BIOMASS WASTE UTILIZATION:
AN APPROACH FOR SOLID WASTE REDUCTION

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ABSTRACT

Three approaches have been devised by Central Philippine University (CPU) in utilizing the enormous biomass waste generation in Western Visayas region of the Philippines. These approaches are direct combustion, gasification and pelleting/briquetting. Gasification technologies developed by the University include steam-injected stoves and gasifiers are all fuelled by either rice husks or sawdusts and are good alternatives in reducing the generation of such wastes. To explore options for value adding to Alternative Fuels and Raw materials (AFR), a manually-driven pelleting/briquetting machine was developed and tested at Calajunan waste disposal facility in Iloilo City. This test included recovered light packaging materials, carbonized rice husks, sawdusts and low grade quality paper residuals to produce pellets which may be utilized as AFR by the cement industry. A second test for pelleting/briquetting was also done in order to produce alternative fuels for household consumption as substitute for wood fuel and charcoal. A total potential use of 18 to 139 tons of biomass per year may be utilized from the waste generation of Western Visayas based on the actual number of user of stoves and gasifiers. These approaches developed can help reduce emission of harmful gases to the atmosphere caused by the indiscriminate open burning of biomass wastes. Converting biomass wastes into pellets and briquettes can serve as substitute fuel for household and industrial heat applications.

INTRODUCTION

Annually, the Philippines generate large volumes of agricultural wastes. This can be attributed to the fact that the country utilizes almost one-third of its agricultural lands for rice production (FAO, 2000), and is considered as a promising option to enhance resources utilization instead of open burning or uncontrolled waste disposal, which are still the dominating practices for agricultural and municipal waste management in the Philippines. During post-harvest phases large volumes of biomass residues are being generated on many agricultural used areas. One of the ubiquitous generated agricultural waste is rice husk, the outer covering of paddy which is removed after rice milling and accounts for 20-25% of its weight (Jenkins, 1989). The total rice husk potential for the country according to the Crops Statistics of the Bureau of Agricultural Statistics was estimated to be 3.14 million metric tons in 2005. Western Visayas (Figure 1), one of the rice producing regions of the Philippines generates approximately 313,400 metric tons of rice husks and among the 6 provinces composing the region, the Province of Iloilo generates the highest volume at 165,000 metric tons annually (compare http://www.aseanenergy.org/download/eaef/105-2004%20Project%20Summary%20for%20web.pdf). These voluminous wastes are often dumped at the back of rice mills, simply left along the roads during travelling or at the backyards of rice mills to decompose, or thrown into natural depressions or near creeks, rivers and

Figure 1 Location of Iloilo City, Western Visayas, Philippines

streams. In worst cases, these wastes are openly burned on rice fields, an activity specifically banned by Republic Act 9003, also called the Ecological Solid Waste Management Act of 2000 (Oposa, 2002), since this practise generates and emits harmful gases into the atmosphere.

Failure to utilize rice husk is tantamount to wasting a high calorific resource since this waste contains a heating value of 3000 kcal/kg (Beagle, 1978) and with its widespread availability, it could clearly be a practical source of energy (Borman & Ragland, 1998) if properly utilized. The use of rice husks as fuel for cooking using appropriate technologies like cookstoves and gasifiers can minimize dependency on fuel wood and charcoal reducing the impact of deforestation. In addition, the increasing cost of fossil fuels has also led the consumers to explore other potential sources of energy.

One such potential source of energy is the recovery of other useful wastes in a disposal facility. In Iloilo City, a 100-day material recovery test was done at the Calajunan disposal facility to recover organic waste and Alternative Fuels and Raw materials (AFR) that can still be processed into useful source of energy such as fuel for industrial and household use (Paul, et al, 2009). These discarded waste materials from the disposal facility may be explored further by converting them into pellets and briquettes using the most viable mixture. The practice of generating fuel energy from solid wastes like biomass and AFR can be an environmentally sound technique for waste reduction, and contribute largely to enhance solid waste management.

OBJECTIVES OF THE STUDY

The following are the objectives of this study:

1. To develop technologies that utilize biomass wastes as source of energy;
2. To document the design specifications and operating performance of the direct combustion technologies developed in terms of boiling time, fuel consumption rate, percent char produced, steam consumption rate, and thermal efficiency;
3. To document the design specifications and operating performance of the gasifier technologies developed in terms of fuel consumption rates, percent char produced, and thermal efficiency;
4. To document the operating performance of the pelleting and briquetting technologies in terms of finding the most viable mixture in producing pellets as alternative fuels and raw materials for industrial use and briquettes for household application using only biomass wastes; and
5. To identify the advantages and limitations of the developed technologies as an approach in reducing solid wastes.

MATERIALS AND METHODS

Technologies Developed for Biomass Waste Utilization

Three major types of technologies have been developed at CPU for the utilization of biomass wastes in an attempt to help reduce the inappropriate disposal of these wastes. The direct combustion stoves were developed especially for areas with no access to electricity. These technologies, as shown in Figure 2, are easy to operate. These started with simple designs of step-grate and conical stoves in which the rice husk fuel is directly loaded into the hopper. For the step-grate, the fuel is burned on top of a slatted metal grate built in an inclined manner to allow combustion of the fuel to continue. Unlike the conical stoves in which the fuel is burned inside an inverted cone grate where burning takes place with the supply of both primary and secondary air. These stoves consist of major parts like the pot holder, fuel hopper, ignition port, discharge lever, char pan, and support stand. In an aim to continually improve the design of cooking stoves, CPU developed stoves that integrate the use of steam. These new technologies, namely, the side-in and super turbo stoves inject steam into the combustion chamber of the stove providing substantial heat to satisfy the highly endothermic chemical reactions during combustion. The mixture of air and steam during operation serves as the gasifying agent, thus producing a turbulent pinkish-luminous flame that is different from the previously developed biomass cooking stoves. These steam-injected stoves have an additional part of steam tank, steam burner, and steam injector.

Figure 2 Direct combustion stoves developed for biomass waste utilization, namely from left to right: step-grate stove, conical stove, side-in, and the super turbo

The biomass gasification technologies developed (Figure 3) for thermal application, in turn, ranged from single to multi-burner gasifier stoves for household and industrial use, to dual-reactor and continuous-flow type gasifiers for industrial applications. These technologies basically consist of similar parts, namely: air moving device (fan/blower), burner, char chamber, char grate, discharge lever, chimney, gas pipe, gas regulator, pot holder, and reactor. During the operation of these gasifiers, the burning layer of biomass fuel in the reactor moves downward until all the fuel is used up. The more air is introduced by the fan/blower in the fuel bed, the faster is the downward movement of the fire. It is during this early stage of gasification that the heat generated vaporizes the volatile components present in the biomass fuel in the presence of limited air. As the combustion zone moves downward, the fuel is left inside the reactor in the form of char. The unburned carbon present in char then reacts with the air that is supplied by the fan/blower thus producing combustible gas.

A manually-driven pelleting machine and briquette molder were developed to explore options of value adding to materials that have been recovered as Alternative Fuels and Raw materials (AFR) during a 100-day recovery test at the Calajunan disposal facility of Iloilo City, Philippines. AFR materials included mostly light packaging materials, biomass wastes like carbonized rice husks (CRH) and sawdusts, and low quality waste paper which were converted into pellets and briquettes. Pellets mixed with plastic materials were produced for industrial utilization while briquettes, without the mixture of light packaging materials, could be used as substitute fuel for cooking (Figure 4).

Figure 3 Gasifier technologies designed for biomass waste utilization, namely from left to right: single-burner, multi-burner, dual-reactor, and continuous-flow type gasifiers

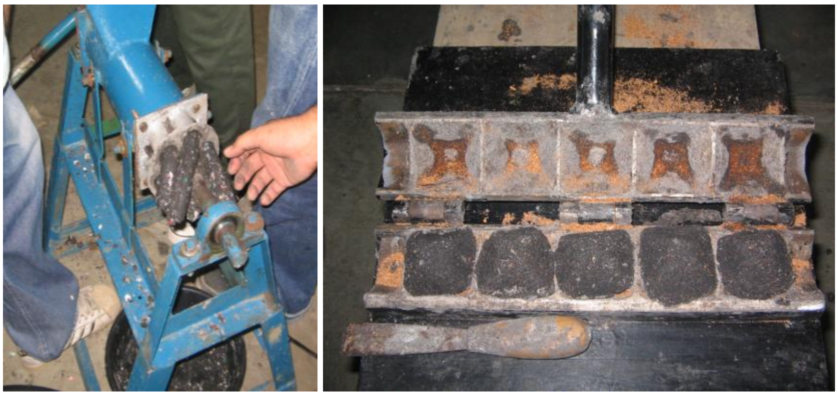

Figure 4 Pelleting machine and briquette molder used for converting wastes into pellets as AFR for industrial use and briquettes for household use

Performance Evaluation

Evaluation of the technologies developed was done at the Appropriate Technology Center of Central Philippine University, Iloilo City, Philippines. These technologies were tested on their capacity to utilize biomass wastes. Biomass waste like rice husks were obtained from near-by rice mills. The sawdusts and CRH used for briquetting and pelleting were mostly obtained from Guimaras Island with some CRH from stoves and gasifiers developed while the AFR materials used, mostly made of light packaging materials, were recovered during a 100-day recovery test at the Calajunan waste disposal facility of Iloilo City.

Basically, the procedure in evaluating the direct combustion stoves and gasifiers were very similar. For direct combustion stoves, the biomass fuel was loaded into the hopper to determine initially the fuel capacity of the stove. After ignition of fuel the cooking pot with certain volume of water was placed on the pot holder for the thermal efficiency of the stove using the water boiling test. Operation continued and biomass fuel was loaded to the hopper until the water boiled while burnt fuel or char was discharged at the bottom of the grate by slightly manipulating the lever. After the operation, data on: weight of fuel consumed, weight of char produced, weight of water evaporated, initial and final temperature of water, total operating time, and steam evaporated from steam-injected stoves were collected. After which, parameters like fuel consumption rate, steam consumption rate, percent char produced, and thermal efficiency were analyzed.

For gasifiers, biomass was loaded until it filled entirely the reactor of the gasifier. The fuel was then ignited while its air moving device (fan/blower) was switched on. This device was responsible in delivering the needed amount of primary air for rice husk gasification to produce combustible gas for cooking. A cooking pot with water was also used for the boiling test and the operation was timed until all the fuel in the reactor was converted into char. Similar data with that of the direct combustion stoves were gathered and parameters analyzed except for the exclusion of steam consumption rates.

The pelleting machine and briquette molder were simple devices developed to provide low cost solutions in utilizing AFR from a disposal facility and biomass wastes like CRH and sawdusts. The pelleting machine used contained a feeder at the top, a rotating screw for compaction at the center, and a final outlet with changeable die plates. Two workers were needed to operate this machine. One person is responsible in feeding the prepared mixture while the other person manipulates the screw by gradually rotating it until pellets come out of the die plate. The briquette molder, on the other hand, is a smaller unit that can be operated by one person only. The machine consists of two symmetric half forms with five molders each. These were connected on one side with a hinge and on the opposite side with a handle, thus creating a movable top that could be opened after the prepared mixture has been compacted. Compaction of the briquettes was done after the prepared mixture was placed at the bottom half of the molder by closing and pressing down the movable top against it. After manual pressure has been exerted, the movable top was opened and the briquettes were removed for sun-drying.

Preparing the Mixture for Pelleting/Briquetting Evaluation

The needed materials for this specific test were made available in sacks with shredded AFR coming from the Calajunan disposal facility. The particle size of the shredded AFR was approximately 4 to 10 millimeters (mm). The CRH and sawdust were smaller in a range of 0.1-0.6 mm. Corn starch used as binding material was obtained from a local supermarket. These materials were then mixed by hand until a homogeneous mixture was created. The corn starch was weighed and then carefully suspended in water for boiling until a jelly-like appearance was produced. The binding material was then mixed with the dry mixture until again a homogeneous state was reached. The particle size distribution and properties of the different ingredients are essential for the stability and density of the produced pellets, because potential airspace volumes in-between the bigger particles can be filled with smaller ones. Bigger and smaller particles together create a more stable compound.

RESULTS AND DISCUSSIONS

Design Specifications and Operating Results of Stoves and Gasifiers

Table 1 presents the design specifications of the four different types of direct combustion stoves developed that utilize biomass waste as fuel, a common type of solid waste generated in most parts of the country. Among the four stoves, the step-grate and the conical-type are not steam-injected since they were the pioneering stoves developed unlike the side-in and the super turbo which operate with steam as an enhancing factor in their performance. As further shown, the four stoves have similar dimensions, with the step-grate having the widest diameter at 22 cm while the three others have a diameter of 17 cm. In terms of width and height, step-grate is wider at 50 cm but a bit lower at 45 cm compared to those of the other stoves at 47 cm and 51 cm, respectively.

As to the stove operating performance (Table 2), all the stoves were designed to be operated continuously as long as burned fuel is replaced in the hopper. A 1000 ml water was used for the boiling test in which the non-steam-injected stoves registered a boiling time of between 9 to 10 min, whereas, the steam-injected stoves registered a faster boiling time of between 6 to 7 min. The data obtained further indicate that as the fuel consumption rate of the stove increases, the boiling time decreases. This can be attributed to the increase in the heat energy given off by the biomass fuel. In terms of percentage char produced, the four stoves converted the biomass wastes into char by a range of 25 to 28% by weight of rice husk. This shows that the discharge from these stoves were mostly char and not ash which is 15 to 22% by weight of rice husk (Kaupp, 1984). The significance of this char is that it can still be processed into another useful form of fuel which is briquette. Water boiling test was used in computing for the thermal efficiency of the stoves. This parameter measures the percentage of heat energy produced by the fuel reaching the water in the pot. As presented in the table, the data obtained for the stoves were almost similar at 9.87 to 10.64%. This shows that steam is not a factor in the production of heat by the biomass fuel.

Table 1 Design specifications of the direct combustion stoves

Type of Stove	Steam-Injected	Hopper Type	Diameter of Combustion Chamber (cm)	Max. Width of Stove (cm)	Max. Height of Stove (cm)
Step-Grate	no	step grate @ 5 hor. slots	22	50	45
Conic	no	conical	17	47	51
Side-In	yes	conical	17	47	51
Super Turbo	yes	conical	17	47	51

Table 2 Results of the operating performance of the direct combustion stoves

Type of Stove	Vol. of Water (ml)	Boiling Time (min)	FCR (g/min)	Char Produced (%)	Steam Con. Rate (ml/min)	Thermal Eff. (%)
Step-Grate	1000	10.00	28.82	28.34	-	10.11
Conic	1000	9.22	26.00	24.58	-	9.87
Side-In	1000	7.18	29.00	26.67	3.93	10.64
Super Turbo	1000	6.00	30.00	25.00	6.67	10.49

Five different types of gasifiers were developed for biomass waste utilization. Unlike the direct combustion stoves that can be operated without the aid of an air-moving device, gasifiers are dependent on this device as a source of limited air during the combustion of biomass in the reactor.

As shown in Table 3, the single and double-burners for household use (H/U) and industrial use (I/U) were batch-type in terms of mode of feeding. The single-burner which is driven by a 16-watt static fan has a single reactor and the smallest among the five gasifiers in terms of size. The double-burner gasifier for household use is the smallest compared to the other double-burner designed for industrial use. The former has an inner reactor diameter and height of 20 cm and 95 cm, respectively, while that of the latter is 95 cm and 124 cm, respectively. There are two gasifiers designed for continuous feeding, one is a dual-reactor in which two reactors are operated alternately making the operation non-stop. The other gasifier has only one reactor but it was designed that burned fuel can be discharged at the bottom without interrupting the gasification process, unlike the rest of the four gasifiers that unloading can only be done once all the fuel inside the reactor has been used up. The two continuous-type gasifiers have the same inner reactor diameter of 25 cm and height of 100 cm.

Table 3 Design specifications of the gasifiers

Type of Gasifier	Mode of Feeding	Air Moving Device	No. of Reactor	Diameter of Inner Reactor (cm)	Ht. of the Reactor (cm)
Single-Burner	Batch-type	Fan	1	15	60
2-Burner (H/U)	Batch-type	Blower	1	20	95
2-Burner (I/U)	Batch-type	Blower	1	40	124
Dual-Reactor	Continuous-type	Blower	2	25	100
Continuous-Flow	Continuous-type	Blower	1	25	100

The operating performance of the gasifiers shows that each has a different fuel capacity that ranges from 1,200 g for the single-burner to 20,000 g for the initial filling up of the continuous-flow. The batch-type gasifiers can be operated in 30 to 50 min on the average. Each of the reactor of the dual design can be operated for 30.48 min, a data that is similar to that of the double-burner for household use since the two gasifiers have also similar specifications. The continuous-flow with its initial loaded capacity was operated for 145.80 min or nearly 2-1/2 hours. Among the five gasifiers, the double-burner for industrial use had the highest fuel consumption rate (FCR), however, the general data revealed that as the length of operating time increases, the fuel consumed per unit tends to increase also. This parameter indicates that the last three types of gasifiers are the most ideal in utilizing biomass wastes since they require more wastes per operation. The continuous-flow gave the highest conversion of biomass fuel into char by almost 50%. This is due to its mode of feeding in which the fuel is continually loaded while also manipulating the discharge lever without unloading the entire burned fuel. The four other gasifiers including the dual-reactor have nearly similar percent char produced that ranged from 21 to 28% due to their batch-type mode of feeding in which the entire burned fuel has to be unloaded first before a new a batch of fuel is to be loaded. This is the same principle for the dual-reactor except that it has two reactors that work alternatively making its operation continuous. Using again the water boiling test for thermal efficiency computation, the continuous-flow registered the highest efficiency at 63.49% followed by the dual-reactor at 39%, whereas, the batch-type gasifiers have a thermal efficiency of less than 11%. The two continuous-type of gasifiers have the highest value due to their longer operating ability making them consume more fuel and utilize more heat (Table 4).

Table 4 Results of the operating performance of the gasifiers

Type of Gasifier	Wt. of Fuel used (g)	Op. Time (min)	FCR (g/min)	Char Produced (%)	Thermal Eff. (%)
Single-Burner	1,200	45.00	26.67	28.05	11.42
2-Burner (H/U)	2,120	30.60	69.28	24.68	4.74
2-Burner (I/U)	14,700	52.20	281.61	21.91	2.86
Dual-Reactor	5,000	30.48	164.04	25.00	39.00
Continuous-Flow	20,000	145.80	137.17	48.90	63.49

Results of Pelleting and Briquetting Tests

Fifteen different tests, as presented in Table 5, were conducted using different mixing ratios of plastic wastes and paper from the disposal facility, and biomass wastes like carbonized rice husks (CRH) and pure sawdust. The materials were mixed with corn starch as binding material, although waste paper was also tried as alternative binding material for household fuel production in some of the test runs. Paper was not used in the industrial fuel mixtures, because it was assumed that the quantitative demand on paper required for the pellet mixture would not be available within the local municipal solid waste (MSW) stream.

Table 5 Summary of composition and mixing ratio used for the pelleting and briquetting tests

Test No.	Plastic		CRH		Sawdust		Paper		Corn Starch		Water	
	(g)	(%)	(g)	(%)	(g)	(%)	(g)	(%)	(g)	(%)	(g)	(%)
1	500	10	2000	40	1000	20			1500	30	3000	38
2	1000	18	2000	36	1000	18			1500	27	3000	35
3	1500	25	2000	33	1000	17			1500	25	3000	33
4	2500	39	500	8	500	8			3000	46	2000	24
5	2500	42	500	8	500	8			2500	42	2000	25
6			3000	55	1000	18			1500	27	2000	27
7			2000	53	500	13			1250	33	2000	34
8			2000	47	1000	24			1250	30	2000	32
9			2000	50	1000	25			1000	25	2000	33
10			2500	50	1000	20	1000	20	500	10	2000	29
11			2500	50	1000	20	1500	30			2000	29
12			2000	40	1000	20	2000	40			2000	29
13			1000	20	1000	20	2500	50	500	10	2000	29
14			1000	20	1000	20	3000	60			2000	29
15							5000	100			2000	29

As shown in Table 5, the first 5 tests were done to analyze the maximum percentage of plastic wastes that could be added to biomass wastes like CRH and sawdust with corn starch as binding material for the pelleting test. This test aimed to determine the feasibility of producing pellets as an AFR for industrial applications. Based on the results, the plastics used started out with the least percentage as component material, while CRH and sawdust have higher percentage and hence were gradually decreased as plastics were increased. The amount of binding material was also increased with the amount of plastics. Among the five tests for AFR pellet production, Test 4 with components of 39% plastic, 8% CRH, 8% sawdust, 46% corn starch, and 24% water gave the most suitable mixture for the manual production of pellets containing plastics. The mixture of 8.5 kg was processed with the pelleting machine in less than half an hour corresponding to an output of approximately 15 kg per hour of dry pellets. The other tests also produced pellets but these were not as compact as those of Test 4. Furthermore, it is difficult to manually produce pellets with mixtures of more than 40% plastic using the machine developed because the materials can not anymore be screwed out of the die plate. However, if the design would be improved, a possibility of utilizing more plastic wastes may be achieved.

Tests 6 to 15 were done to determine the best mixture for household fuel production using only biomass wastes. Tests 6 to 9 were done with corn starch used as the binding material. Results revealed that a mixing ratio of 47% CRH, 24% sawdust, 30% corn starch, and 32% water appeared to be the most suitable mixture for the manual production of household fuel. The worker using this mixture was able to produce 5 kg of briquettes per hour with 20 min spent in preparing the dry mixture of 4,250 g. Tests 10 to 15 were done with paper, pre-treated using a pulping machine, as the main binding material except for Tests 10 and 13 which made use of additional 10% corn starch. Based on the results, briquettes produced with a little amount of corn starch are the most suitable (20% CRH, 20% sawdust, 50% paper, 10% corn starch, and 29% water). The test further revealed that paper alone can not replace starch as binder. In Test 15, which used only paper and water, the machine was able to produce very compact briquettes with 21 briquettes produced in 5 min.

Impacts of the Biomass Technologies on Solid Waste Reduction

Table 6 presents the summary of biomass technologies developed and their impact in terms of amount of biomass wastes, specifically rice husks, that may be reduced from the estimated yearly generation in the Western Visayas Region of the Philippines. The rice husk generation was based on the actual rice production of the region with 20% of its weight alloted for rice husks (Jenkins, 1989). As shown, based on the actual number of units sold in the region, the total utilization of biomass wastes when used for an estimated 6 hours daily for 8 months operation range from 18 tons/yr to as high as 139 tons/yr. When computed further, approximately 0.17% of these rice husks maybe reduced from the actual generation of such waste. This value maybe insignificant, however, if every household with open access to biomass wastes would be encouraged or provided with such technology, this value is foreseen to increase. Presently, biomass wastes are mostly dumped at the back of rice mills, usually causing problems on its disposal. Others are burned openly or under uncontrolled conditions affecting the air environment. The use of these stoves and gasifiers would help prevent the practice of open burning indiscriminately biomass wastes because they could be utilized as fuel for heat applications.

Table 6 Impact of the technologies developed as an approached in reducing the generation of biomass wastes

Technology Developed	No. of Units Sold	FCR (tons/yr)	Ave. RH Generation of Iloilo (tons/yr)	RH Reduced (%)
A. Direct Combustion Stoves				
1. Conic	12	27	313,400	0.01
2. Side-In	38	95		0.03
3. Super Turbo	29	75		0.02
B. Gasifier				
1. Single-Burner	60	139		0.04
2. 2-Burner (H/U)	3	18		0.01
3. 2-Burner (I/U)	5	122		0.04
4. Dual-Reactor	3	42		0.01
5. Continuous-Flow	4	47		0.01
Total	154	565	313,400	0.17

The method of converting other types of solid wastes is also feasible by converting them into pellets and briquettes. Plastic wastes from the disposal facility can also be utilized as AFR for industrial applications provided that they can be sieved into smaller particles (less than 0.25 in.) in order for these materials to be converted easily into pellets using the manually-driven pelleting machine. The use of this machine could produce an output per hour of 15 kg. However, this rate of production is way too low if used at the Calajunan disposal facility. Earlier studies at Calajunan had revealed that up to 20% of AFR could be recovered, which translates to > 30 tons/day (Paul, et al, 2007 & 2009). To achieve more production of pellets in order to cope with the generation of wastes at the disposal facility, a much larger and mechanized pelleting machine would be needed to provide a higher output.

The production of briquettes for household purposes using the necessary materials like CRH, sawdust, corn starch and water is possible. Using a hand-driven briquette molder, a person could achieve an output of approximately 5 kg/hr. Further, it is revealed that paper alone can not replace starch as a binder.

CONCLUSIONS

As an agricultural country, great potentials on the utilization of biomass wastes can be achieved using the technologies developed at CPU. The utilization of these wastes as fuels in stoves and gasifiers could help reduce problems on its disposal especially on rice milling areas with limited space. Another approach, which is the conversion of biomass wastes like rice husks and sawdusts into briquettes, is also a feasible option for waste reduction. Briquettes produced can be a used as alternative fuels for household consumption to substitute charcoal, a still widely used household fuel in the Philippines.

The method of recovering useful wastes from the disposal facility of Iloilo City and converting them into pelletized Alternative Fuels and Raw materials (AFR) is also a feasible option for waste reduction. These AFR pellets are foreseen to be an ideal substitute fuel for industrial applications.

The following are the benefits derived and limitations from the use of the biomass utilization technologies:

1. The stoves and gasifiers are ideal technologies in solving problems on the disposal of biomass wastes since these wastes can be used directly as fuel for heat applications.
2. By using biomass wastes the cost of cooking in a household as well as in small–scale industries spending on conventional fuel sources such as electricity and wood can be significantly reduced.
3. Carbon dioxide emissions released by the indiscriminate open burning of biomass wastes which also contributes to the ozone layer depletion leading to problems of more environmental concerns like climate changes can be reduced with the proposed alternative technologies.
4. It will help preserve the forest by reducing the cutting of trees for the production of wood fuel thus, minimizing problems concerning drought during summer, flood and erosion during the rainy season.
5. The by-product of rice husks after using them as fuel is char, which is another viable byproduct which can be converted into briquettes and pellets using the briquette molder and pelleting machine developed. These briquettes and pellets can be used as an alternative fuel for household and industrial use.
6. The technologies developed are best applied in areas with abundant supply of biomass wastes.

In conclusion, the approach of generating fuel energy from solid wastes like biomass and AFR is considered as a promising option to enhance resources utilization instead of open burning or uncontrolled waste disposal. This can be an environmentally sound technique for waste reduction, and contribute largely to enhance the solid waste management especially on the Western Visayas part of the Philippines.

PROPOSED NEXT STEPS

Commercialization and intensive promotion of the specifically developed stoves and gasifiers are already underway to fully increase public awareness that these technologies can already be utilized and are available as a low- cost source of fuel like rice husks and sawdusts.

The mixtures that were identified are suitable for pelleting as well as briquetting and could be tested on a larger scale using industrial equipment, whereas, corn starch as a binder should be replaced by cheaper binders. In terms of producing briquettes for household use, it is reasonable to continue product development towards a toolkit for this purpose, which includes the briquette molder, instructions on the production procedure and mixing ratio to be used. The product could then be distributed to be tested at the household level in Calajunan. Tests will be done on the quality of briquettes produced particularly to determine general physical and chemical properties such as water content, ash content, volatile compounds, fixed carbon content, and heating value. Further analyses should clarify the elementary composition including carbon, hydrogen, oxygen, nitrogen, and sulfur; and oxidation analysis and determination of properties of the ashes especially the melting point.

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