

EFFICIENCY AND ECONOMICS OF CONCRETE-PLASTIC-DRUM BIOGAS DIGESTER AS LOADED WITH DIFFERENT COMBINATION OF SUBSTRATES

Francis Eric C. Largo
Cebu Technological University-Barili Campus
Eduardo Z. Alama
Department of Agriculture Region VII

ABSTRACT

Bio-digesters are implements that convert organic matter to biogas and fertilizer (Thy *et al.*, 2003). Waste from livestock and crops can be utilized as biogas energy. Bio-digester effluent can be applied to crops as fertilizer. Despite of its usefulness, durable and efficient designs are more affordable for commercial farms. Less costly small scale bio-digester requires frequent maintenance (SNV Netherlands, 2010). The backyard farmers demands a durable, cheap but efficient at the least level of animal population. Hence, a study was conducted in order to evaluate the efficiency, physico-chemical attributes and economic benefits of Concrete-Plastic-Drum-Biogas Digester as loaded with different combinations of substrates. The independent variables were: Treatment 1- (Swine Waste), Treatment 2-(Swine Waste + Human Waste) and Treatment 3- (Swine Waste plus Human Waste plus Giant Taro Plant). Parameters used were: 1) cooking time, 2. biogas yield 3. volume of effluent and sludge, 4.biogas recovery efficiency, 5.savings from using the biogas instead of LPG, 6. value of effluent and sludge fertilizer, 7. Marginal Benefit Cost Ratio (MBCR) and 8. the Marginal Rate of Return (MRR). Physico-chemical characteristics of CPDBD during the conduct of the study such as temperature, pH and EC were also observed and analyzed. Kruskal Wallis and Dunn-Bonferroni Test were used in the statistical treatment through SPSS version 20. Results proved that CPDBD loaded with swine waste alone (T_1) was considered as the best treatment. The Concrete-Plastic-Drum Biogas Digester loaded with swine manure was more efficient and effective as it recovered methane at 58% efficiency and 249 liters of biogas per day.

Keywords: Biogas, Biogas Digester, Biogas Substrates, Biogas Economics and Efficiency

INTRODUCTION

Bio-digesters are implements that convert organic matter to biogas and fertilizer (Thy *et al.*, 2003). Waste from livestock and crops can be utilized as biogas energy. Bio-digester effluent can be applied to crops as fertilizer. Despite of its usefulness, durable and efficient designs are more affordable for commercial farms. Less costly small scale bio-digester requires frequent maintenance (SNV Netherlands, 2010).The backyard farmers demands a durable, cheap but efficient at the least level of animal population.

Basic biogas designs are the Chinese concrete-fixed dome, the Gobar Indian concrete with a metal or plastic floating gas holder and the Vietnamese Tubular Polyethylene digester (TPED) (SNV Netherlands, 2010). New

improved designs were based on these basic designs. Improvements were inspired by some technical and financial limitations of the said digesters (Ojario, 2005). The Chinese type is more durable but demands more investment. It is less efficient because of much pressure inhibiting gas production. Gobar Indian type can be installed at less cost than Chinese type but needs high maintenance and short lived. TPED type of BAI are cheaper and easier to install but not durable and needs high maintenance (SNV Netherlands, 2010).

A cheaper, durable and efficient small scale biogas digester must be innovated in order to make it practical for backyard farmers. With this in mind, the researcher has come up to test the efficiency of Concrete-Plastic-Drum Biogas Digester as loaded with different combinations of substrates.

CONCEPTUAL FRAMEWORK

Cost, durability and efficiency of bio-digesters depend on designs and operational parameters. Loading mode, mixing of substrates (Barnet *et al.*, 1978), orientation of biogas (Fry and Merrill, 1973), construction material, exposure to sunlight, dimension, size (Arnott, 1985), tilt and cost (Fry, 1974) must be considered for a good design. Co-digestion, temperature, loading rate, load composition, HRT (Seadi, 2008), pH and substrates (Schnurer *et al.*, 2010) are operational parameters which will also affect the efficiency of biogas production. Substrates vary in digestibility, protein, energy, mineral contents and some inhibitors that may affect biogas efficiency and economics of operation.

MATERIALS AND METHODS

Biogas Design and Technology

Underground parts of digester body, the inlet and the outlet with a pressure stabilizer sump were made of iron bar reinforced concrete. The aboveground of the digester body was made of plastic drum functions as a digester tank and a gas holder when biogas is accumulated.

Height of the digester body including the plastic drum gas holder was 130 cm, the width is 90 cm and the length is 220 cm. Horizontal orientation gives enough HRT and cleaner effluent.

The digester was dug underground in order to facilitate easy loading, because the inlet can be installed lower than the canals of the swine house. The biogas was designed for a continuous substrate loading process. There are inlets for continuous loading, first is the inlet for swine manure and urine, second is the bowl of the attach toilet while third inlet is the outlet when it is stabilizing pressure.

A removable wooden swivel arm can stir, mix and disturb the slurry inside the digester was installed. The gas holder is a permanent type and is not moving compared to the Indian go bar design which is moving and creates maintenance problem, but the pressure is also stabilized because of the change of the overflow sump into a stabilizer sump.

Water sealed bowl of the toilet supplies human manure and urine for co-digestion with food waste load on the other main inlet for swine urine and manure. The stabilizer sump on the outlet of the digester was used as an automatic mechanism during the re-entry of slurry into the digester.

Experimental Design

Treatments were applied on CPDBD in sequence for three months duration with 7 days rest period. T₁ were loaded with Swine Waste, T₂ with Swine Waste plus Human Waste and T₃ with Swine Waste plus Human Waste plus Giant Taro Plant. Daily averages of parameters was analyzed through Kruskal Wallis Test to determine the significant differences among treatments. Dunn-Bonferroni Test was used to identify the best treatment. Statistical analysis was done through SPSS version 20.

Cooking time, biogas yield, volume of effluent and sludge and biogas recovery were the parameters to measure biogas efficiency. Savings from using the biogas instead of LPG, value of effluent and sludge fertilizer, Marginal Benefit Cost Ratio (MBCR) and Marginal Rate of Return (MRR) were computed and analyzed to evaluate economic benefits. Physico-chemical characteristics of CPDBD during the conduct of the study such as temperature, pH and EC were also gathered.

Experiment Procedures

Loading Rates Computation

The following were the amounts of loading rates base on availability in the locality as computed according to the formula of Ojario (2005).

Treatment 1: 2.26 kg swine manure + 0.5 kg swine urine = 2.76 kg

Treatment 2: 2.26 kg swine manure + 0.5 kg swine urine, plus 800 human manure + 200 grams food waste = 3.76 kg

Treatment 3: 2.26 kg swine manure + 0.5 kg swine urine plus 800 human manure + 200 grams food waste plus 3 kilos wild giant taro = 6.76kg of substrate or 7 kg.

Administration of Treatments

Treatment 1: First Month (Swine Waste)

Manure and urine from one 80 kilos swine was loaded in the inlet through washing it from the swine house. A substrate-to-water ratio of 1:10 was applied so as to have more water to drain the manure to the inlet. This was administered for three weeks in which each week represented the replications. The administration of swine manure had ended at the third week allowing the last week to use up the effect of the previous load to prepare for the next treatment.

Treatment 2: Second Month (Swine Waste plus Human Waste)

Administration of treatment 1 was resumed plus the manure, urine and food waste from human heads. Human manure and urine were loaded in the toilet bowl inlet directly into the digester body every time it is used. Food waste was loaded in the main inlet combined with swine manure and urine. Similar to treatment one, this was also ended in third week allowing the load to be used up before the next treatment..

Treatment 3. Third Month (Swine Waste plus Human Waste plus Giant Taro Plant)

In treatment 3, the administration of treatment 1 and treatment 2 were added with three (3) kilos hydrolyzed wild giant taro loaded every day. Replications were also the first three (3) weeks of feeding. Three weeks representing the replications were equal to 21 days multiplied to the amount of hydrolyzed wild giant taro needed per day which was three (3) kilos, a total of 63 kilos dried wild giant taro was soaked into the sump for hydrolysis. Before loading wild giant taro it was hydrolyzed first in advance for one week.

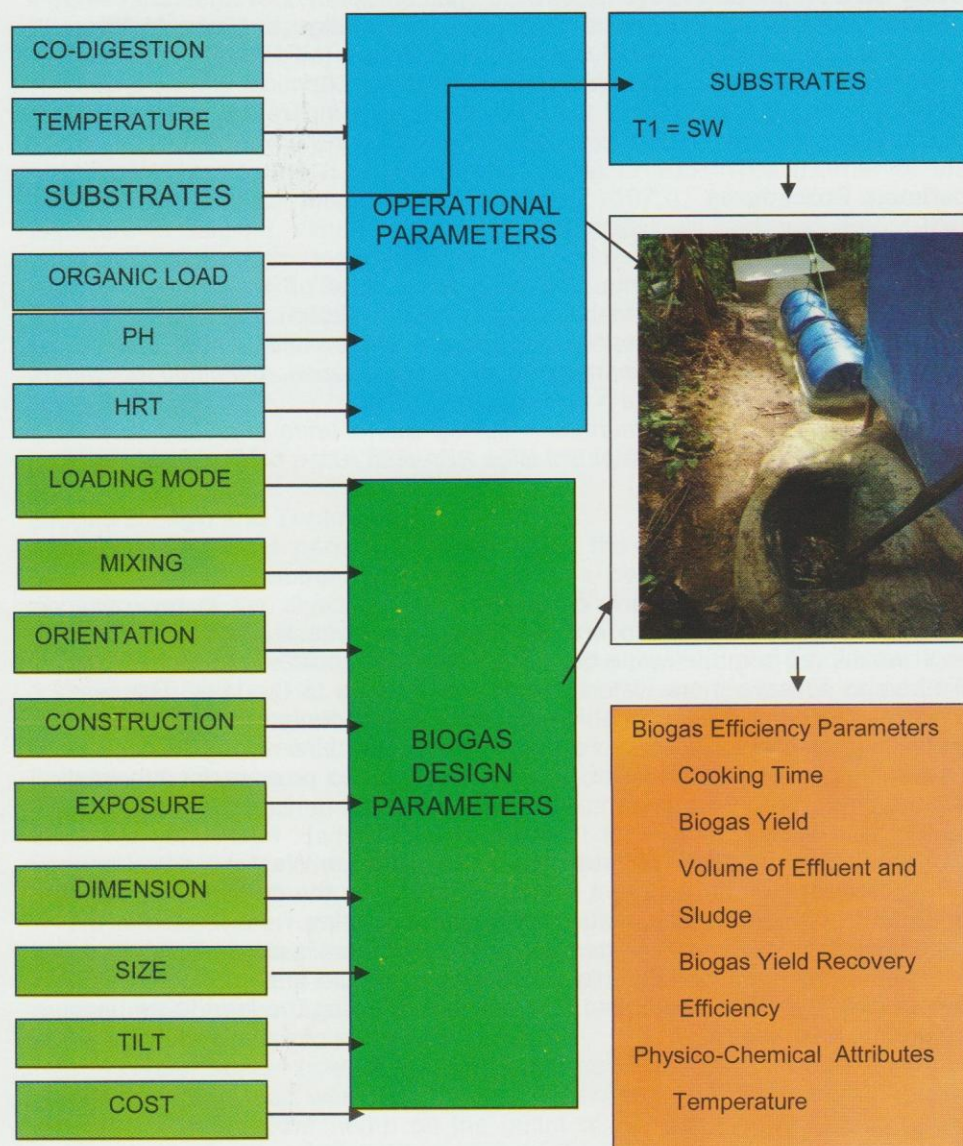


Figure 1. Conceptual Framework.

Wild Giant Taro Hydrolysis/Fermentation

Using the effluent in the stabilizer sump of the biogas of the last loads, 63 kilos of dried wild giant taro stem and leaves were soaked within the sump of the existing biogas digester. The mixture was stirred two (2) times a day until the dried giant taro were dissolved or hydrolyzed with the effluent.

Loading Hydrolyzed Giant Taro

Three kilos of hydrolyzed wild giant taro were scooped with a pail and dropped into the inlet of the biogas. Although some of hydrolyzed taro enter into the outlet when the gas was used, mostly of the soaked wild giant taro floated and needed to be scoop and loaded into the inlet in order to have a clear amount that was mixed with swine and human manure and food waste.

Daily Monitoring of Influent and Effluent Temperature

For better analysis on efficiency of this study, the actual daily temperature on the slurry was recorded. A digital thermometer with an external electrode was inserted into the influent and effluent three times a day at the same hours.

Daily Monitoring of Hydrogen Ion Concentration (pH) of the Effluent and Influent

Gas yield is also affected by pH. Daily pH was recorded to monitor its relation with gas yield.

RESULTS AND DISCUSSION

Biogas Efficiency Parameters

Assessment on operational efficiency of a technology is very important to convince farmers of its practicality. The length of cooking time, biogas yield, biogas recovery efficiency and volume of effluent of CPDBD as loaded with different substrates was presented in Table 1.

Table 1. Biogas efficiency of CPDBD as loaded with different substrates. Means of different superscript within columns were found significant using Dunn-Bonferroni test at 5% alpha.

Treatments	Cooking Time (minutes)	Biogas Yield (liters)	Biogas Recovery Efficiency (%)	Volume of Effluent (liters)
T ₁ -SW	62.14 ^a	249.24 ^a	58.66 ^a	14.10 ^c
T ₂ -SW+HW	61.90 ^a	251.43 ^a	39.41 ^d	40.00 ^d
T ₃ -SW+HW+GT	41.81 ^d	166.67 ^d	12.45 ^c	60.00 ^a
Kruskal Wallis (P-value)	0.000	0.000	0.000	0.000

Cooking Time

Treatment loaded with swine waste (T₁) and added with swine + human wastes (T₂) were comparable but significantly higher than treatments feed with a combination of swine waste, human waste and giant taro (T₃). Addition of

human waste in T_2 and human waste and giant taro in T_3 have not significantly increased the length of cooking time. Human manure and urine are highly digestible but waste from two individual in a home were not enough to cause a significant increase in cooking time. Higher potential yield of T_3 were not realized as it gave the shortest cooking time among treatments. This may be caused by some inhibitors in giant taro substrate.

In a study reported by Pankaj, K. (2006), two inches burner consumed 330 liters of biogas in an hour which was higher than the 249 liters in 62 minutes for treatment feed with swine waste alone (T_1) in this experiment. The nozzle of biogas burner used in this experiment was only half of an inch which causes the longer cooking time in smaller amount of biogas.

Biogas Yield

Yield of biogas from T_1 and T_2 were comparable but that of T_3 was the lowest ($p=0.000$). The addition of human waste and giant taro in swine waste had not significantly increased the yield of T_2 and T_3 respectively. The amount of human waste from two persons was not able to significantly increase biogas yield in T_2 . Higher potential yield of giant taro (T_3) were not realized. The biogas yield of T_1 was enough to supply the needed energy for one person according to the report of Pankaj, K. (2006). However, biogas yield of swine waste in this experiment (249 liters) were higher than reported by Pankaj, K. (2006) at 180 liters per day.

Based on the fluctuations of biogas yield of treatments in Figure 2, it was observed that yield of T_1 was increasing in the last week of the study. Biogas yields of T_2 were fluctuating in the first and stable in the second and third week. Treatment 3 had a higher biogas yield in first week and continuously dropping steeply in the end of second week and started to recover in the third week. As observed, there were inconsistencies of biogas yields in T_3 and was found not associated to the pH of slurry and EC because both of these variables were similarly fluctuating. However, it was observed as an interaction of other intervening variable because pH and EC during the conduct of the study was not manipulated and it erratically changes. It was professed by the researcher that the solubility of food waste and giant taro were the reason in the low actual yield compared to its potential yield of T_2 and T_3 . Giant taro's solubility might be inhibited by the itchy characteristics of its content killing the methanogenic and other bacteria responsible for biogas production.

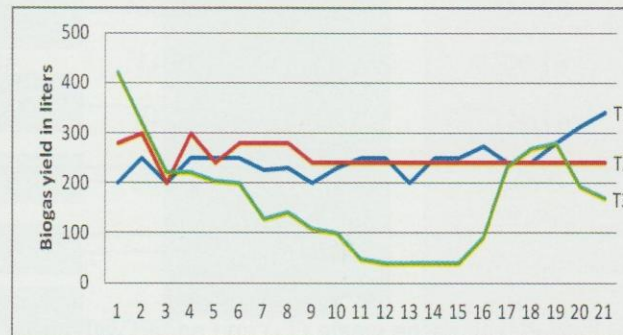


Figure 2. Recorded changes in biogas yield of treatments from day 1 to 21.

Biogas Recovery Efficiency

In Figure 3, T₁ with a treatment mean of 58.66% shows significantly the highest biogas recovery efficiency. Treatment 1 having the highest level of biogas recovery over potential yield was observed as the most efficient.

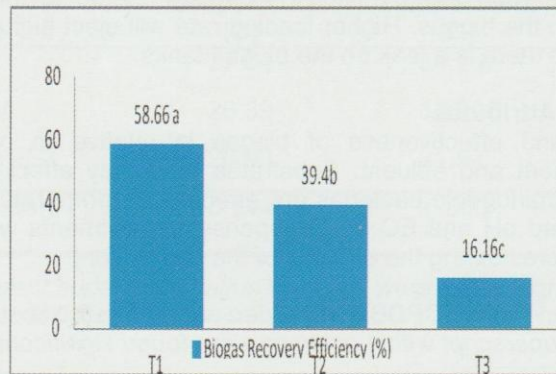


Figure 3. Biogas recovery efficiency.

Taking into account the computations on potential yield of Treatment 2 and 3, it was expected that these treatments should have higher biogas yield and biogas recovery over potential yield. Otherwise, the result of the experiment were the opposite, T₃ which was intentionally assigned to produced higher efficiency as a possible solution to the high cost of swine production limiting biogas adaptability to small scale hog raisers produced the lowest biogas yield and efficiency. Similarly, T₂ was also designed to maximized yield of biogas using alternative substrates so as cut dependence on swine manure as biogas loads had suffered the same failure as T₃. Even though T₂ and T₃ had higher potential yield, but its solubility was not as good as in swine manure alone. Swine manure were predigested inside the intestine of animals, and pelleted swine feeds were ground finely and are precooked and this contributed to the high solubility of swine manure and to its high biogas yield and efficiency. On the contrary, food waste especially kitchen waste like vegetable clippings, tissues, fruit peels were not ground, precook and digested by animals and these limits the solubility of substrates in T₂ and caused scum and clogging on the biogas digester tank. Moreover, T₃ might had an even more complicated cause, although giant taro are carbohydrates sources and is expected to have higher biogas yield than T₁ and T₂, its yield and efficiency were the lowest even lower than the control (PRABL 2007). Pre-trial experiment on August 2011 prior to the conduct of the study, the researcher had observed that giant taro had produced high amount of biogas. However that giant taro was dried for two weeks in sunny days. In contrast, giant taro used in T₃ was not dehydrated as during the time it was a series of rainfall for two weeks.

The researcher profess that the non-dehydration of giant taro had affected its capacity to produced biogas maybe because of the intimidation of its itchy characteristics. Maybe proper drying destroys the itchy content in a giant taro substrate which resulted to the said trial success of giant taro. Solubility and scum was another cause as the giant taro substrates floats once it mixed with the slurry.

Volume of Effluent

T₃ having the highest ($p=0.000$) volume of effluent was a predictable response of the treatments, owing to the fact that it used higher amount of substrates and enough volume of water to maintain the ideal mixture of slurry. The volume of water and slurry mixture is directly related to the volume of effluent ejected from the biogas. Higher loading rate will eject higher volume of effluent except when there is a leak on the biogas tanks.

Physico-Chemical Attributes

Efficiency and effectiveness of biogas is relative to pH, EC and temperature of influent and effluent. Substrates feed may affect pH and EC while vitality of methanogenic bacterias are affected by temperatures. Table 2 presents the recorded pH and EC as a response to treatments while Table 3 shows the temperatures during the conduct of the experiment.

Table 2. pH and EC of CPDBD as loaded with different substrates.
 Means of different superscript within columns were found significant using Dunn

Treatments	pH of Influent	pH of Effluent	EC of Influent (ms)	EC of Effluent (ms)
T ₁ -SW	7.50 ^b	7.81 ^a	4.69 ^a	5.07 ^a
T ₂ -SW+HW	7.62 ^{ab}	7.62 ^b	4.44 ^a	4.74 ^b
T ₃ -SW+HW+GT	7.75 ^a	7.76 ^b	2.98 ^b	4.82 ^{ab}
Kruskall Wallis (P-value)	0.000	0.021	0.000	0.006

-Bonferroni test at 5% alpha.

pH

CPDBD loaded with T₁-Swine Waste significantly had the lowest ($p=0.000$) pH of Influent but had the highest ($p=0.021$) pH of influent. Lower influent pH of T₁ than T₂ and T₃ signifies much faster fermentation. High effluent pH of T₁ may be caused by its higher efficiency of biogas recovery. There is a positive correlation between biogas recovery efficiency and pH of effluent.

EC

The lowest ($p=0.000$) EC was observed in T₃ or CPDBD loaded with a combination of swine waste, human waste and giant taro plant. EC measures the amount of digested substrates in an influent as free ions. Therefore, the lower the EC readings in an influent also means that the lower the digestibility of a substrates. However, effluent EC of T₃ was found comparable to that of T₁ which has high digestibility. This may support that there is another intervening factor that inhibits the biogas yield efficiency of giant taro in T₃ which was expected to give higher actual yield.

Table 3. Ambient, compost heap and inside biogas temperature during the conduct of the study.

Treatments	Ambient Temperature (C)	Compost Temperature (C)	Inside Biogas Temperature (C)
T ₁ -SW	27.04	34.20 ^a	27.64 ^b
T ₂ -SW+HW	26.39	33.29 ^a	28.25 ^a
T ₃ -SW+HW+GT	26.93	31.57 ^b	28.24 ^a
Kruskall Wallis (P-value)	0.144	0.000	0.000

Means of different superscript within columns were found significant using Dunn-Bonferroni test at 5% alpha.

Temperature

Average ambient temperature during the conduct of the study was comparable ($p = -0.144$) among all treatments. Compost heap temperature was found lowest ($p = 0.000$) in T₃ while that of T₁ and T₂ was significantly higher. This lower temperature of compost heap during the conduct of T₃ may not be the cause of its lower biogas efficiency. The temperature inside the biogas of T₃ was significantly higher than T₁, yet the latter gave the highest biogas yield recovery efficiency. This may support that the low biogas recovery efficiency of T₃ may be caused by an inhibitor not anticipated by the design of this experiment.

Economic Benefits

Since farming is business, operational efficiency is not enough to convince farmers to adopt certain technology. Table 4 presents the economic benefits of loading different substrates on CPDBD.

Table 4. Economics efficiency of CPDBD as loaded with different substrates.

Treatments	Value of Effluent and Sludge (Pesos)	Savings (pesos)	MBCR	MRR
T ₁ -SW	1851.33 ^c	4082.67 ^a	1.00 ^b	100.00
T ₂ -SW+HW	3302.52 ^b	3474.33 ^b	2.25 ^a	125.52
T ₃ -SW+HW+GT	5412.18 ^a	353.00 ^c	0.86 ^b	-8.90
Kruskall Wallis (P-value)	0.034	0.039	0.038	0.107

Means of different superscript within columns were found significant using Dunn-Bonferroni test at 5% alpha.

Value of Effluent and Sludge Fertilizer

The value of effluent and sludge fertilizer is directly proportional to the amount of substrates loaded in the biogas (Ojario, 2005). This relationship was displayed in the means on the value of effluent and sludge fertilizer in Figure 3. It was concluded that T₃ had significantly ($p=0.034$) the highest value of effluent and sludge fertilizer. However nothing is surprising on this finding as this coincides with the direct relationship between the amount of organic loads, the amount of effluent and sludge fertilizer to its values.

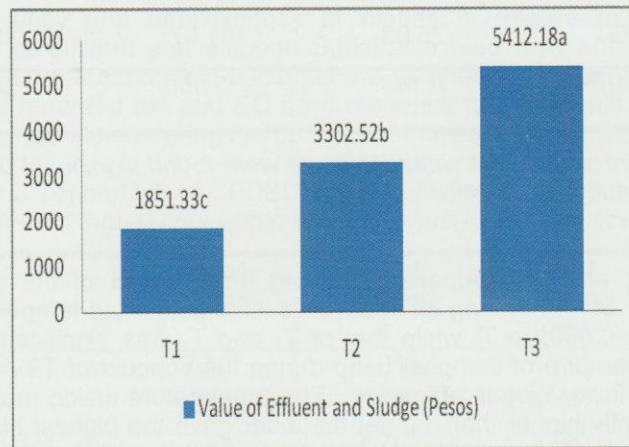


Figure 4. Value of effluent and sludge fertilizer produced from CPDBD as fed with different combination of substrates.

In spite of the failure of T₃ to produce high volume of biogas, amount of effluent and sludge were continuously produced which accounted the treatment with the highest value of effluent and sludge fertilizer.

Savings on the use of biogas as substitute to LPG

As shown in Figure 4, T₁ or CPD biogas digester loaded with swine manure alone got the highest amount of savings, T₂ or CPD biogas digester loaded with swine manure, human and food waste was second while T₃ or CPD biogas digester fed with additional three kilos of giant taro saved the lowest in one year. Statistical analysis disclosed a highly significant difference leading to the rejection of the null hypothesis. This implied that the different combination of substrates had affected the amount of savings among treatments. Upon pair comparison analysis, it revealed that means of T₁ and T₂ were comparable and T₃ were significantly different at lower amount of savings. However, in business sense, T₁ with P608.00 higher savings than T₂ is considered as the best treatment because it is 17% higher and 17% difference in net income is a good advantage as banks are giving 5% to 15% interest on your savings in time deposit.

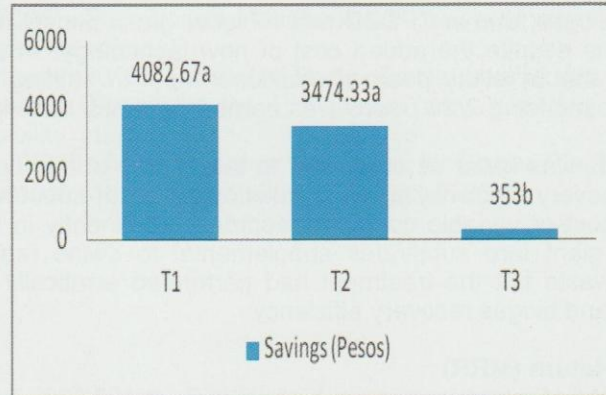


Figure 5. Savings on the use of biogas as substitute to LPG Marginal Benefit Cost Ratio (MBCR).

Figure 5 presented the marginal benefit cost ratio (MBCR) on all treatments. As exposed, T₂ or CPD biogas loaded with swine and human waste got the highest MBCR with a mean of 2.26, followed by T₁ and T₃ with a mean of 1.0 and 0.91. T₁ (Swine Waste) has an MBCR of one since it was assumed as the traditional technology of biogas as fed with swine manure and the addition with human waste and giant taro was the new tested innovation.

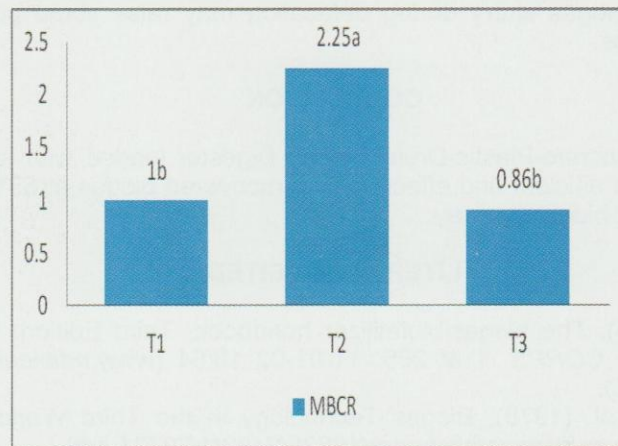


Figure 6. Marginal benefit cost ratio of CPDBD as fed with different combination of substrates.

After subjecting to Kruskal Wallis test, it showed that there was a significant difference among treatment means. Hence, the null hypothesis was rejected and it was concluded that the addition of human waste and giant taro had affected the MBCR of treatment means. Likewise, Dunn-Bonferroni analysis uncovered a significant difference on treatment means' comparisons. As presented in Table, T₂ has the highest MBCR (2.26) and is statistically significant over other treatments revealing that the addition of human waste to

swine manure as biogas feed in CPDBD had a higher gross benefit than using swine manure alone despite the added cost of new technology. An MBCR of 2.26 in T_2 means that in every peso of additional input in shifting to a new technology, a corresponding 2.26 pesos was earned as gross benefit or gross income.

MBCR of T_3 was lower as compared to the T_1 due to their low biogas yield or biogas recovery efficiency and the additional cost of substrates in T_3 . Higher treatment cost or variable cost was recorded prominently in T_3 on the use of additional giant taro substrates supplemental to swine manure and human and food waste but the treatment had performed erratically having a lower biogas yield and biogas recovery efficiency.

Marginal Rate of Return (MRR)

Marginal rate of return was found highest in T_2 at 125.53%, followed by T_1 with a mean of 100% while T_3 had the lowest at -8.9%. Comparable MRR ($p=0.107$) of T_1 and T_2 means that the additional unit of investment in the addition of human waste in T_2 had not significantly increased the amount of its net benefit. Having a lower treatment cost and higher biogas yield and biogas recovery efficiency attributed to the high MRR of T_1 . T_3 which had lower biogas recovery rate and additional expenses on modified biogas parts and the cost of giant taro as supplemental biogas fed in T_3 had dropped its MRR to negative 8.9%.

The addition of human waste (T_2) to swine waste (T_1) has lead to 25% more MRR but the hassle in loading personally on the biogas and the danger of direct contact biogas slurry during defecation may raise some practical and health risk issues.

CONCLUSION

The Concrete-Plastic-Drum Biogas Digester loaded with swine waste alone was more efficient and effective as it recovered biogas at 58% efficiency and 249 liters of biogas per day.

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