The University of Texas at Austin, Department of Mechanical Engineering

Viability of sawdust briquettes for rural Ghana

Honors Thesis

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5/25/2011

Contents

ABSTRACT

The growing demand for solid fuels in the developing world has begun to place enormous pressure on natural resources with an especially heavy toll on the forests of sub-Saharan Africa. The main energy sources for much of the developing world are scavenged wood and charcoal. These fuels contribute heavily to indoor air pollution causing 1.6 million deaths annually. In this study we look at the possibility of using waste sawdust from the timber industry as a potential fuel source. We saw that under modest pressure (achievable using hand presses) one can make a durable sawdust briquette capable of withstanding manufacturing, transportation, and final use. These results show promise in the field of biomass briquetting; we can see that high pressure methods that require costly capital investment are not necessary to create a reliable fuel from biomass waste.

INTRODUCTION

FUELS IN THE DEVELOPING WORLD

Around the world an immense portion of the population relies heavily on combustion of charcoal or biomass for cooking and heating purposes. Approximately 50% of the world's households rely on unprocessed solid fuels for cooking and heating; this number reaches approximately 80% in the developing world [1, 2]. In the developing world, people often turn to the forest to meet their energy demands. In some parts of Africa fuel wood consumption is 30,200% the natural replacement rate [3]. In the last decade, demand for fuel wood increased to 1.55 billion cubic meters per year [3]. This puts strain on the environment and leads to deforestation, soil erosion, and desertification [3]. In order to combat these growing problems, technological and culturally sensitive solutions need to be put in place to curb the use of non-renewable resources.

One solution currently being implemented in dozens of countries are more efficient cook stoves. These cook stoves increase the combustion efficiency and subsequently reduce the total demand of fuel. In Ghana, the Gyapa cook stove is a common improved cook stove that is being sold in rural areas where people rely on fuel wood and charcoal to cook. These cook stoves are a step in the right direction, however their efficiencies still have much to be desired of. In fact, one study found that of the fourteen improved cook stoves tested, only three functioned more efficiently than a traditional three-stone fire [4]. This study shows the reason that many cook stove programs around the world have failed after a very short period of time. Another drawback of the cook stove is that users must still rely on fossil fuels or nonrenewable forests in order to obtain fuel. In order to supply this energy without placing further strain on the ecosystem we must search for more sustainable fuel sources.

ALTERNATIVE FUEL SOURCES

One solution to the energy/environment problems in the developing world and the focus of this paper is to turn to more sustainable fuel sources. In particular, to use agricultural biomass wastes to produce a fuel that will be comparable to the existing fuel wood and fossil fuels. In Ghana, the timber industry presents just such a waste product: sawdust.

Timber is the leading export of Ghana; in 1990 approximately 1.36 million m^3 of log production was recorded [5]. During processing, however, roughly 55% of the timber collected becomes a waste product. Of this, 21% is in the form of sawdust, which presents a fire hazard for saw mill owners and must be disposed of in a controlled way [5]. The sawdust is typically transported off the sawmill site or locally burned, leading to pollution [5]. Converting the sawdust into a viable fuel source for improved cook stoves would not only provide a much needed fuel source but would also decrease the burden of waste sawdust on saw mills and decrease the amount of pollution caused from the current disposal of the sawdust.

In this study, we focused on the potential use of the sawdust, currently not being used, in order to create briquettes that could be used in existing Ghanaian cook stoves.

INDOOR AIR POLLUTION

A major contributor to the burden of disease in the developing world is indoor air pollution. Furthermore, a large portion of this pollution comes from the combustion of biomass and charcoal for use in cooking and heating. In 2000, it was estimated that over 1.6 million deaths were caused by the combustion of solid fuels for cooking and heating [6, 7]. This burden of disease is also highly skewed toward women and children, who are more likely to spend large time spans in close proximity to these burning fuels [7]. Figure 1 shows the distribution of deaths related to indoor air pollution across the world. One can see that the developing world, where solid fuel cooking/heating are common, are disproportionately affected.

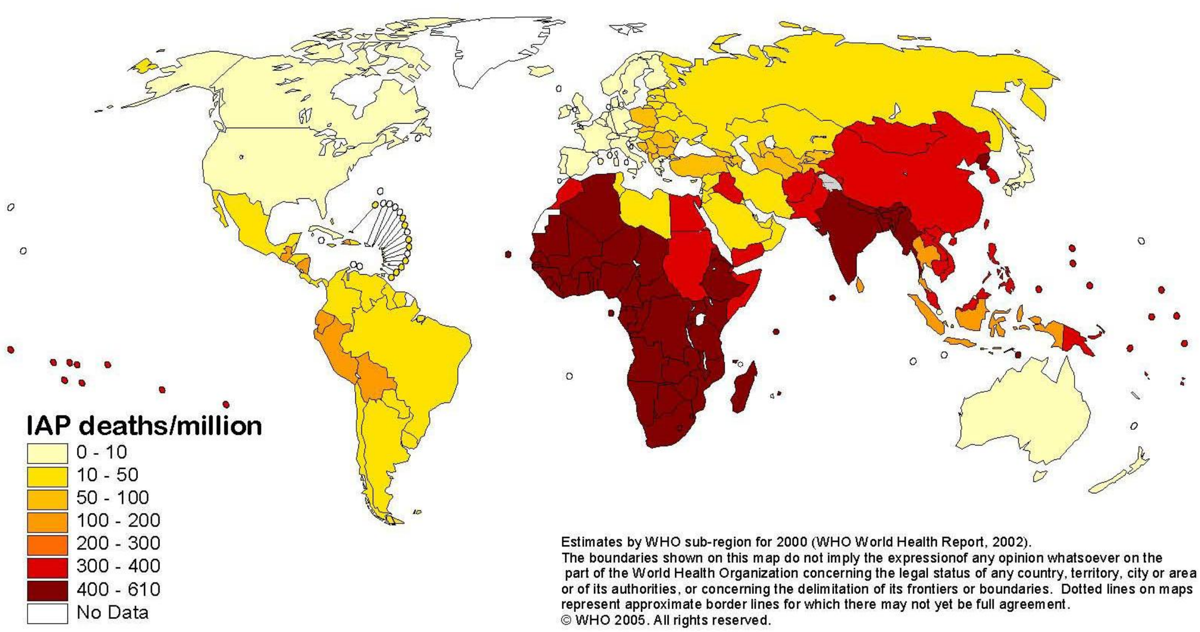

Figure 1: Distribution of deaths attributed to indoor air pollution [7]

There are several pollutants produced in the combustion of biomass and charcoal. The major hazardous pollutants include particulate matter, carbon monoxide, nitrogen dioxide, sulfur oxides, formaldehyde, and polycylic organic matter [8-10]. In 2000, it was estimated that between 1.5 and 2 million deaths were caused by indoor air pollution from biomass and charcoal combustion (roughly 4-5% of worldwide mortality) [7, 11]. For these reasons, preventing indoor air pollution has become a priority for many international development agencies and national health organizations.

Improved cook stoves represent part of the solution to indoor air pollution. Figure 2 shows the reduction in CO (carbon monoxide) and $PM_{2.5}$ (particulate matter less than 2.5 micrometers in diameter) obtained through the use of the Gyapa improved cook stove. However, comparing these emissions to the Air Quality Standards of the U.S. Environmental Protection Agency quickly demonstrates that the pollution is well above healthy levels. For example, the EPA suggests the $PM_{2.5}$ count be under 35 μg/m^3, where as a household using an improved cook stove will have $PM_{2.5}$ levels in excess of 250 μg/m^3 [12, 13]. It is clear that improved cook stoves alone cannot solve the indoor air pollution problems of developing nations. Minimizing these harmful combustion by-products should be a priority when developing alternative fuel sources.

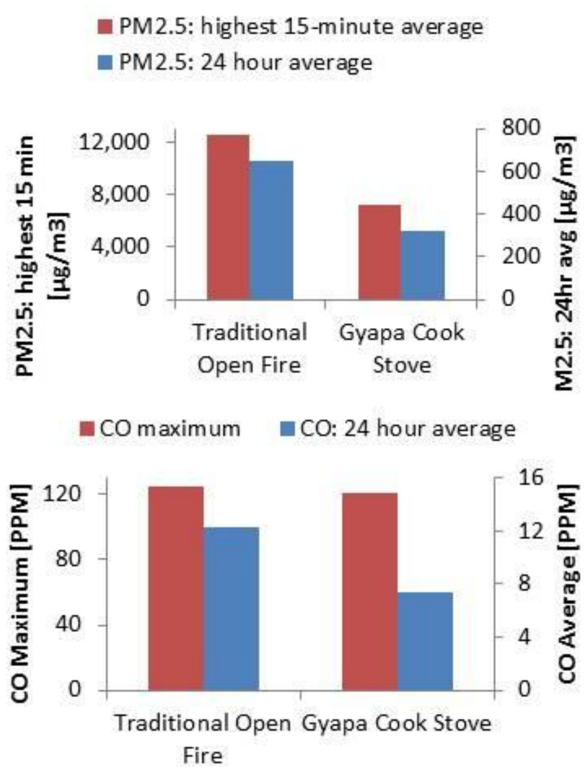

Figure 2: Reduction in emissions when using an improved cook stove compared to a traditional three stone fire [6]

Technical Background

Several studies have been conducted in regards to the densification of biomass for fuel purposes. Most studies, however, have been focused on high pressure compaction present in industrial presses. These studies have used standard ram/piston presses in order to briquette the biomass. The briquettes were then studied for their relaxation behavior, durability, compressive strength, water resistance, and combustion profiles. Fewer studies have been conducted in the range of pressures that can be achieved by a hand press. These studies focused on pressures between 5 and 7 MPa; looking at the relaxation behavior, mechanical strength, and burning characteristics of the briquetted materials.

Studies focusing on high pressure application have ranged in pressures from 20 to 1,000 MPa [14-18]. These studies have shown the behavior that different biomass substances exhibit after biomass briquetting; studies have involved olive refuse, paper mill waste, sawdust, wheat straw, tea waste, straw, etc. Important conclusions have been the presence of a pressure plateau, above which the bonding properties of the briquettes do not significantly improve [17]. Determining if this plateau exists in low pressure applications would be of interest. It was also shown that certain biowaste was not suitable for briquetting, even under high pressures; olive refuse exhibited a mechanical strength that was too low to be considered a viable fuel without the use of a binder to hold the biomass particles together [16]. These studies have been useful in determining which agricultural waste products could be used in industrial ram/piston or screw presses. However, the high capital investment and maintenance expertise associated with industrial briquetting have led to a series of failed programs in developing nations [19].

Fewer studies have focused on low pressure briquetting achievable during hand pressing. A study by Chin et al. (2000) found a distinct plateau at approximately 4,000 kPa of briquetting pressure, above which the improvement in briquette properties became minimal. This study investigated sawdust, rice husk, peanut shell, coconut fibre, and palm fibre as briquetting materials. The sawdust was found to have the best briquetting properties [18]. The results of this study reinforced the use of sawdust as the raw material for the current investigation.

Methodology

In order to determine if the sawdust could be briquetted into a viable fuel source several tests were conducted to quantify the durability and combustion characteristics of the briquettes. Testing was also done in order to compare the briquettes to the traditional fuel sources of scavenged wood and charcoal.

Briquette Formation

In order to perform both combustion and durability testing, two briquette shapes were created: disc and slab. The disc shapes represent the type of briquette that would eventually be used in cook stoves. This briquette was used during the durability and outdoor combustion testing. The slab shape was created in order to have an appropriate platform to perform the combustion rate and temperature testing. It allowed for sufficient quantities of thermocouples to be inserted at appropriate distances to ensure repeatable results.

The briquettes were pressed using a hand press that was designed and constructed by a senior design team in the Mechanical Engineering Department at The University of Texas at Austin. The press, which can be seen in Figure 3, was made in order to simulate the kind of pressures attainable using only manual power. It consisted of a screw press and a pressure sensor providing accurate production data. The discs were formed in a perforated PVC pipe that allowed for excess water to drain away and multiple briquettes to be formed at the same time. The slabs were formed in perforated wood mold and produced individually.

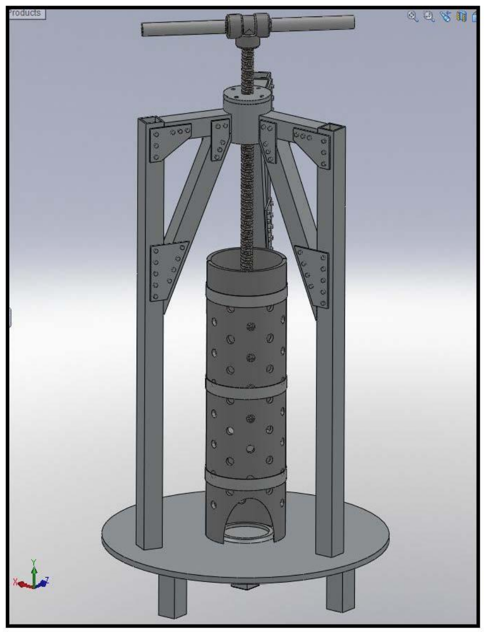

Figure 3: CAD drawing of the laboratory press

Combustion Testing

When considering the potential for a cooking fuel, two factors become most important: burn temperature and burn rate. The best fuel will have a high burn temperature and a slow burn rate. Charcoal is a popular cooking fuel because, once lit, it will burn at high temperatures for an extended amount of time without needing to add fuel or be attentive to the fire.

Laboratory Combustion Testing

In order to determine the burn rate of the briquettes the test setup shown in Figure 4 was constructed. This testing method involved creating the briquettes in a rectangular slab shape. The briquette was placed on a cement base with cement blocks on both sides. The air flow was forced from one end to the other, in order to have more repeatable testing procedure. The briquette was then ignited at the front using a heating coil and power supply, resulting in a defined and consistent combustion plane. Thermocouples were brought up through the cement base, laying in a line perpendicular to the plane of combustion at 1.5" intervals. These gave clear temperature readings for the combustion front, and also allowed for the determination of the burn rate as a function of the speed of the combustion front. Video, taken directly from above, and visual measurement markers were also used to determine the propagation speed of the combustion front.

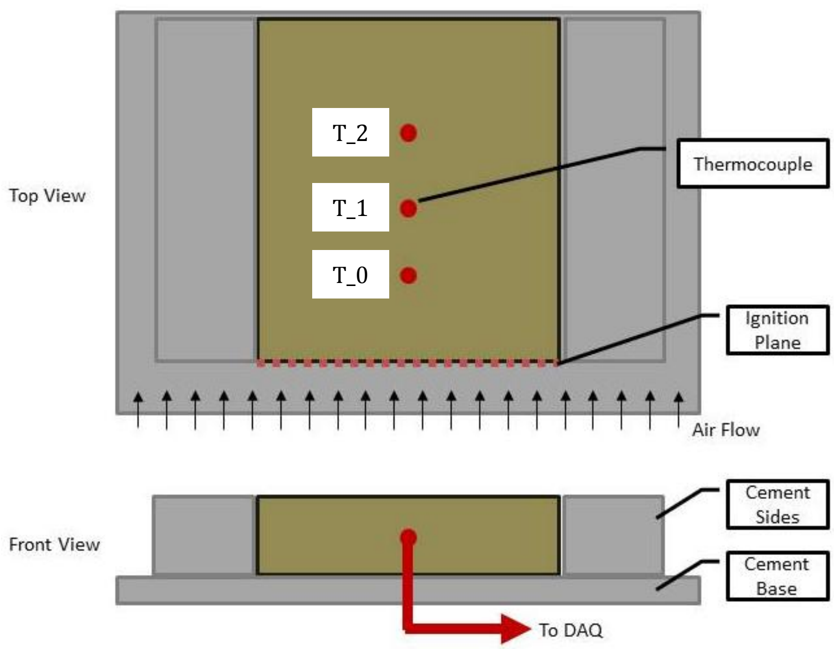

Figure 4: Laboratory combustion setup used to determine that combustion temperature and combustion rate

Outdoor Combustion testing

In order to compare the briquettes to the standard fuels of scavenged wood and charcoal, outdoor tests in a Ghanaian improved cook stove were conducted. Outdoor testing would provide the most realistic environment for the end use of the briquettes. The test conducted was a simple water heating test [20]. A predetermined mass of fuel was placed into the combustion chamber of the cook stove and ignited using an electric resistance heater, turned on for a specific amount of time. Thermocouples took the temperature of the water and fuel bed over the course of the test. The most effective fuel would be the one which achieved the highest temperatures and over the longest time.

Durability Testing

In order to serve as a viable fuel source, sawdust briquettes would need to be durable enough to withstand production, transportation, and final use. Therefore, the durability of the briquettes was studied using a shatter index test.

Shatter testing

The shatter test used was the ISO-R 616. The test involved dropping the briquettes from a specified height onto a steel plate. The dropped briquettes were then placed on sieve and the percentage of mass retained was measured. The process was repeated until all the pieces of the briquettes passed through the sieve. The percentages were then summed together to form the shatter index of the briquette. A higher shatter index represents a more durable briquette.

RESULTS AND DISCUSSION

The results of several rounds of durability and combustion testing are shown below.

COMBUSTION TESTING

LABORATORY COMBUSTION TESTING

Several rounds of laboratory combustion testing were performed. These tests were necessitated by the fact that the outdoor tests were not able to capture the combustion characteristics of varying briquette densities

During these tests the only parameter changing was the density of the sawdust briquette. The burn rate and burn temperature were then captured in order to determine how important density was in the combustion characteristics.

The temperature profiles of the various densities (0.15, 0.23, & 0.30 g/cm^3) can be observed in Figure 5. In Figure 5 one can see the time at which the combustion front reached the final thermocouple. We can see from this that the difference between the densities lies in the burn rate and not the burn temperature. One can see that as the density of the sawdust increases, the combustion front takes significantly longer to reach the final thermocouple. The corresponding temperature profiles for the front and middle thermocouples can be found in Appendix A.

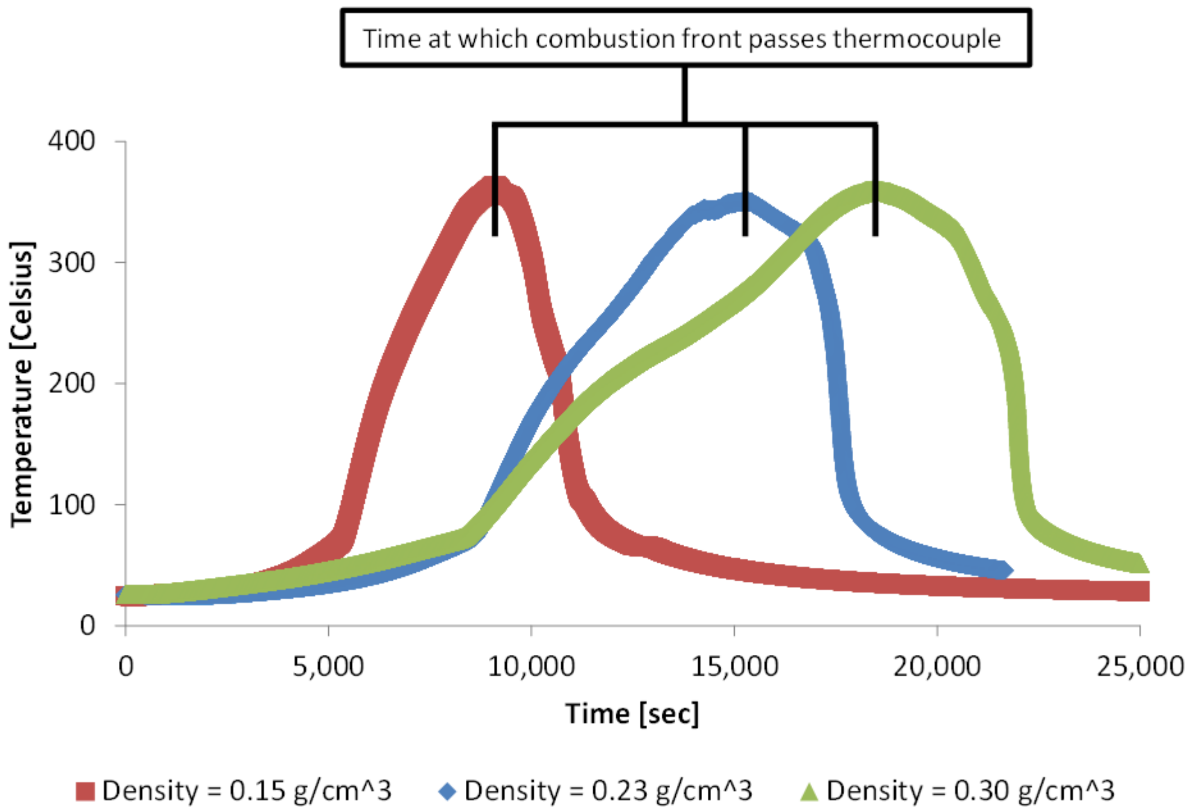

Figure 5: Difference between temperature profiles of the final thermocouple between the varying sawdust densities

The differences in the combustion characteristics are captured in Figure 6 and 7 where we can see that the temperature variance is insignificant between tests while the burn time increases substantially with increasing density. These figures show that in order to create the most effective fuel we would want to increase the density of the briquettes as high as possible; which would provide longer combustion times. Increasing the combustion temperature, however, would require a material property to be changed.

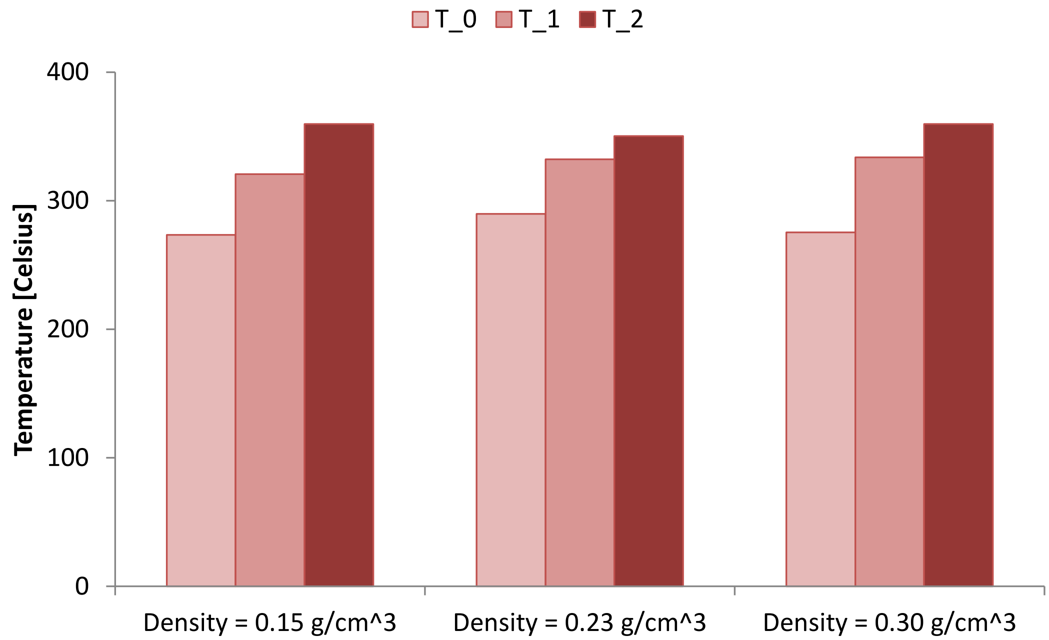

Figure 6: Combustion temperatures for the varying sawdust densities. T_0, T_1, & T_2 represent the front, middle, and back thermocouples respectively in the laboratory combustion setup

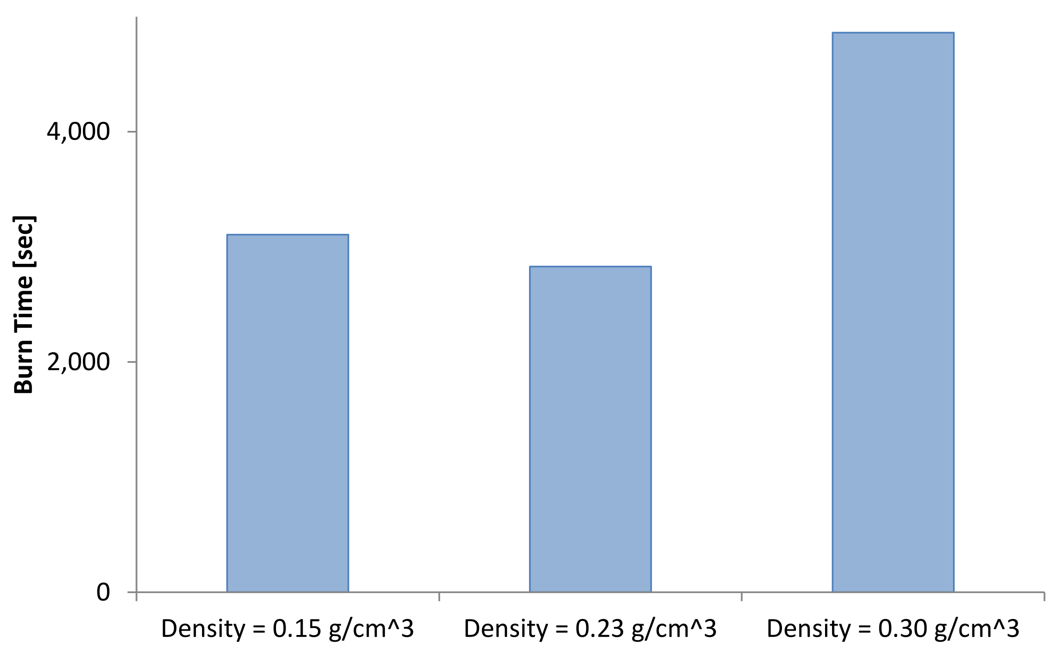

Figure 7: The time taken for the combustion front to proceed from the front thermocouple to the back thermocouple in the laboratory combustion setup

Outdoor Combustion Tests

The results of the outdoor combustion tests can be seen in Figure 8. It shows the water temperature profile using various fuel types: charcoal, sawdust briquettes, wood, and loose sawdust. Higher and sustained temperatures indicate the most effective fuel. One can see that the sawdust briquettes performed very well in comparison to both the charcoal and the scavenged wood. Each fuel had distinctive characteristics. The wood which burned completely in the flaming combustion regime produced high temperatures quickly, but for the shortest time span. The charcoal and the sawdust briquettes had similar profiles, achieving high temperatures less quickly than the wood, but sustaining them for a longer period. The loose sawdust produced low temperatures and did so at a very slow rate.

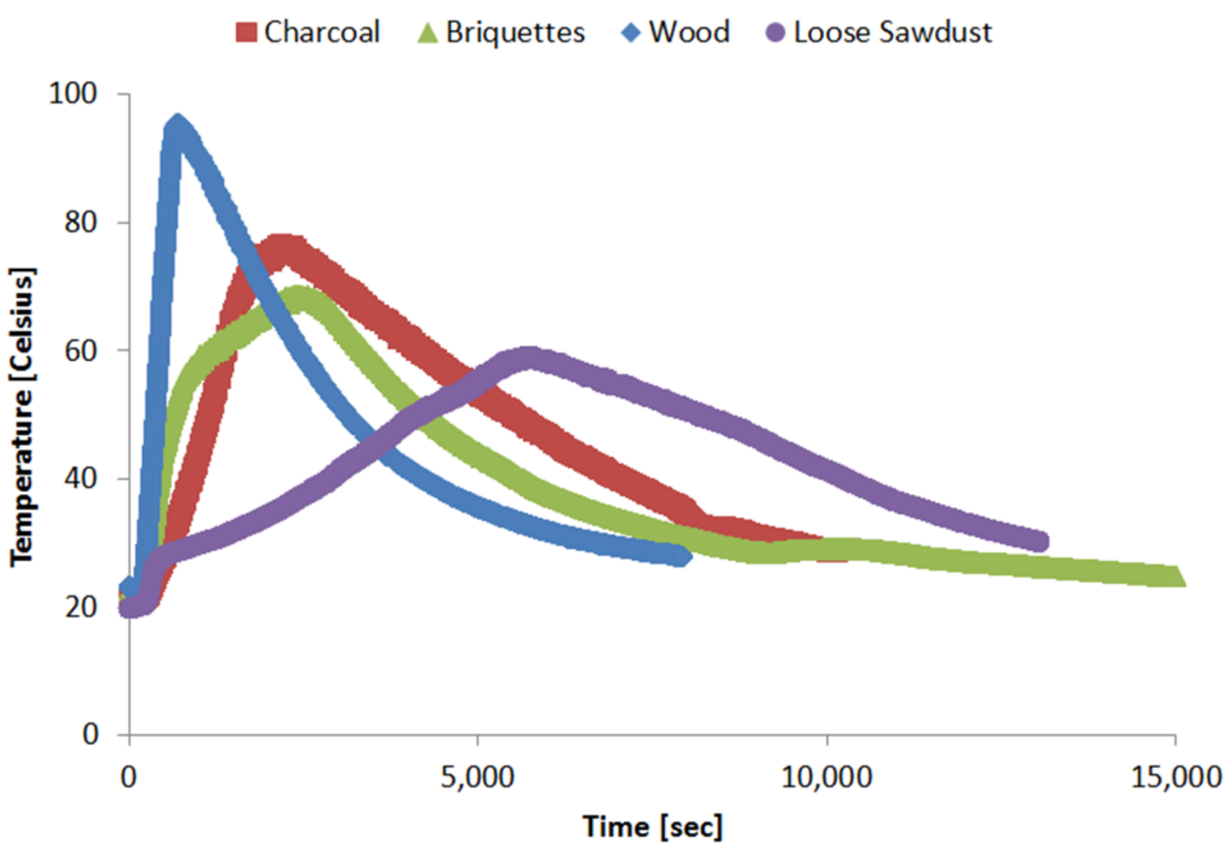

Figure 8: Water temperature profiles for varying fuels in outdoor tests

The results of Figure 8 are summarized in Figure 9 which shows the maximum water temperatures achieved and the time needed to reach them. The wood and charcoal achieved water temperatures 39% and 11% higher than the briquettes respectively. One can also see that the wood achieved this elevated temperature much more rapidly than the briquettes and charcoal. However, from Figure 8 we see that the wood exhausted all its energy in a short time, while the charcoal and briquettes were able to sustain high temperatures for a longer period.

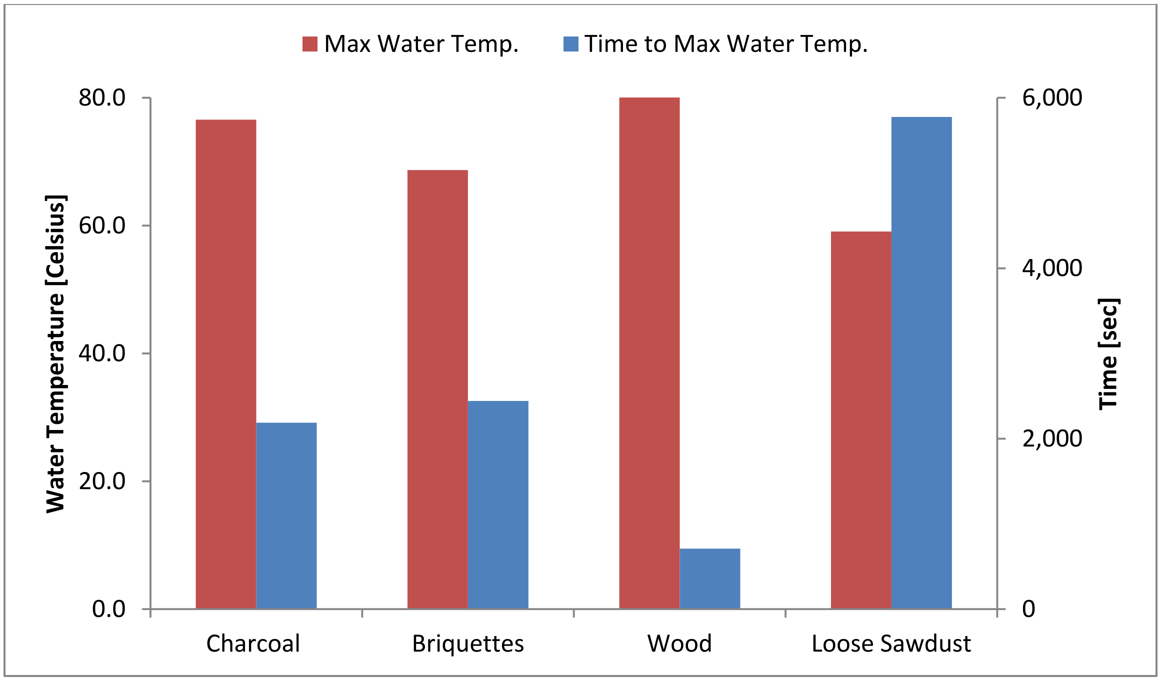

Figure 9: Summary of water temperature results in outdoor tests

Figure 10 shows the maximum temperatures (of the two thermocouples) achieved in the combustion bed. One can see that there is almost no difference between the maximum temperatures achieved in the combustion bed between the charcoal, the sawdust briquettes, and the wood.

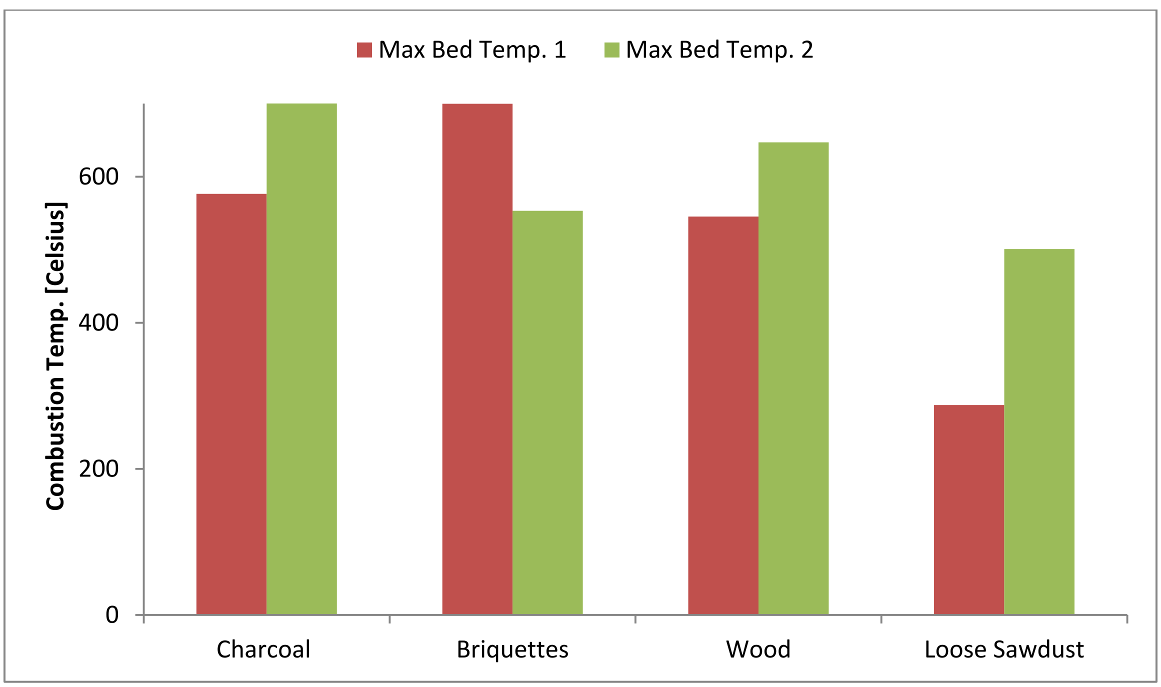

Figure 10: Maximum combustion bed temperatures during outdoor tests

Durability Testing

The ISO-R 616 was used to quantify the durability of the various briquettes. Below, Figure 11, we see the first round of testing for durability. This first round was used to compare the yucca and newspaper binders. These two materials have been used as briquetting binders for other biomass materials, and therefore were studied here. The shatter index was a method of qualitatively comparing briquettes, from which one can obtain which briquettes were more durable relative to each other. One can see that using shredded newspaper (allowed to soak in water for several days) as a binder resulted in the most durable briquettes. In fact, they obtained the highest level of durability measured by the shatter index. These briquettes, with newspaper binder, did not ever fall apart during the drop tests. The yucca binder provided a significant increase over using only sawdust, a ten-fold increase. These briquettes, however, broke down into small fragments after various drops. The yucca binder also required the boiling of the yucca root in order to break it down into a paste like substance. This extra effort and energy in production along with the fact that yucca is a very common food in Ghana would make it difficult to justify its use as a binder.

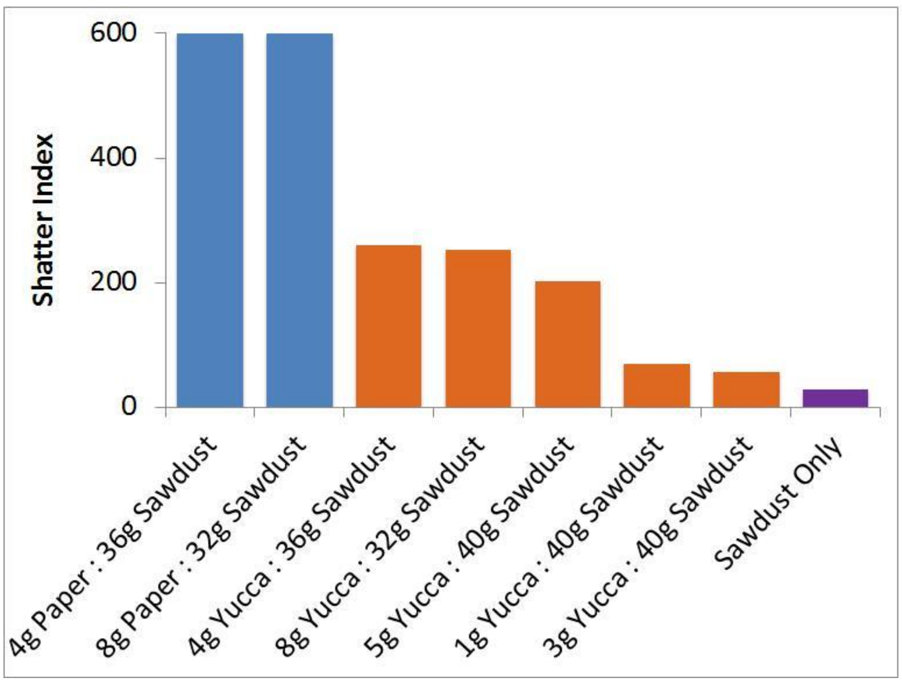

Figure 11: Results from first round of durability tests

In the second round of durability testing the newspaper content of the briquettes was varied. The results are shown in Figure 12. From this figure we can see that the durability of the briquettes steadily increases with the percentage of newspaper used. This means that the actual paper binder content will need to be determined onsite, based upon the transportation/handling needs of the users. Figure 12 also shows that the paper content had little effect on the density of the final briquettes; meaning that other factors would need to be adjusted in order to achieve higher density briquettes.

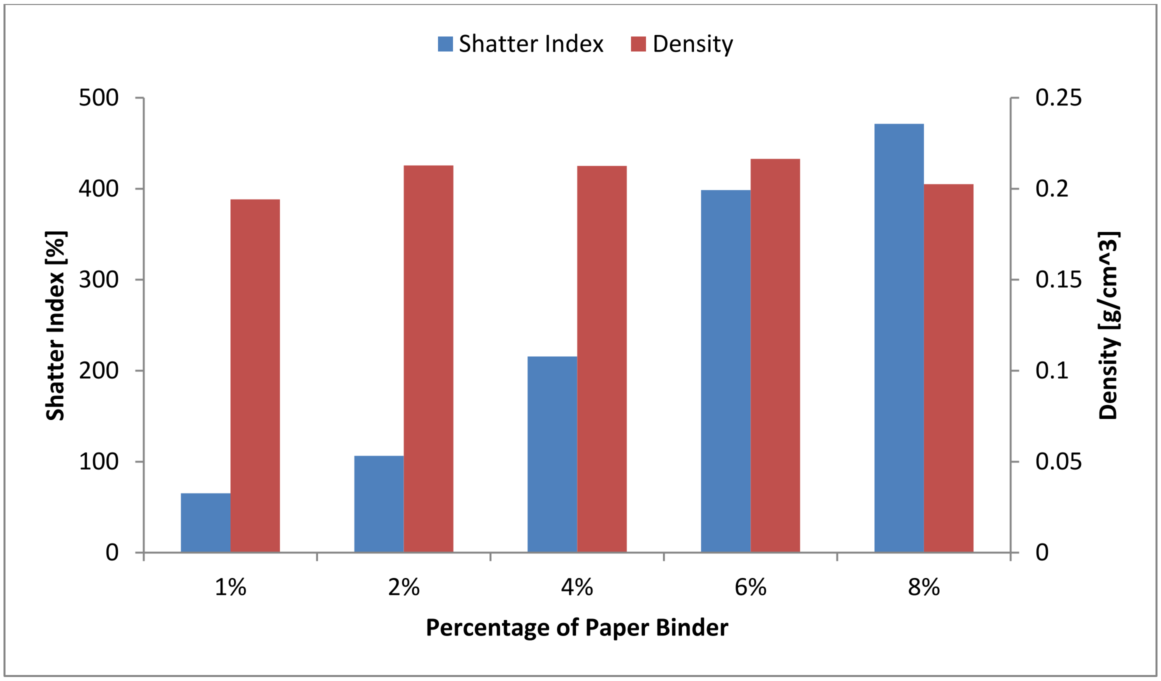

Figure 12: Results from second round of durability tests also showing densities achieved

CONCLUSIONS

This study resulted in several interesting findings that could be used to develop sawdust briquettes in Ghana and other locations where this waste product is readily found.

The fact that durable briquettes can be created using only sawdust and paper is an encouraging fact. Based upon the research performed in this study, one would expect these briquettes to be manufactured, transported, and used in a simple and hassle-free manner. The ability to bind together the sawdust particles into a solid fuel at low pressures signifies that this could be a viable fuel source for rural locations adjacent to large timber processing facilities.

The combustion testing showed that increasing the density of the products significantly increased the combustion time of the briquettes. A longer combustion time would mean that the user would need to replace the briquettes less frequently; which makes the fuel more attractive. The increased density, however, did not increase the burning temperature of the sawdust. The burn temperature is a material property that is unaffected by the density. The outdoor testing showed that the briquettes burning characteristics were comparable to that of charcoal. They provided high temperatures over a sustained period.

The results of combustion and durability testing showed that sawdust briquettes can be manufactured and used in place of wood or charcoal without significantly affecting one's ability to cook or heat.

Future Work

This study addressed two key issues associated with converting loose sawdust into a viable solid fuel: durability of the briquettes and combustion characteristics of the sawdust. However, an equally important factor is the combustion by-products that are released during use of sawdust as a fuel. Solid fuel combustion contributes significantly to indoor air pollution and the global burden of disease. The potential health effects of introducing the sawdust as a fuel need to be addressed before it is appropriate to recommend sawdust briquettes as an alternative to scavenged wood and charcoal. A thorough analysis of the emissions involved in combustion of sawdust briquettes needs to be performed.

Other factors that also need to be addressed include how the following factors affect the durability and combustion of the briquettes: humidity/water content, foreign debris inside the briquettes, varying sawdust types, sawdust particle size, and large scale production.

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APPENDICES

APPENDIX A: LABORATORY COMBUSTION TESTS

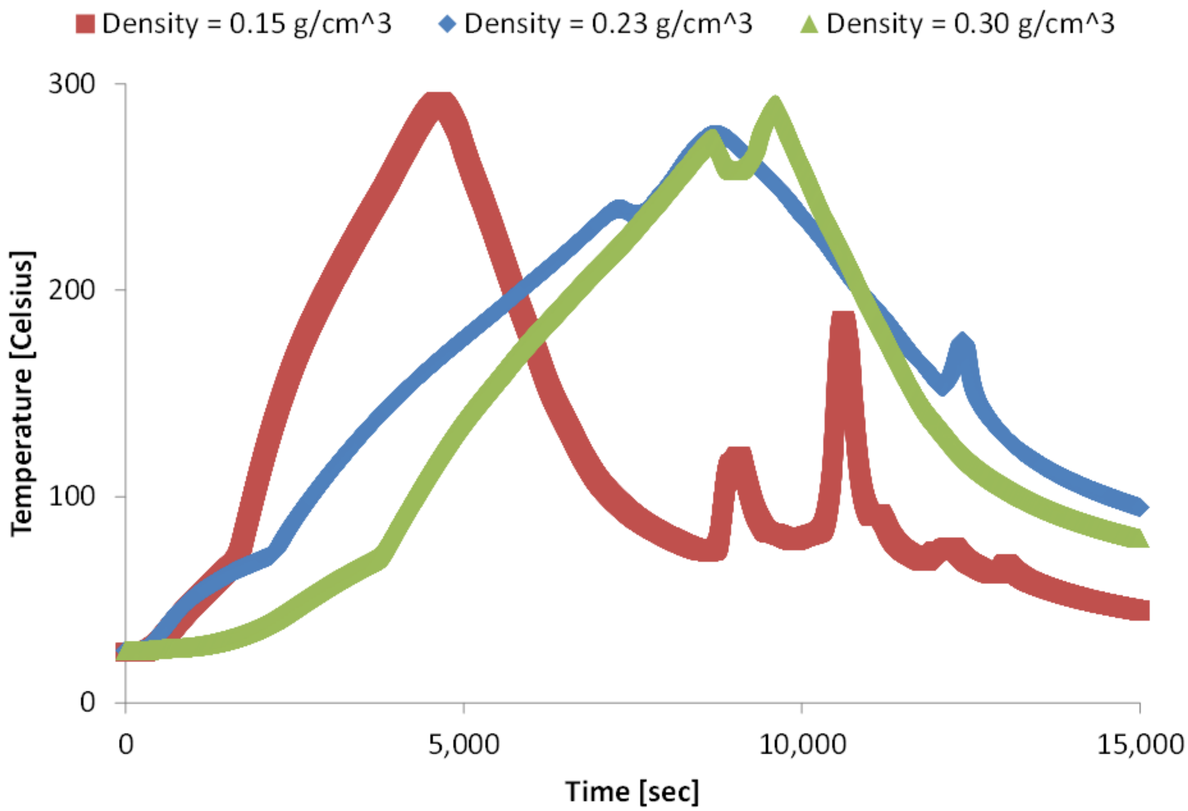

Figure13: Temperature profile differences of the front thermocouple between the three sawdust densities

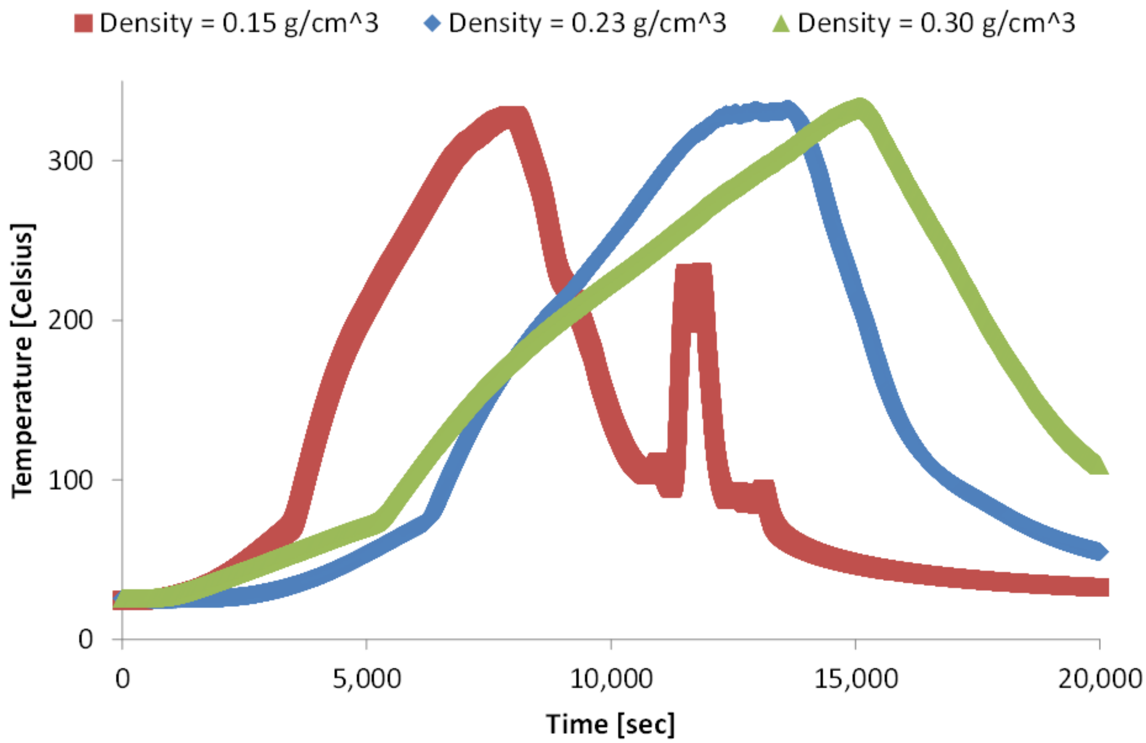

Figure 14: Temperature profile differences of the middle thermocouple between the three sawdust densities

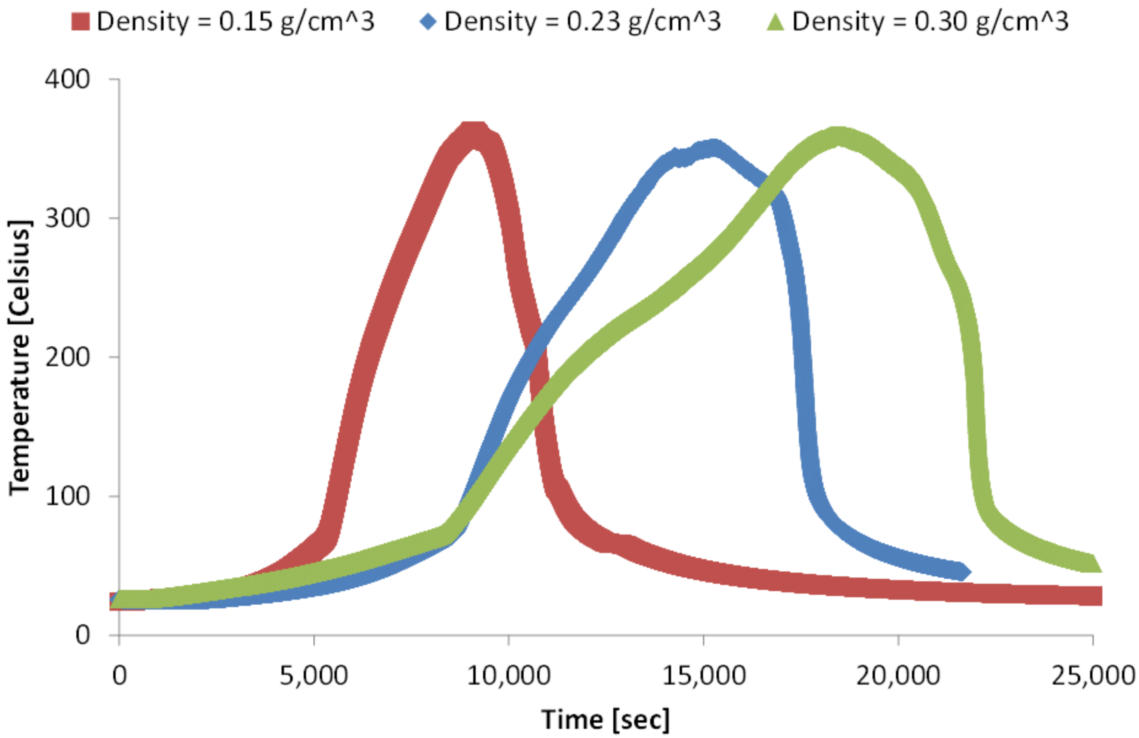

Figure 15: Temperature profile differences of the front thermocouple between the three sawdust densities

APPENDIX B: OUTDOOR COMBUSTION TESTS

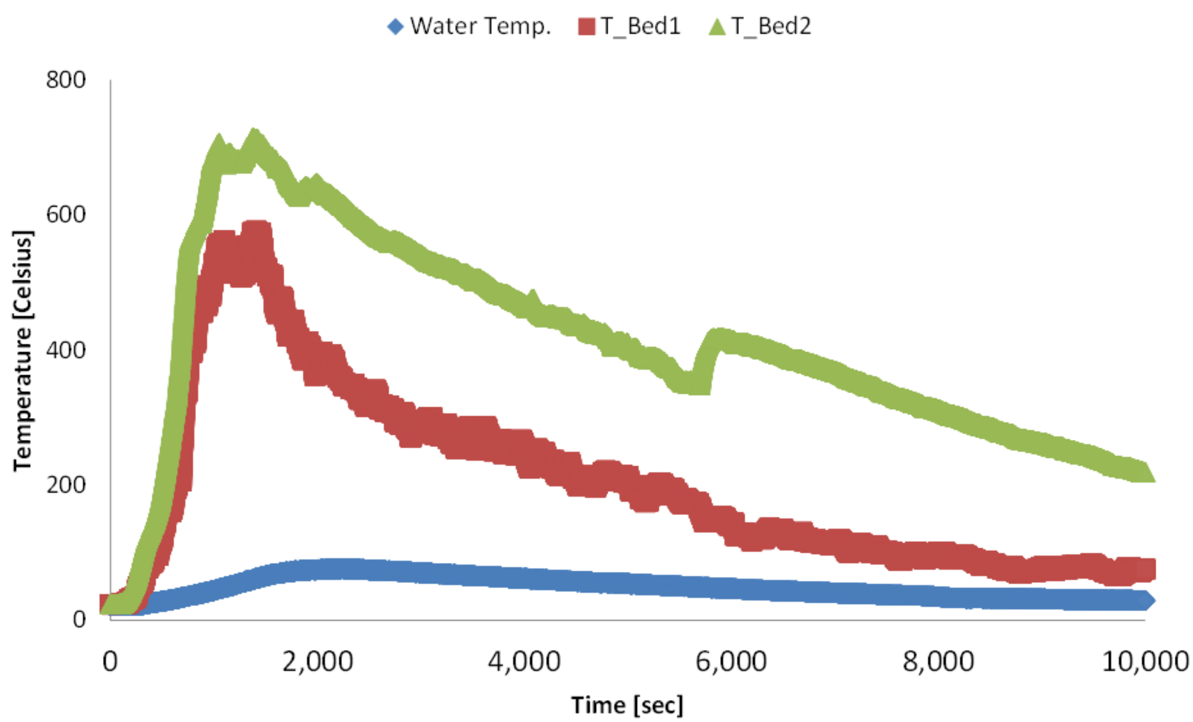

Figure 16: Temperature profile during outdoor combustion test using charcoal

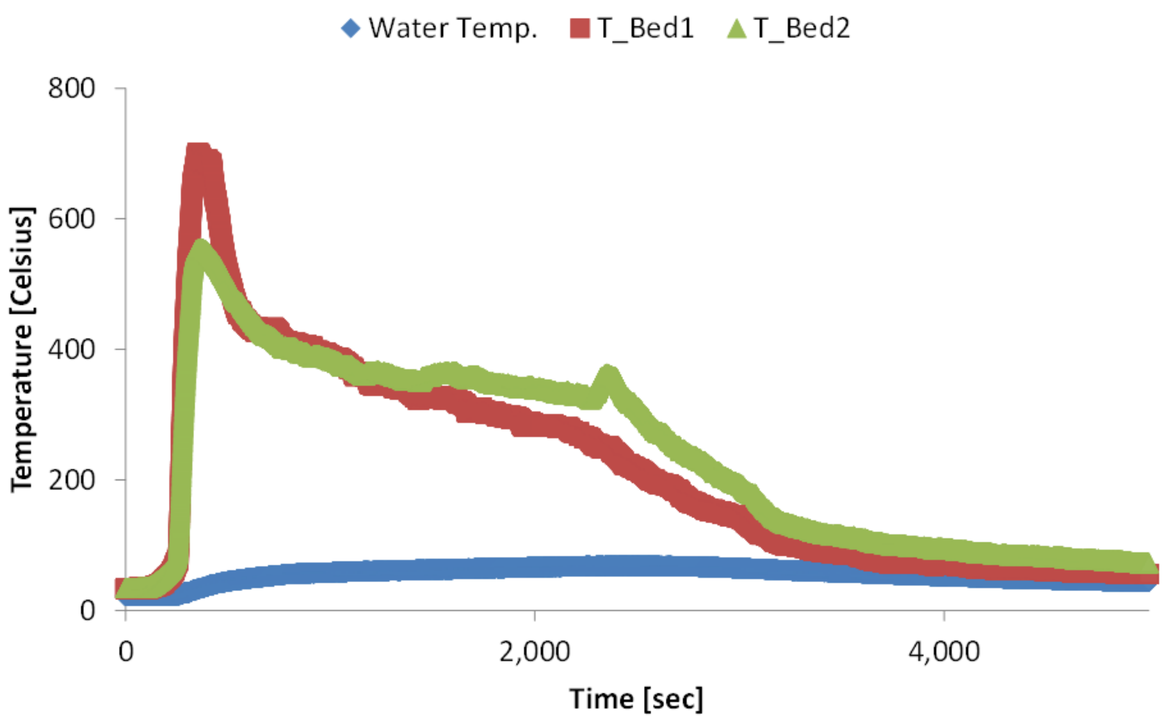

Figure 17: Temperature profile during outdoor combustion test using sawdust briquettes

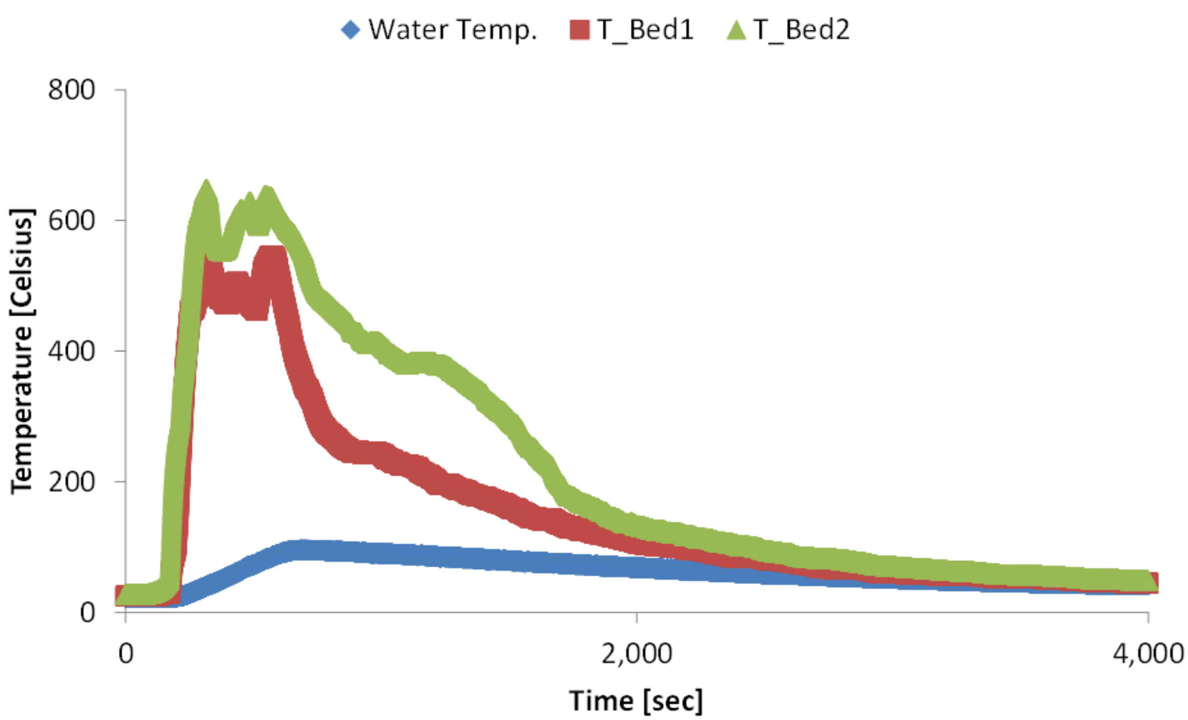

Figure 18: Temperature profile during outdoor combustion test using wood

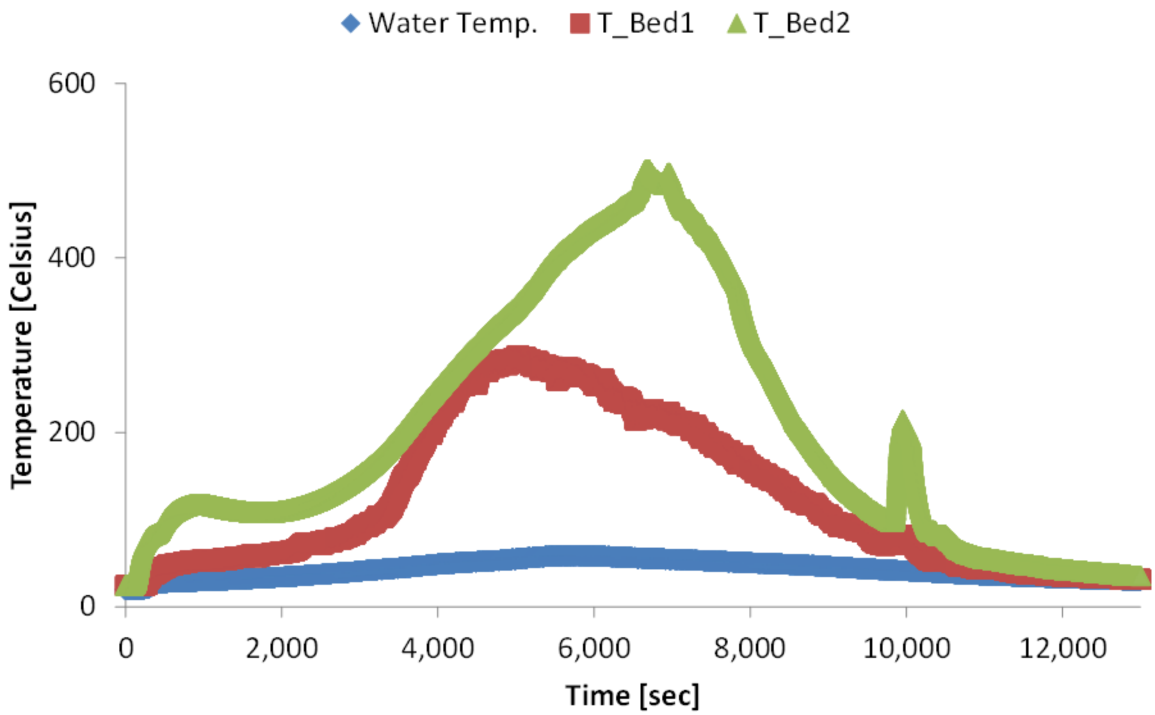

Figure 19: Temperature profile during outdoor combustion test using loose sawdust

Appendix C: Durability Testing

Table 1: Data from the first round of durability testing

Briquette	Pressure	Dwell Time	Sawdust	Yucca Binder	Paper Binder	Note	Shatter Index	Average Shatter Index	Mass	Diameter	Height	Density
[#]	[kPa]	[min]	[g]	[g]	[g]		[%]	[%]	[g]	[in]	[in]	[g/cm^3]
1	7000	1	36	0	4	48 hr soak	599		39.2	3	1.4	0.24
2	7000	1	36	0	4	48 hr soak	600	599	39.3	3.1	1.4	0.23
3	7000	1	36	0	4	48 hr soak	599		38.3	3.1	1.4	0.22
4	7000	1	32	0	8	48 hr soak	600		39.9	3	1.3	0.26
5	7000	1	32	0	8	48 hr soak	600	600	39.7	3.1	1.4	0.23
6	7000	1	32	0	8	48 hr soak	600		38.7	3.1	1.3	0.24
17	7000	1	36	4	0	n/a	n/a	260	n/a	n/a	n/a	n/a
18	7000	1	36	4	0	n/a	260		n/a	n/a	n/a	n/a
19	7000	1	32	8	0	n/a	236	252	n/a	n/a	n/a	n/a
20	7000	1	32	8	0	n/a	267		32.7	3.1	1.1	0.24
21	7000	1	40	15	0	n/a	154		44	3.1	1.6	0.22
22	7000	1	40	15	0	n/a	226	148	44.6	3.1	1.6	0.23
23	7000	1	40	15	0	n/a	51		41.9	3.2	1.6	0.20
24	7000	1	40	15	0	n/a	161		42	3.2	1.6	0.20
25	12000	1	40	5	0	n/a	160		40	3.2	1.5	0.20
26	12000	1	40	5	0	n/a	178	201	41.6	3.2	1.6	0.20
27	12000	1	40	5	0	n/a	211		39.5	3.2	1.5	0.20
28	12000	1	40	5	0	n/a	256		40.5	3.2	1.4	0.22
29	12000	1	40	1	0	high H2O	90	69	40.6	3.2	1.4	0.22
30	12000	1	40	1	0	high H2O	49		39.5	3.3	1.5	0.19
31	12000	1	40	3	0	high H2O	58	56	39.3	3.2	1.4	0.21
32	12000	1	40	3	0	high H2O	55		40	3.2	1.5	0.20
33	7000	1	40	0	0	24 hr soak	34		41.6	3.3	1.6	0.19
34	7000	1	40	0	0	24 hr soak	6	27	41.1	3.2	1.6	0.19
35	7000	1	40	0	0	24 hr soak	41		40.2	3.2	1.5	0.20

Table 2: Data from the second round of durability testing

Briquette	Pressure	Dwell Time	Sawdust	Paper Binder	Shatter Index	Average Shatter Index	Mass	Diameter	Height	Density	Avg. Density
[#]	[kPa]	[min]	[g]	[g]	[%]	[%]	[g]	[in]	[in]	[g/cm^3]	[g/cm^3]
1	7000	1	39.6	0.4	60		39.8	3.3	1.5	0.19	
2	7000	1	39.6	0.4	52	65	40.9	3.2	1.5	0.21	0.19
3	7000	1	39.6	0.4	83		39.2	3.3	1.5	0.19	
4	7000	1	39.2	0.8	127		40.4	3.2	1.4	0.22	
5	7000	1	39.2	0.8	109	106	41.4	3.2	1.4	0.22	0.21
6	7000	1	39.2	0.8	82		38.6	3.2	1.5	0.20	
7	7000	1	38.4	1.6	205		40	3.2	1.4	0.22	
8	7000	1	38.4	1.6	221	216	41.1	3.2	1.5	0.21	0.21
9	7000	1	38.4	1.6	221		39.3	3.2	1.4	0.21	
10	7000	1	37.6	2.4	402		39.9	3.2	1.4	0.22	
11	7000	1	37.6	2.4	392	399	41.1	3.2	1.5	0.21	0.22
12	7000	1	37.6	2.4	402		39	3.1	1.4	0.23	
13	7000	1	36.8	3.2	408		37	3.2	1.4	0.20	
14	7000	1	36.8	3.2	465	471	38.8	3.2	1.4	0.21	0.20
15	7000	1	36.8	3.2	542		38.9	3.2	1.5	0.20	