil and coal. (Rajapakse, R.M.G., 2007) Billions of tons of agricultural residue are generated each year in the developing and developed countries. This volume of biodegradable wastes can be converted to an enormous amount of energy and raw materials (Quartey, 2011).

Isabela province is known for its wide area devoted for agriculture. In fact, it contributes 21% of the annual national yellow corn production. With this large volume of production, Isabela was then declared as the country's top corn producing province. Moreover, as second highest rice growing province, Isabela also produces 15% of the aggregate national rice production annually. (The Official Website of the Province of Isabela, 2015)

Agricultural production amplifies the increase of agricultural waste. Agricultural waste is produced as a result of various agricultural operations. It includes manure and other wastes from farms, poultry houses and slaughterhouses; harvest waste; fertilizer run- off from fields; pesticides that enter into water, air or soils; and salt and silt drained from fields. (Glossary of Statistical Terms, n.d.) Agricultural waste is potentially a resource. As for high calorific solid wastes, briquetting is one of the ways to turn the wastes into treasure. (How to Make Briquettes from Daily Wastes, 2014) Briquetting process is the conversion of agricultural waste into uniformly shaped briquettes that are easy to use, transport, and store. (El-Haggar, 2007) Briquettes are very cheap as they are manufactured from waste. They are additionally used as a substitute fuel for cooking purposes and several other heating processes. (Tamilvanan, 2013) Combustion characteristic index of mixed biomass depends on the proportion of components, where the lower proportion of domestic waste in mixture, the better combustion characteristic index of mixed biomass fuel. (Zhang et al, 2011)

One of the major problems in the production of briquette is the lack of machines designed for this purpose. Some machines are improvised, and some are costly due to the fact that those machines are not intended for the purpose of briquetting. One of the machines that were not developed yet in the process of briquetting is a machine for mixing this biomass. Mixing biomass is very laborious and so manual mixing is famous to briquette producer.

Ribbon mixers are widely used in practice because they are capable of providing high speed convective mixing (M.Halidan et. al., 2018). Ribbon-type mixers, one of the fixed-type mixers, have been employed in various industrial processes, but few experimental studies are reported on them. The operation of the horizontal ribbon mixer is based on the principle of mechanical fluidization of the mixed product. Components of different particle size and bulk density will be well very finely homogenized and mixed in the shortest possible time. Mixers of this type are used for mixing dry powders, granules or short fibers and for moistening, balling and granulation of the same materials or for mixing liquids and pastes with low viscosity. (Marczuk, 2017)

This study is in support to the promotion of renewable energy as source for fuel through briquetting, by conducting testing and evaluation of the ISU Ribbon Type Mixer for biomass mixing.

Methods

Description of the ISU-Ribbon Type Biomass Mixer

The ISU-Ribbon type biomass mixer consists of an engine as prime mover, double layer ribbon agitator, a U shape mixing chamber, and a discharge chute as major parts (Fig. 1.). The machine was made out of G.I. sheets, shafts and pillow block bearing, bolts and nuts, steel matting, belts and pulleys, flat bars and angle bars, and wheels. The prime mover used in the machine is a 6.5 hp gasoline engine positioned at one end of the U shape chamber. The transmission of power from the engine to the shaft where the ribbons are welded was facilitated by chain and sprocket.

Figure 1. The ISU-Ribbon Type Mixer

Principles of Operation

The ISU- ribbon type biomass mixer consists of a prime mover, double layer ribbon agitator, and a U shape cylinder. Biomass is fed into the mixing chamber. The inside ribbons move the biomass toward the end of the ribbons blender whereas the outside ribbons move the material back towards the center of the ribbon blender which makes the biomass get full mixing. Material outlets are located at the end of cylinder bottom. The outside ribbons driven by the main shaft moves the materials to the discharge outlet. The machine was mounted to a frame with wheels and provided with hitching point to facilitate mobility.

Figure 2. The mixing chamber of the ISU-Ribbon Type Mixer

Preparation of the Sample

The samples for testing were a combination of three biomass namely corn cob, corn stalk, and rice hull. Samples were gathered at San Roque, San Mateo, Isabela, Philippines. The corn stalk and corn cob were shredded using the ISU-Shredding-Chipping machine. To ensure that the shredded biomass have almost the same sizes, it was sorted using the ISU-Rotary Siever.

Performance Evaluation

Mixing Rate

It is the weight of biomass fed and mixed per unit time, expressed in kilogram per hour. (PAES 259:2011)

$$MR = \frac{Wfi}{To} \quad (1)$$

Where:
MR = mixing rate, kg/h
Wfi = total weight of mixed ingredients input, kg
To = total operating time, h

Fuel Consumption Rate

It is the amount of fuel consumed by the engine per unit time. (PAES 258:2011)

$$\mathrm{Fr} = \frac{\mathrm{Fc}}{\mathrm{Te}} \quad (2)$$

Where:
Fr = fuel consumption rate, L/h
Fc = amount of fuel consumed, L
Te = engine operating time, h

Coefficient of Variation of the Mixed Biomass

It is the statistical representation of the precision of distribution of the different biomass. (PNS/PAES 258:2011) Rice hull was used as the tracer in this experiment because it can be easily distinguished and segregated from other biomass that was used.

$$CV = \frac{\sigma}{\mu}\, x\, 100 \quad (3)$$

$$\sigma = \sqrt{\frac{\sum(x-\mu)^2}{(n-1)}} \quad (4)$$

Where:
CV = Coefficient of Variation, %
σ = Standard Deviation
x = weight of rice grain in the sample, g
μ = mean weight of rice grain in the sample, g
n = number of samples

Statistical Analysis

In this study, the performance evaluation test was analyzed using Completely Randomized Design (CRD) single-factor factorial experiment with three replications. The Factors were the following:

Treatment (Engine Speed)
T_1 = 1800-2000 rpm
T_2 = 2001-2200 rpm
T_3 = 2201-2400 rpm
T_4 = 2401-2600 rpm
T_5 = 2601-2800 rpm

The three biomass that were mixed were corn cob, corn stalk, and rice hull with a weight of 3 kg each.

Results

Mixing Rate

The mixing rate of the ISU-Ribbon Type Mixer is a measure of the capacity of the machine to mix a certain amount of biomass per unit of time. The result of the performance test for mixing rate were shown in Table 1. The mixing rate of the machine had a grand mean of 135.94 kg/h.

Analysis of Variance shown in Table 2 revealed that the variation of the engine speed had no significant effect on the mixing rate of the machine. This might be due to the small increment in the engine speed for each treatment. The small increment was not enough to cause significant variation in the mixing rate.

The relationship of the mixing rate and engine speed was determined through the application of linear regression and correlation analyses with mixing rate as the dependent variable and engine speed as the independent variable. The scatter diagram shown in Fig. 3 indicated that the two variables were directly related linearly, implying that as the engine speed was increased, the mixing rate also increased. The linear association of mixing rate and engine speed was high as indicated by the obtained correlation coefficient value of 0.983 or 98.3%. The regression model equation developed was,

$$y = 0.0479x + 24.51 \qquad \text{(eq. 5)}$$

Where;

y = Mixing Rate in Kg/hr
x = Engine Speed in rpm

The coefficient of determination (R2) value of 0.9662 means that 96.62% of the variation in the mixing rate was due to the variation in the engine speed. The slope of the regression line indicated that for every one rpm increase in engine's speed, it resulted to 0.0479 kg/h increased in mixing rate. It must be noted that the model equation developed is only applicable within the engine speed range of 1,892 to 2,677 rpm considered in the study.

Table 1. Mixing Rate (kg/h) of the ISU-Ribbon Type Mixer at Different Engine Speeds (rpm).

Treatment	Replication			Total	Mean
	R_1	R_2	R_3		
T_1	110.88	113.21	119.47	343.56	114.52
T_2	83.33	150.00	158.82	392.16	130.72
T_3	135.00	139.53	126.17	400.70	133.57
T_4	114.16	142.11	194.24	450.51	150.17
T_5	146.74	157.43	147.95	452.12	150.71
Grand Total				**2039.05**	
Grand Mean					**135.94**

Table 2. Analysis of Variance for Mixing Rate (kg/h) at different Engine Speeds (rpm) of the machine.

Sources of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F-Value		
				F-Computed	F-Tabular	
					5%	1%
Between Engine Speed	4	2736.83	684.209	0.99^{ns}	3.48	5.99
Within Engine Speed	10	6911.57	691.157			
Total	14	9648.41				
CV = 19.34				ns- Not Significant		

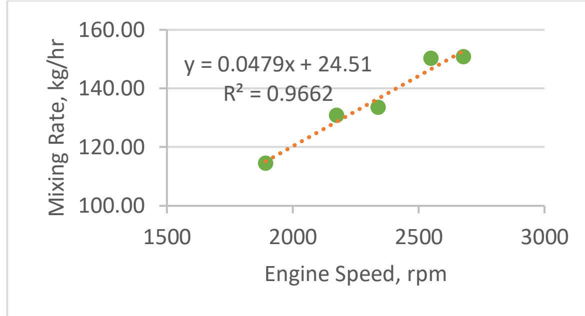

Figure 3. Scatter Plot for the Mixing Rate (kg/h) and Engine Speeds (rpm) of the machine.

Fuel Consumption Rate

The rate of fuel consumption of the machine is a measure of how much fuel was consumed by the machine for every unit of time of operation. The fuel consumption rates of the ISU-Ribbon Type Mixer at different engine speeds were listed in Table 3. The fuel consumption ranged from 0.422 to 0.608 L/h when the machine was operated at a speed of 1,892 to 2,677 rpm.

The Analysis of Variance presented in Table 4 indicated that the fuel consumption rate was highly affected by the increased in the engine speed. Results illustrated further that with the increase in rpm, the fuel consumption rate also increased. This was due to the fact that fuel consumption was directly related to the magnitude of the engine in doing work. The highest fuel consumption rate was 0.608 L/h which was obtained at an engine speed range of 2601-2800 rpm (T5). On the contrary, the lowest fuel consumption rate recorded was 0.422 L/h obtained at an engine speed range of 1800 to 2000 rpm (T1).

Table 3. Fuel Consumption Rate (L/h) of the ISU-Ribbon Type Mixer at Different Engine Speeds (rpm).

Treatment	Replication			Total	Mean
	R_1	R_2	R_3		
T_1	0.493	0.415	0.358	1.266	0.422^{a}
T_2	0.454	0.433	0.388	1.275	0.425^{a}
T_3	0.525	0.450	0.561	1.535	0.512^{ab}
T_4	0.634	0.537	0.583	1.754	0.585^{b}
T_5	0.587	0.612	0.625	1.824	0.608^{b}
Grand Total				**7.655**	
Grand Mean					**0.510**

Note: Means with the same superscripts are statistically the same.

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Table 4. Analysis of Variance for Fuel Consumption Rate (L/h) at different Engine Speeds (rpm).

Sources of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F-Value		
				F-Computed	F-Tabular	
					5%	1%
Between Engine Speed	4	0.09045	0.02261	9.69**	3.48	5.99
Within Engine Speed	10	0.02333	0.00233			
Total	14	0.11378				
CV = 9.46 $LSD_{0.01}$=0.1249				**Highly Significant		

Comparison of means using Least Significant Difference (LSD) Test was performed to identify which means were statistically different. As indicated in Table 3, means that had the same superscripts were found to be statistically the same. Thus, T1, T2, and T3 did not vary significantly from each other. This implies that the fuel consumption rate did not differ markedly when the mixer was operated at an engine speed range of 1,800 to 2,400 rpm. Likewise, T3, T4, and T5 were found to be not significantly different relative to each other implying also that the fuel consumption rates were the same even when the machine was operated at a speed range of 2,201 to 2,800 rpm.

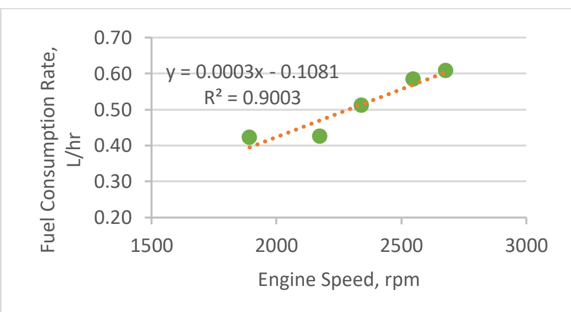

Figure 4. Scatter Plot for the Fuel Consumption Rate (L/h) and Engine Speed (rpm) of the machine.

Figure 4 presented the scatter diagram of fuel consumption rate and engine speed. A high direct linear relationship was also depicted between the two variables, indicated by a high correlation coefficient value of 0.95. The regression model equation developed was

$$y = 0.0003x - 0.1081 \qquad \text{(eq. 6)}$$

Where;

y = Fuel Consumption Rate, L/h
x = Engine Speed, rpm

The coefficient of determination (R2) value of 0.9003 indicated that 90.03% of the variation in the fuel consumption rate was due to the variation in the engine speed. The slope of the regression line implied that for every one rpm increase in the engine speed, the fuel consumption rate increased by 0.0003 L/h. It must be emphasized that the developed equation is applicable only within the speed range of 1,892 to 2,677 rpm used in the regression modelling done.

Coefficient of Variation

The mixing quality is a measure of the homogeneity or uniformity of a mix and is calculated from one of the basic measures of variability, the coefficient of variation which is the most commonly used measures. The closer this value to zero, the more uniform the mix. For clearer visualization, its value is subtracted from 1 and expressed in percent (%). Thus, a 100 % mixing quality or coefficient of variation value of zero refers to the best mixing condition, which, however, is practically not achievable. (Mixing Quality-Definition, n.d.)

In this study, rice hull was selected and used as the tracer that represented the behavior of other biomass materials. The coefficient of variation of rice hull in the mixed biomass at different engine speeds were listed in Table 6. The smallest value of coefficient of variation obtained in 2,601 to 2,800 rpm was 14.05%. The overall mean of the Coefficient of Variation was 16.81%.

Table 5. Coefficient of Variation (%) of Rice Hull Content of the Mixed Biomass at different Engine

Treatment	Replication			Total	Mean
	R_1	R_2	R_3		
T_1	25.94	21.41	20.05	67.40	22.47[a]
T_2	19.14	20.16	15.32	54.62	18.21[ab]
T_3	14.57	14.63	15.64	44.84	14.95[b]
T_4	13.62	14.92	14.56	43.11	14.37[b]
T_5	13.65	14.19	14.31	42.15	14.05[b]
Grand Total				**252.12**	
Grand Mean					**16.81**

Speed (rpm)

Note: Means with the same superscript are statistically the same.

The Analysis of Variance presented in Table 7 revealed that the coefficient of variation was highly influenced by the variation in engine speed. Comparison of means using Least Significant

Difference Test showed that the coefficient of variation of rice hull contents in T1 and T2 did not differ significantly when the mixer was operated at 1,800 to 2,200 rpm. The same results were obtained with T2, T3, T4, and T5 or within the engine speed range of 2,100 to 2,800 rpm.

Table 6. Analysis of Variance for Coefficient of Variation (%) of Rice Hull Content at different Engine Speeds (rpm).

Sources of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F-Value		
				F-Computed	F-Tabular	
					5%	1%
Treatment	4	152.979	38.2447	11.27**	3.48	5.99
Error	10	33.936	3.3936			
Total	14	186.915				

CV = 10.96 **Highly Significant**
$LSD_{0.01}$ = 4.7666

The coefficient of variation as reflected in Figure 5, had a declining trend as the engine speed increased. The inverse non-linear relationship was high as indicated by a high correlation coefficient value of 0.997 or approximately 1. The line of best fit for the data was a second-degree polynomial with high coefficient of determination R2 value of 0.9942. Moreover, the trend depicted that the coefficient of variation was fairly high for T1 and decreased sharply down to T3. However, from T3 to T5, the change in the coefficient of variation slowed down, an indication of minimal differences in coefficient of variation or better mixing was reached when the engine speed ranged from 2,201 to 2,800 rpm. The model equation developed was

$$y = 1E\text{-}05x2 - 0.0739x + 113.13 \qquad \text{(eq. 9)}$$

Where;

y = Coefficient of Variation, %
x = Engine Speed, rpm

This model can explain 98.23% of the variability in the coefficient of variation.

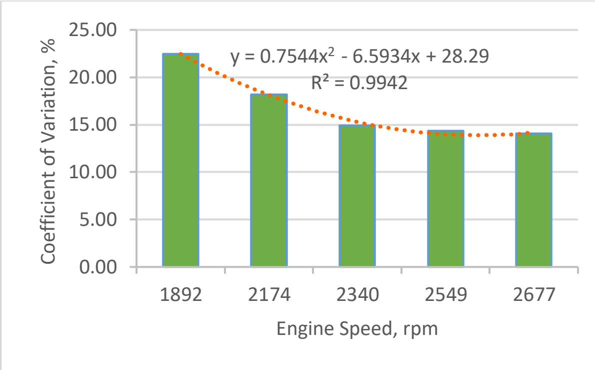

Figure 5. Scatter Plot of the Coefficient of Variation (%) of Rice Hull Content at different Engine Speed (rpm).

Economic Analysis

The economic analysis for the ISU-Ribbon Type Mixer was performed to determine its economic viability. The total machine cost was ₱ 42,086.00 with an estimated machine life of 10 years. Assumptions for the calculation of economic analysis of the machine and its computations are shown in Appendix B. A summary table for the computed values is provided in Appendix C. The computed total fixed cost included the investment cost, depreciation cost, interest on investment, tax and insurance, and repair and maintenance costs amounted to ₱10,900.27/year. Variable cost which included the labor cost and fuel consumption cost was ₱148,608/year. These summed up to a total operating cost of ₱159,508.27/year.

The projected total annual income of the machine was ₱ 345,600/year. After subtracting from it the total operating cost of the machine resulted to an annual net income of ₱186,091.726/year. The computed benefit cost ratio was 1.167:1 which means that investing on the machine will be beneficial since benefit is 1.167 times the cost of operation. The computed number of years it will take to recover the initial investment or known as payback period is 0.226 years. The obtained break-even point was at 78,987.493 kg of mixed biomass produced per year. Thus, the breakeven usage computed was 65.823 days/year which means that the machine must be utilized for more than 1,579.752 working hours to gain profit. The estimated return of investment of 4.422 means that the invested money on the machine will be recovered 4.422 times.

Conclusion and Future Works

Conclusions

Based from the result of the study, the following conclusions were made.

1. The mixing rates of the ISU-Ribbon Type Mixer at 1800-2000 rpm, 2001-2200rpm, 2201-2400 rpm, 2401-2600 rpm, and 2601-2800 rpm, were 114.52 kg/h, 130.72 kg/h, 133.57 kg/h, 150.17 kg/h, and 150.71 kg/h, respectively.
2. The highest mixing rate of the machine of 150.71 kg/h was achieved at an engine speed range of 2,601 rpm to 2,800 rpm.
3. Within the engine speed range of 1,800 to 2,800 rpm, the mixing rate increased as the engine speed increased.
4. The coefficient of variations obtained at engine speed range of 1800-2000 rpm, 2001-2200rpm, 2201-2400 rpm, 2401-2600 rpm, and 2601-2800 rpm, were 22.47%, 18.21%, 14.95%, 14.37%, and 14.37%, respectively.
5. The smallest value of coefficient of variation was 14.05% obtained at an average engine speed of 2,677 rpm.
6. The trend in the coefficient of variation was declining as the engine speed increased.
7. The fuel consumption rates of the ISU Ribbon Type Mixer operated at an engine speeds of 1800-2000 rpm, 2001-2200rpm, 2201-2400 rpm, 2401-2600 rpm, and 2601-2800 rpm, were 0.422 L/h, 0.425 L/h, 0.512 L/h, 0.585 L/h, and 0.608 L/h, respectively.
8. The machine had the lowest fuel consumption rate of 0.422 L/h when operated at the lowest engine speed ranged from 1,800 to 2,000 rpm.
9. Within the engine speed range of 1,800 to 2,800 rpm, the fuel consumption rate increased as the engine speed increased.
10. The variation on the engine speed of the ISU-Ribbon Type Mixer has significantly affected the fuel consumption rate and the coefficient of variation.
11. The total machine cost is ₱42,086.00 with a total operating cost of ₱159,508.27/year.
12. Under the assumptions considered in the economic analysis, the machine was found to be a good investment with a benefit of 1.167 times that of the cost of operation.
13. The machine is expected to have an annual net income of ₱186,091.726/year, and a return of investment of 4.422 times that of the initial cost of the expected annual net income.
14. A payback period of 0.226 years or 2.712 months was expected based on the assumptions considered in the economic analysis.
15. The ISU-Ribbon Type Mixer is capable of mixing different biomass.

Recommendations

Based on the result of the study, the following are recommended;

For Operation,

1. To attain the highest mixing rate of the ISU-Ribbon Type Mixer, it must be operated at an engine speed of 2,601 to 2,800 rpm.
2. To obtain higher homogeneity or uniformity of a mix, the machine must be operated at an engine speed ranging from 2,601 to 2,800 rpm which gives a lower coefficient of variation.

For Modification,

1. To attain higher mixing capacity, consider increasing the diameter of the mixing chamber.
2. Consider providing a loading chute to reduce spillage during loading of biomass into the mixing chamber.

For Further Study,

1. Based on the result of the analysis in the mixing rate of the machine, the small increment in the engine speed was not enough to cause significant variation in the mixing rate. Consider testing the performance of the machine using higher increment of the engine speed.
2. Consider other biomass materials also in testing the machine.

Ethical Considerations (11 Bold)

This section includes the declaration of protocols followed as part of the ethical considerations of your study especially when dealing with human and animals as subject of your study. (10)

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