CHARACTERISTICS OF FUEL PELLETS PRODUCED FROM COTTON GIN BY-PRODUCTS AND GUAYULE BAGASSE

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Abstract

Utilizing agricultural plant wastes/residues from harvesting or agricultural processing operations can be an effective means of turning currently unused biomass into useful commodities. Despite extensive research efforts and the potential volume generated each year, very few uses for cotton gin by-products (CGB) have developed into widespread commercial acceptance. One possible solution is to increase the co-product value by blending two such products to make a product of higher value. The objectives of this study were to fabricate fuel pellets using CGB processed through the COBY Process utilizing different ingredients (including guayule bagasse), and to compare the physical properties and emissions during burning of the resulting pellets with conventional premium grade wood pellets. Two sources of CGB were used in conjunction with other ingredients to produce seven different types of CGB fuel pellets treatments. The names and ingredients used for the seven different treatments were: (1) Lbk 4, CGB from Lubbock, Texas with 4% added corn starch; (2) Lbk 10, CGB from Lubbock with 10% added corn starch; (3) Lbk 55, CGB from Lubbock with 5% added corn starch and 5% crude cottonseed oil; (4) Miss 4, CGB from Stoneville, Mississippi with 4% added corn starch; (5) Miss 10, CGB from Stoneville with 10% added corn starch; (6) Miss 55, CGB from Stoneville with 5% added corn starch and 5% crude cottonseed oil; (7) Guayule Mix, guayule bagasse (75%) mixed with Lbk 4 (25%); (8) commercial wood pellets. The results revealed that depending on the ingredients used and the method of manufacturing, an acceptable fuel pellet could be produced from CGB. However, when the fuel is burned in a commercial pellet stove without taking into consideration the air-to-fuel ratio necessary for a change in fuel type, the emissions for all CGB fuel pellets exceeded those of the premium grade wood pellet used in this study. One of the fuels used in this study that showed great potential was the Guayule Mix treatment. The emissions from firing the Guayule Mix fuel were the lowest of any of the CGB treatments as well as being closest to the wood pellet emissions. However, the Guayule Mix pellets still had a high ash content that would need to be addressed. The idea of blending one type of biomass to make up for the potential shortcomings of another is one of the items that surfaced when the results were evaluated. Future investigations involving fuel pellets from CGB will focus in the following areas: (1) assisting stove manufacturer's in modifying or developing a stove to accommodate biomass fuel pellets that have differing fuel properties from conventional wood pellets, (2) refining the CGB process to minimize the ash content of the fuel, and/or (3) evaluate blending other biomasses with CGB to develop a fuel which can more readily be used in the existing pellet stoves currently available.

Introduction

Utilizing agricultural plant wastes/residues from harvesting or agricultural processing operations can be an effective means of turning currently unused biomass into useful commodities. One of the residues researched extensively over the last few decades has been the by-products from cotton gins also known as gin trash or gin waste (Thomasson, 1990). Over the years, research on the utilization of cotton gin by-products (CGB) has been performed to evaluate the usefulness and feasibility of this biomass for various applications including fire logs (Karpiscak et al., 1982), energy source (Beck and Clements, 1982; Lacewell et al., 1982; LePori et al., 1982; Parnell et al., 1991; White et al., 1996; Zabaniotou et al., 2000), livestock feed (Holloway et al., 1974; Conner and Richardson, 1987; Poore and Rogers, 1995), raw materials in asphalt roofing products (Kolarik and Smith, 1978), and compost (Hills, 1982; Shumack et al., 1991; Truhett, 1994, Tejada et al., 2001; Tejada and Gonzalez, 2003). About 2.25 million tons of CGB are estimated to be generated each year across the cotton belt of the United States (Holt et al., 2000). Despite extensive research efforts and the potential volume generated each year, very few uses for CGB have developed into widespread commercial acceptance. Some of the more successful applications involve using CGB as a portion of the feed ration for livestock in feed yards (non-dairy), bedding for dairies, and in producing compost (Holt et al., 2000). Today, much of the available CGB is still disposed of by returning it back to the soil. These applications, while successful in various localized situations, utilize only a small portion of the available CGB.

Based on problems encountered in previous research studies, it was determined that a process, that can add value to the CGB to enhance commercial use of this biomass would be beneficial. A process utilizing CGB was developed to at the United States Department of Agriculture, Agricultural Research Service (USDA-ARS), Cotton Production and Processing Research Unit's facility in Lubbock, Texas. The procedure, designated as the COBY Process (Holt and Laird, 2002), was originally designed for the purpose of adding value to CGB to develop various useful end products such as livestock feed, fuel, and mulch. To date, various products produced from the COBY Process have been evaluated for their performance. The products evaluated so far are: (1) ingredient in livestock feed (Johnson, 2000; Holt et al., 2003a), (2) mulch (Holt et al., 2005b; Holt et al., 2005c), and (3) fuel pellet (Holt et al., 2005a). An economic study on the manufacturing and distribution of fuel pellets produced by the COBY Process was also undertaken (Holt et al., 2003b; Holt et al. 2004).

One of the questions not evaluated in the previously mentioned COBY studies was, "What effect will blending other biomasses with CGB have on the value of the products produced?" For this study, guayule bagasse was mixed with processed CGB to develop a fuel pellet. Guayule (*Parthenium argentatum*) is a hardy, drought-resistant native of the southwestern United States (McGinnies and Mills, 1980). Guayule is a source of natural rubber that has been researched and investigated at length over the past century. In the early 1900's, guayule was considered as an alternative source of natural rubber in the United States due to the high cost of rubber from the *Hevea* plant (*Hevea brasiliensis)* grown in the Amazon region (Bonner, 1991). Over the years, varying degrees of success have followed the utilization of guayule as a natural rubber, with the economics of production and extraction of the latex being one of the greatest hindrances to widespread commercial application (Foster and Coffelt, 2005). The current economic forecast suggests that in order for guayule to become a crop which can compete without subsidies, rubber yields must be increased and/or commercial utilization of processing coproducts must be identified and developed (Wright et al., 1991). Nakayama (2005) states that commercial development of guayule will depend on using as much of the plant as possible, which includes the residual resin and biomass generated from latex extraction. One of the more recent discoveries is the hypoallergenic properties of guayule latex that is unlike the latex from *Hevea* that can cause allergic reactions ranging from mild rashes to life-threatening anaphylactic shock. Even though *Hevea* is the world's primary natural latex source, it contains numerous allergy-causing proteins which affect an estimated 20 million Americans allergic to this latex (Siler and Cornish, 1994). The demand for an alternative natural latex source along with the hypoallergenic properties of guayule latex prompted the Yulex Corporation (www.yulex.com) to build a facility in Maricopa, AZ to produce natural rubber latex. For guayule, 90% of the plant material is available for coproduct development (Nakayama, 2005). The facility for latex extraction in Maricopa will be producing about 13 tons of bagasse daily beginning in early 2006. As Yulex expands production, it is estimated that 10 to 20 times this amount of bagasse will become available. From a past study, Nakayama et al. (2003) reported that the energy value of the guayule resin to be 16,400 BTU/lb with the resin comprising approximately 10% of the guayule bagasse. Due to the high energy value of the guayule bagasse along with the fact that cotton and guayule are grown in the same areas of the United States, this byproduct was selected as a potential biomass source that could be used to enhance the properties of fuel pellets produced from CGB alone.

The objectives of this study were two-fold: (1) Fabricate fuel pellets using CGB processed through the COBY process utilizing different ingredients (including guayule bagasse) and to determine the physical properties of the pellets produced; and (2) Evaluate the emissions derived from the prepared pellets using a commercially available pellet stove designed for residential heating and to compare such results with emissions from conventional premium grade wood pellets.

Materials and Methods

Materials

The wood pellets used in this study were purchased from one of the vendors listed on The Pellet Fuels Institute's website (PFI, 2005). The CGB used came from the USDA-ARS cotton ginning laboratories in Stoneville, Mississippi and Lubbock, Texas. The CGB from Mississippi contained all the waste streams from the ginning operation with the exception of the lint cleaner waste (i.e., motes). The Texas CGB contained only the waste stream from the Extractors (i.e., stick and bur machines). All the CGB were processed using the COBY Process (Holt and Laird, 2002) at the USDA-ARS, Cotton Production and Processing Research Unit in Lubbock, TX.

The two sources of CGB were used in conjunction with other ingredients to produced seven different types of CGB fuel pellets. The names and ingredients used for the seven different treatments were: 1) Lbk 4, CGB from Lubbock with 4% corn starch; 2) Lbk 10, CGB from Lubbock with 10% corn starch; 3) Lbk 55, CGB from Lubbock with 5% corn starch and 5% crude cottonseed oil; 4) Miss 4, CGB from Stoneville with 4% corn starch; 5) Miss 10, CGB from Stoneville with 10% corn starch; 6) Miss 55, CGB from Stoneville with 5% corn starch and 5% crude cottonseed oil; and 7) Guayule Mix, guayule bagasse (75%) mixed with Lbk 4 (25%).

Equipment and pellet processing

A schematic of the process used to produce the CGB fuel pellets used in this study is shown in Fig. 1. The raw material was loaded using pneumatic conveyors into a live-bottom bulk feed bin with five 9-in. augers. Upon exiting the feed bin, the gin by-products were sprayed with a gelatinized cornstarch solution. The starch in the COBY process is added in an effort to reduce abrasion on the processing equipment resulting from the raw material. The sprayed material was conveyed, in twin cut-and-fold mixing augers, to a side-feeder that force-fed the byproduct slurry mix into an Insta-Pro model 2000 extruder (Insta-Pro International, Des Moines, IA). The product exiting the extruder was conveyed to a belt drier where it was dried with 275°F air. Upon exiting the drier, the material was cooled and stored in totes. The material produced for each treatment was pelleted at a commercial animal feed manufacturing facility near Lubbock, Texas with a CPM 7000 series Pellet Mill (California Pellet Mill, Crawfordsville, Indiana). At the commercial facility, the raw material was force-fed into the pellet mill where the product was pelleted into 1-in long pellets, ¼-in in diameter. As the material was being fed into the pellet mill, water was added to help the material flow through the pellet mill and help form the pellets. The desired range of the moisture content of the material entering the pellet mill ranged from 15 to 20%. Upon exiting the pellet mill, the material fed onto a belt cooler, to a shaker table that removed fines, to a bucket elevator, to a finished pellet bin, and then bagged for storage. Each bag contained approximately 50 lb of pellets.

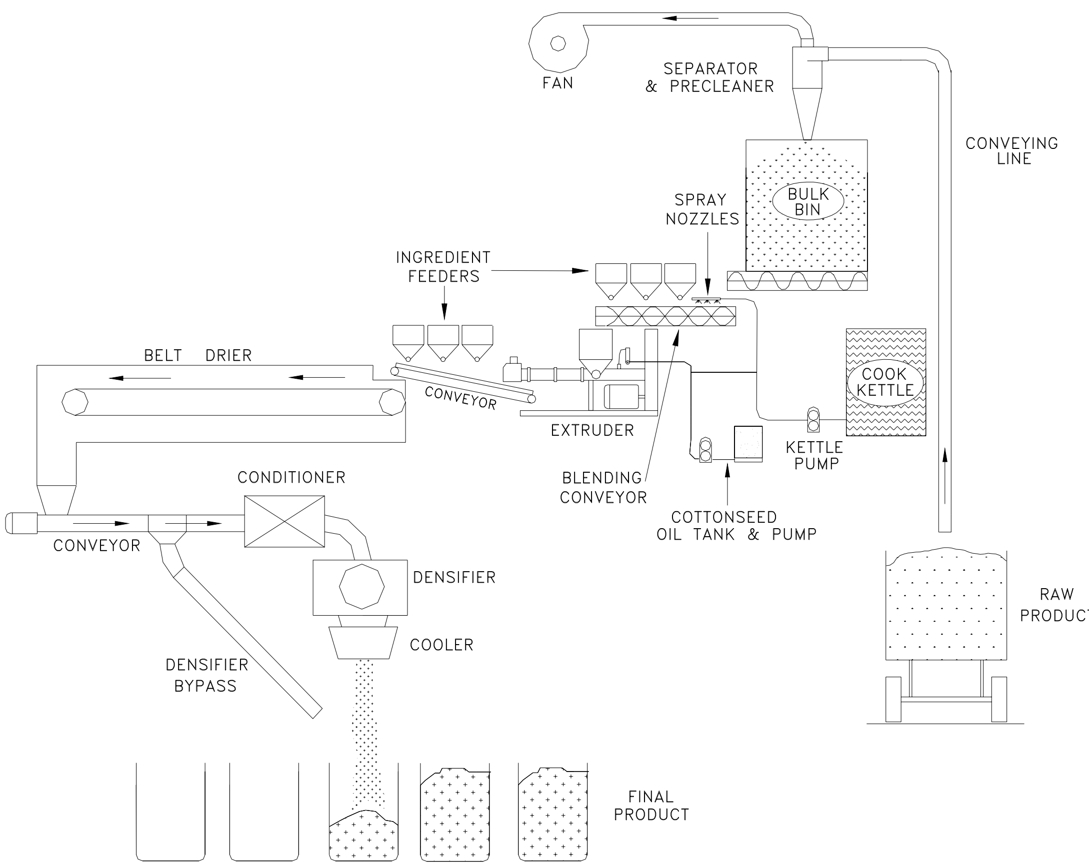

Figure 1. Schematic of the equipment used in the COBY process to produce the seven cotton gin by-product fuel pellets evaluated in this study.

The gelatinized starch slurry consisted of 1 lb of starch to every gallon of water in the cook kettle. The starch slurry was applied at a consistent rate via a piston pump driven by a direct current (DC) motor regulated by a closed-loop control system. The control system consisted of a flow meter with a 0 to10 VDC output signal to the DC drive regulating the speed of the motor driving the starch pump. The amount of gelatinized starch added to the by-products was 4 or 5% by weight of the raw material depending on the treatment. In the case of the 4% add-on, the amount of starch added for a bulk bin feed rate of 15 lb/min of by-products would be 0.6 lb/min. For the 10% starch treatments, 5% starch was added in gelatinized form and the remainder was applied through the dry ingredient feeders. The 5% corn starch and 5% crude cottonseed oil treatments were produced by applying 4% gelatinized starch, 1% dry starch, and 5% crude cottonseed oil. The cottonseed oil was injected into the starch line and applied through the starch spray nozzles. Water was injected as needed into the extruder barrel during processing. Starch, in the dry form, was added to help control the moisture content of the material exiting the extruder. The excess moisture is utilized by the dry starch and heat in the extruder causing the dry starch to gelatinize in the extruder barrel.

The feed rate from the bulk feed bin was determined from a mathematical relationship established before producing the pellets. A DC motor and drive was used to regulate the output from the bulk feed bin. The DC motor powered the feed bin augers through a 64 to 1 gear and sprocket reducer. Before processing the mulch, the raw material was loaded into the bulk feed bin and emptied at four different drive settings into a collection bin placed on a scale. The amount of material emptied during the 15 min of operation was recorded for each of the four settings. This procedure was repeated three times for each setting to develop the mathematical formula necessary to determine the raw material output of the bulk feed bin at various intermediate settings of the DC drive. Temperatures of the extruder were recorded from two type-K thermocouples placed within the thermocouple wells located on the extruder barrel. The desired temperature range of the material exiting the extruder was 219 to 241 °F.

Even though the extruder was not specifically needed in the manufacturing of fuel pellets, it was used to help condition and mix the CGB and ingredients prior to pelletization. It should be noted that the extruder is beneficial for improving digestibility (livestock feed) and sterilizing weed seeds (mulch), but is actually a hindrance for the production of fuel pellets. Ideally, to achieve maximum production rate, the material would be ground prior to the addition of starch and other ingredients and go through a mixer, conditioner, and into the pellet mill and forego the extruder altogether.

The Guayule Mix was produced by hand-mixing guayule bagasse with Lbk 4 material at a mixing ratio of 4 to 1prior to pelletizing.

Analytical Analyses

Once all the treatments had been manufactured, two 1 lb-samples were collected and sent to one of the laboratories randomly selected from the list on the Pellet Fuels Institute website (PFI, 2005). In an effort to eliminate any possible bias, each sample was labeled with a numeric code instead of names. A total of two measurements were made for each parameter measured.

Pellet stove burn tests

The Quadra-Fire Classic Bay 1200 pellet stove (Hearth & Home Technologies, Coleville, Washington) was used for the stove burn tests. Tests were conducted at the Coleville manufacturing facility using the Condar method (Barnett, 1985). The test method is a simplified variation of EPA Reference Method 5G (U.S. EPA, 1997). For each test, the stove's fuel supply hopper was loaded with pellets. The stove was activated and allowed to operate for not less than 15 min before starting the run and initiating the data acquisition and emission measurement systems. The delay was necessary so that the pellet stove would be operating under "normal" conditions while the emissions were being measured. The Quadra-Fire stove has an exhaust and convection fan with adjustable speeds. For testing, both fans were set on "high".

After the startup period, the data acquisition and emissions measurement systems were activated and the testing began.

Each test was performed for 1 h. The data acquisition system either recorded or calculated the following: (1) stack temperature, (2) oxygen (O_2) content of stack gas, (3) carbon monoxide (CO), (4) stack dilution factor, (5) burn rate, (6) heat transfer efficiency, (7) combustion efficiency, and (8) overall efficiency. The amount of particulate emitted was calculated after the test was completed and the filters recovered.

The gas analyzers were checked, before and after each run, for proper zero, calibration error, sampling system bias, and zero/span drift using certified calibration gases that covered the range of emissions measured. The calibration gases used for the analyzers were certified gases that were within 2% of the manufacturers tag value.

The fuel supply to the fire pot was turned off and the stove allowed to cycle down (i.e., turn off the convection blower) upon completing a test run, following the manufacturer's timeframe programmed into the stove's electronics. While the stove cooled down, the particulate filter was recovered and the data acquisition file checked for any data logging errors. After the stove had cycled down, all the unburned fuel in the pellet supply hopper and screw was removed. The next pellet fuel to be tested was placed into the stoves supply hopper and the process repeated, after the stove had been cleaned out and all pertinent data recorded.

Experimental design and analysis

The pellet stove burn testing was setup and analyzed as a randomized block design with day as the blocking factor. The treatments tested were: (1) Lbk 4, (2) Lbk 10, (3) Lbk 55, (4) Miss 4, (5) Miss 10, (6) Miss 55, (7) Guayule Mix, and (8) Wood. Each treatment was replicated at least two times. Standard analysis of variance was used to analyze the data to determine statistically significant differences among the eight treatments by the Ryan-Einot-Gaberiel-Welsch Multiple Range Test (SAS, 2003) at the 95% confidence level.

Results and Discussion

Analytical results

The analytical data (Table 1) show that the calorific value was higher for the Guayule Mix than for any of the other fuel pellets, even for the Lbk 55 and Miss 55 that had the addition of crude cottonseed oil. This is not surprising considering the addition of the guayule bagasse at 25% of the total mix compared with LBK 55 and Miss 55 with the crude cottonseed oil at only 5%. Even though the Guayule Mix treatment had a higher calorific value, the bulk density was similar to the Lbk 55 and Miss 55 pellets, which had the lowest bulk densities of all the treatments. The Pellet Fuel Institute specifies that pellets should have densities of 40 lb/ft^3. Both of the fuel pellet treatments with cottonseed oil were below the specified density. The reason for the low densities was due to the addition of oil at the same level as the starch. The starch acted as a binder for the CGB; however, the oil acted as a lubricant and restricted the adhesive properties of the starch. Thus, because the starch and oil were added at equal amounts (5%), the benefit gained from the cottonseed oil in calorific value was negated by the lubricity of the oil in terms of manufacturing a "quality" pellet. In reality, the ratio of starch to oil should have been around 2 (i.e., twice as much binder as oil) in order to produce a higher density pellet more in line with the PFI standard. Unlike the treatments with cottonseed oil, the Guayule Mix pellets had lower bulk densities primarily due to the lack of binder added to the Lbk 4 guayule bagasse mix. The only binder (starch) added to the Guayule Mix pellets was the starch contained in the Lbk 4 material. Thus, the amount of residual resin in the guayule bagasse along with the starch in the CGB were not enough to allow for a denser pellet to be manufactured using our equipment.

The ash content was higher in fuel pellets containing CGB than the premium grade wood pellet (Table 1). Even though the overall CGB fuel pellet ash content is 2 to 3 times lower than the ash content traditionally associated with "gin waste" (Domalski et al., 1986; Jenkins, 1993), it is still large enough to be a factor in pellet stoves that are not built to handle "high" ash fuel.

Table 1: Mean property values of seven fuel pellet treatments made from cotton gin by-products and guayule bagasse compared with a commercial wood pellet product.

Treatment	Bulk density (lb/ft^3) [a]	Calorific value [a] (BTU/lb)	Ash [a] (%)	Total sulfur [a] (%)	Total moisture (%)
	--------------------------------------Test Method [b]				
	E873	D5865	D1102	D4239	E871
Lbk 4	40.0	7,917	5.58	0.235	9.55
Lbk 10	42.2	7,865	5.22	0.165	8.84
Lbk 55	33.4	8,949	4.88	0.185	8.77
Miss 4	37.9	7,728	9.75	0.345	9.26
Miss 10	42.3	7,697	8.17	0.310	9.09
Miss 55	30.5	9,000	7.72	0.260	8.32
Guayule Mix	33.3	9,394	5.17	0.200	8.15
Wood	40.9	8,480	0.49	0.025	5.32

[a] Reported values are on a dry basis.
[b] Analytical methods specified are ASTM (American Society for Testing and Materials) procedures.

Pellet stove testing results

The results from firing the eight pellet treatments in a commercial pellet stove (Table 2) were significant for stack temperature, particulate emissions (PM), CO, combustion efficiency, and burn rate. No significant differences were noted for O_2 or heat transfer efficiency. For the PM emissions, wood had the lowest (0.10 lb/mmBTU) whereas Miss 10 had the highest (1.55 lb/mmBTU). These two treatments were the only ones where the PM emissions were significantly different from each other. The Guayule Mix had the second lowest PM emissions at 0.28 lb/mmBTU, which were 43% lower than the third lowest PM emission fuel pellet, Lbk 55. The CO emissions were lowest for the Guayule Mix (15.05 lb/mmBTU) and highest for Miss 55 (25.27 lb/mmBTU). Even though the wood and Guayule Mix pellets had the lowest CO emissions, they were not significantly lower than any other fuel pellet except Miss 55. Combustion efficiency was significantly higher for the wood pellets (96.8%) than for the Miss 10 pellets (83.5%), but not from any other treatment. The Guayule Mix had the second highest combustion efficiency (94.2%) whereas the Miss 55 treatment had the second lowest (84.7%). The fuel consumption, burn rate, during the testing was highest for Lbk 10 (5.21 lb/h) and lowest for Miss 55 (3.08 lb/h). The Guayule Mix pellets had the fifth highest fuel consumption during testing at 4.37 lb/h.

The fact that the emissions were higher for the CGB fuels than for the wood pellets is not surprising considering that the stove was setup and designed to burn wood without any adjustments for the other fuels with different burning characteristics. One item of interest was the extent to which the emissions exceeded those of the wood pellet. According to Moran et al. (2004), the critical factors for optimum burn are pellet feeding rate coupled with the correct amount of air. In this study, these factors were not regulated to optimize the burn rate.

Table 2: Mean measured and calculated parameters from burning eight fuel pellet treatments in a commercial pellet stove, used for residential heating, using the Condar test method.

Treatment	Average Measured/Calculated Parameters [a]						
	ST (deg. F)	O_2 (%)	PM (lb/mmBTU)	CO (lb/mmBTU)	CE (%)	HTE (%)	Burn Rate (lb/h)
Lbk 4	275.7 d	16.9	1.22 ab	21.38 ab	85.8 ab	69.7	4.53 abc
Lbk 10	294.0 bcd	16.1	0.76 ab	18.49 ab	89.8 ab	70.7	5.21 a
Lbk 55	290.5 bcd	17.0	0.65 ab	19.32 ab	89.8 ab	67.6	4.09 bc
Miss 4	279.0 cd	16.7	0.82 ab	21.14 ab	89.4 ab	69.8	3.91 cd
Miss 10	318.0 ab	17.1	1.55 a	22.94 ab	83.5 b	64.6	4.87 abc
Miss 55	283.0 cd	17.9	1.17 ab	25.27 a	84.7 ab	62.0	3.08 d
Guayule Mix	309.5 cb	16.6	0.28 ab	15.05 b	94.2 ab	67.8	4.37 abc
Wood	341.5 a	16.0	0.10 b	15.60 b	96.8 a	67.9	5.08 ab

[a] Column means followed by different letters are statistically different at the 0.05 level of significance. For columns without letters, there were no statistically significant differences. ST = Stack temperature, O_2 = Oxygen, PM = Particulate matter, CO = Carbon monoxide, CE = Combustion efficiency, HTE = Heat transfer efficiency.

Conclusions

This study was undertaken to address two primary questions: (1) can fuel pellets that meet industry standards be produced from cotton gin by-products (CGB) utilizing the COBY Process; and (2) when CGB fuel pellets made from this process are burned in a commercially available pellet stove used for residential heating, how would they perform compared to premium grade wood pellets. The results revealed that an acceptable fuel pellet could be produced from CGB, depending on the ingredients used and the method of manufacturing. However, when the fuel is burned in a commercial pellet stove without taking into consideration the air-to-fuel ratio necessary for change in fuel type, the emissions for all CGB fuel pellets exceeded those of the premium grade wood pellet used in this study.

Overall, CGB fuel pellets can potentially be a viable resource as a heating fuel. However, additional work is needed to determine the optimal burner settings necessary to minimize emissions and maximize performance. Also, the high ash content of the CGB fuel would limit its use in residential applications because the user would have to monitor the firepot and routinely empty it for the stove to work effectively for any length of time. Even though this fuel can be economically produced, it would not be prudent to produce the CGB fuel for consumer use until the ash can be reduced within reasonable limits (< 3%). The ingredients and processing of the fuel must be further refined to the point where a consistent product, can be produced. Likewise, the operational settings of the pellet stove for combustion of such fuel must be developed. It would be ideal if a pellet stove was manufactured so that the air-to-fuel ratio could be adjusted to the fuel being burned.

The results from this study indicate that a promising fuel pellet can be produced from blending guayule bagasse with CGB. The emissions from firing the Guayule Mix fuel were the lowest of any of the CGB treatments as well as being closest to the wood pellet emissions. However, the Guayule Mix pellets still had a high ash content that would need to be addressed by refining the final extraction process. The approach of blending one biomass to make up for the potential shortcomings of another biomass is one of the items that arose from this study. Future investigations involving fuel pellet fabrication from CGB will focus in one of the following areas: (1) assisting stove manufacturer's in modifying or developing a stove to accommodate biomass fuel pellets that have differing fuel properties from conventional wood pellets, (2) refining the CGB process to minimize the ash content of the fuel, and/or (3) evaluate blending other biomasses (wheat stubble, cottonseed hulls, etc…) with CGB to develop a fuel which can more readily be used in the existing pellet stoves currently available in the marketplace.

Acknowledgement

The partial support of this research by Cotton Incorporated is gratefully acknowledged.

Disclaimer

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