NORTHERN ARIZONA UNIVERSITY
College of Engineering, Forestry & Natural Sciences

Research Report Evaluating Steer Manure and Sawdust Mixtures as Alternative Fuel for Improved Jiko Stoves for Women in East Africa

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Final Project Report

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Abstract

This research project was conducted to determine the feasibility of using waste products as an alternative fuel source for developing communities, specifically in pastoral communities. The waste products evaluated were steer manure and sawdust, which were manually compressed into briquettes and burned using an improved Jiko Stove. Three different ratios were tested: 20% sawdust - 80% steer manure, 25% sawdust - 75% steer manure, and 30% sawdust - 70% steer manure as well as a pyrolyzed version of the 30%-70% ratio. To determine the viability of each option, the team measured the time it took 10, 15 gram briquettes of each ratio to boil 250mL of what as well as recorded the particulate matter emissions produced. The analysis performed during testing was done using a thermocouple to measure the temperature of water as well as the temperature within the combustion chamber throughout each test to observe how the energy changes. Additionally, a particulate profiler was used to measure the emissions of Particulate Matter (PM) 2.5 from the time the test begins until the water is visibly boiling. From the analysis, the team concluded that the 25% sawdust - 75% steer manure is the best option because it produced the least amount of PM 2.5 at the same energy change of water compared to the other ratios analyzed. Finally, the report concludes with recommendations for future testing to improve the procedure in attempt to obtain more consistent data during field testing.

Acknowledgements

Air Quality team would like to thank Dr. Dianne McDonnell for being our client on this project. As a client, Dr. McDonnell provided the tools that we need such as the jiko stove for testing data. Also, Dr. Dianne McDonnell provided feedback for every written report that was submitted. The team also would like to thank Professor Alarick Reiboldt for being the technical advisor. Professor Alarick helped with developing a better understanding of the methodology and for providing equipment for testing. Dr. Terry Baxter helped on lab assistant and equipment usage. Lastly, a special thanks to Lab Manager Adam Bringhurst for providing lab space and the Field Station.

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1.0 Introduction

1.1 Background

Biomass energy like firewood and charcoal, used for cooking in developing countries cause substantial indoor pollution, which has negatively impacted the health of many individuals [1]. Women in developing countries such as East Africa, are responsible for cooking and collecting wood as fuel. Those women are the target group who have a high exposure rate to particulate matter (PM) from the smoke produced from burning fuels while cooking, leading to a serious health conditions such as respiratory disease [2].

Figure 1: Map of Africa with Highlighted Region of Concern [3]

1.2 Research Goals

The Alternative Cooking Fuel Research Project proposes to test different ratio mixtures of sawdust and steer manure, dry and pyrolyzed briquettes, to examine which mixture of fuel has the lowest PM emissions and the most efficient in boiling water. The main goal of this evaluation is to compare the briquettes testing data to determine the best fuel alternative for women to use in developing countries. Testing will be completed at the Northern Arizona University (NAU) Campus field station, Trotta's farm. In attempt to mimic the indoor conditions East African women are exposed to health issues. A 10'x10' tent will be erected for testing in an area with the most protection from weather factors such as wind.

1.3 Prediction

Table 1 below shows the team's prediction for PM emissions and boiling time for dry and pyrolyzed briquettes for different amounts of sawdust and Steer manure in each mixture.

Table 1: Dry and Pyrolyzed Briquettes Predictions

	PM Emission		**Boiling Time**	
	High	**Low**	**Long**	**Short**
Dry Briquettes:				
80% Steer Manure, 20% Sawdust	✓			✓
75% Steer Manure, 25% Sawdust	✓			✓
70% Steer Manure, 30% Sawdust	✓			✓
Pyrolyzed Briquettes:				
70% Steer Manure, 30% Sawdust		✓	✓	

This evaluation of fuels consists of making mixtures using different ratios of sawdust and steer manure as dry and pyrolyzed briquettes.

The team predicts that the dry briquettes will have the highest amount of PM and will boil the water faster than the pyrolyzed briquettes due to the absences of organic matter in the pyrolyzed briquettes.

1.4 Constraints

The major constraint in this project is making the experimental variables such as wind speed, temperature, and pressure consistent. For the equipment used when making briquettes and burning the fuel, the team will be challenged to mimic the conditions in East Africa, which means the team could not use the equipment such as a compressor that ordinary families in East Africa have no access to. The safety problem also must be given attention. The team is supposed to assure that the flame would not ignite surrounding vegetation or the tent.

1.5 Further Research

The further effort of cooking fuel would focus on what types of clean fuel could be used. Though, normal families even in the developed countries would not have the access to the clean fuel. The challenge would be to how to make the families in developing country get access to clean fuel source such as ethanol fuel and electricity.

A study group directed by Karanja designed a type of fuel briquettes made by compressing biomass material. By evaluating the combustion properties, chemical composition, emissions of gases, and fine particulate matter, they found that charcoal dust briquettes bonded with soil was the safest for indoor air quality [4].

2.0 Methods

2.1 Preparing Site

The site of the testing conducted was the NAU Field Station as previously discussed. To use this facility, each team member had to complete the NAU Field Safety Training and NAU Chemical Hygiene training. A site visit and safety orientation was conducted with the NAU Lab Manager, Adam Bringhurst to obtain an understanding of where testing could be done on the site. Following the site visit, Mr. Bringhurst requested the team to complete a fire mitigation plan prior to testing to reduce as much potential risk as possible. The plan developed includes removing all surrounding vegetation from the testing area, digging a small trench around where the tent will be placed, and having an operational fire extinguisher on site.

The team and Mr. Bringhurst completed a walk-through of the lab spaces needed within the engineering building, Soils Lab 116 and Environmental Lab 245. These visits focused on the equipment the team will be using such as available ovens, sheets for drying, heat protection, and personal protective equipment.

2.2 Testing Method

The testing method developed for the research conducted was created focusing on keeping the experiment as consistent as possible. The methods were also created to be repeatable in East Africa, focusing mainly on the wealth of the area, the equipment available, and the materials available. Before any testing or prototyping began, the saw dust and steer manure were dried in an oven for 24 hours at

250 degrees Fahrenheit. Having dry materials was essential to the briquette formation because the final briquettes were made by weight, thus all water had to be removed before weighing the materials for mixing. Before mixing could occur, the dried steer manure was manually grinded in effort to make it a finer material ideal for mixing and weighing it in increments of 0.1g.

2.2.1 Prototyping

For all testing, briquettes in different ratios of steer manure and sawdust were created by dry weight. The ratios tested are as follows:

- 80% Steer Manure and 20% Saw Dust (Sample 1)
- 75% Steer Manure and 25% Saw Dust (Sample 2)
- 70% Steer Manure and 30% Saw Dust (Sample 3)

Before the particulate emissions were measured, a prototyping phase was conducted to establish the size and shape of the briquettes to determine which of the samples were feasible to be used in the Jiko Stove. The briquettes were manually compressed and dried using a cooking sheet in the oven at 250 degrees Fahrenheit for 24 hours. The intent of the cooking sheet was to keep the briquettes shape and size consistent by cutting equal squares of briquettes from the sheet. However, the briquettes were not structurally stable enough to be removed from the sheet without crumbling when cut. Therefore, the team decided to form the briquettes as discs by manually compressing the mixed materials between the palms of the hands. Although the exact shape and size of the briquettes were less consistent using this method, the team used 15g of material per briquette, thus making the mass of all the briquettes the same. The same team member compressed the briquettes each time in attempt to keep the process as consistent as possible.

The second parameter tested during prototyping was the amount of binder used in the briquettes. The binder content was tested in attempt to conserve resources because cassava flour may not be readily available in East Africa. To account for this, briquettes of each ratio were made without binder to determine if it would be a viable option to reduce cost and materials used. In previous research done by Abdu Zubairu and Sadiq Abba Gana, 5-7% (by weight) of binder was added into their mixtures of sugarcane bagasse and corn cob, thus the team also tested the samples using 6% binder [5]. The total amount of binder testing of briquettes are as follows:

- Sample 1 with 0% Binder
- Sample 2 with 0% Binder
- Sample 3 with 0% Binder
- Sample 1 with 6% Binder
- Sample 2 with 6% Binder
- Sample 3 with 6% Binder

The final parameter determined from the prototyping phase was the amount of water to be added to the mixtures. The purpose behind this was to determine if steer manure will absorb more water than sawdust or vice versa. Similarly to the binder parameter, a set amount of water needed to be determined before the final testing to keep the final briquette designs as consistent as possible, but had to be tested using all three sample ratios. To determine the water content, the three sample ratios were tested using a total of 50 grams of material. Once the dry weight mixes were completed, 50 mL of water was added to each and thoroughly mixed to allow the water to be absorbed by the materials. This process continued in increments of 10mL of water until the mix couldn't absorb any additional water and it began to pool at the bottom of the mixing container the sample was in. With the respective amounts of water recorded, the team determined the optimal amount of water to be used for each mix in the final briquettes.

2.2.2 Final Briquettes

Once the size, shape, amount of binder, and amount of water were determined from prototyping, the final briquettes for testing could be completed. The final designed briquettes were formed using the predetermined parameters. The dry materials were mixed, compressed manually, and put into the oven to dry. Four different briquettes were tested for their effectiveness to boil water and the amount of particulate matter generated from burning. Figure 2 shows the briquettes the group made and the briquettes formed and tested are as follows:

- 80% Steer Manure and 20% Saw Dust (Sample 1)
- 75% Steer Manure and 25% Saw Dust (Sample 2)
- 70% Steer Manure and 30% Saw Dust (Sample 3)
- 70% Steer Manure and 30% Saw Dust, Pyrolyzed (Sample 4)

Figure 2: Briquettes Made by the team

2.2.3 Pyrolysis

Due to time constraints, only one ratio of the samples being tested were pyrolyzed to remove the organic matter from the sample to determine if this technique had an effect on the particulate emissions and ability to boil water. To accomplish this, an oven set to 450 degrees Fahrenheit was set up with carbon dioxide being pumped into a chamber within the oven to ensure the absence of oxygen. The briquettes used in this process were created following the methodology previously discussed so all water was removed prior to pyrolysis. Due to the high temperatures of the oven, the briquettes were left in the pyrolysis chamber for 1.5 hours before removal. The pyrolysis was done indoors and to be in compliance with the NAU's laboratory regulations, a hose was connected to the top of the oven to release the emissions being burned off outside instead of indoors.

2.2.4 Field Testing

For the final briquette testing, the team performed the burning at the designated field station location. Upon arrival to the site, the outdoor pressure and temperature were recorded. All testing was performed on days within 20 degree of each other to keep the results consistent from outside factors. Next, a five gallon bucket of water was filled and kept inside the field station building in attempt to keep the starting temperature of the water the same for all tests. While one team member was completing this, the others set up the tent for testing as well as the Jiko Stove, pot, particulate counter, and thermocouple within the tent. The thermocouple terminals were placed in the water and in the combustion chamber of the Jiko to record the temperature changes of the briquettes and water during the test. Before ignition, 5mL of lighter fluid was added to each briquette to ensure complete burning occurred. Once set-up was completed, 10 briquettes were initially placed in the combustion chamber of the Jiko, lit using a micro torch, and allowed to burn for 5 seconds for complete burning of all briquettes to occur. After 5 seconds, 250mL of water was transferred into the pot and placed on the Jiko. Upon placing the pot on the Jiko, the particulate profiler and thermocouple programs were started to obtain the time necessary for boiling, the change in temperature, and the emissions produced.

Once the water reached boiling temperature, 98.3 degrees Fahrenheit, the flames were extinguished and the heated water was discarded from the pot. New briquettes were then loaded into the fuel chamber and 250mL of water were obtained from the five gallon bucket. With the new fuel and water, the same process for testing was repeated. For each of the four samples, five different tests were completed, resulting in a total of 20 tests.

2.3 Results

Five tests per ratio was conducted using 10 briquettes per testing, resulting in the total 20 tests conducted. Tables A1-4 in Appendix A show the data from the 20 tests including the PM 2.5 emissions, change of water temperature, change of briquettes temperature, and the energy change of the water. The particulate profiler recorded the PM 2.5 in 10 seconds intervals and the data displayed in the Appendices is the sum of PM 2.5 produced during each test. The energy change was calculated using the equation:

$$\text{Change in Energy} = CpM\ \Delta T$$

Where ΔT = temperature change, M = mass of water, Cp = specific heat and Cpwater = 4.2 x 103 J kg-1 °C-1.

Figures B-1-B-4 in Appendix B shows the PM 2.5 as the temperature changed during each test. Figure 8 illustrates the emissions of PM 2.5 of 25% sawdust- 75% steer manure briquettes and shows all tests had less than 5 million counts/cubic meter. Compared to the ratios tested, this ratio of briquettes had the lowest emissions of PM 2.5. For the 20% sawdust and 80% steer manure briquettes, the water did not boil, which means the variable of final temperature of water was not controlled and wasn’t used in following analysis because it was not a viable option. Additionally, there were multiple outliers as shown in Figure B-3. After considering the testing environment on that exact test day, the team conducted the test of 30% sawdust and 70% steer manure briquettes during extremely windy conditions. It is very likely that those high spikes in the graph are due to wind movement. Figure 3 shows how the wind movement affected the data collecting of the particulate profiler. The smoke that is represented by the white lines in the figure would rise to the top area of the tent. However, the wind which is represented by the blue arrow in Figure 3 could change the direction of the smoke movement resulting in the smoke cycling back to the Particulate Profiler under the influence of the wind. Then, the Particulate Profiler collected the recycled PM 2.5, resulting in collecting an excessive amount of PM 2.5.

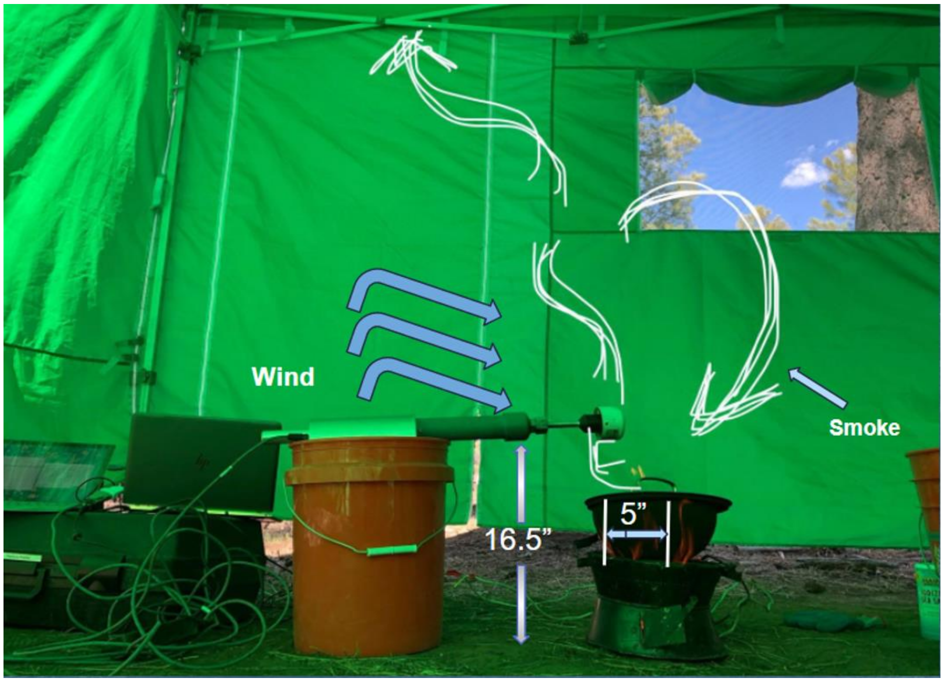

Figure 3: Influence of Wind Movement among Data Collecting

2.4 Analysis

A multi-linear regression graph was used for the data analysis of three ratios of briquettes and is shown in Figure 4. Only three of the four ratios were used because, as previously discussed, the data of 25% sawdust - 75% steer manure briquettes was not representative, and therefore not included in the analysis. For 30% sawdust -70% steer manure, the two tests of data which produced more outliers were omitted when generating the regression line to avoid errors in the results. The y-axis represents the emission of PM 2.5, while the x-axis represents the energy change of water. One point in the figure represents the total emissions of PM 2.5 with the total energy change of water for each test of the three ratios analyzed.

The bottom orange line, which represents 25% sawdust -75% steer manure illustrates that the PM 2.5 emissions did not increase much as the total energy change increases. On the contrary, the blue line, which represents pyrolyzed 30% sawdust-70% steer manure suggests that this ratio of briquettes could generate large amount energy but has the highest PM 2.5 emissions. Comparing the pyrolyzed version to dry version of 30% sawdust -70% steer manure briquettes, the dry briquettes generated less PM 2.5 emissions given the same energy change.

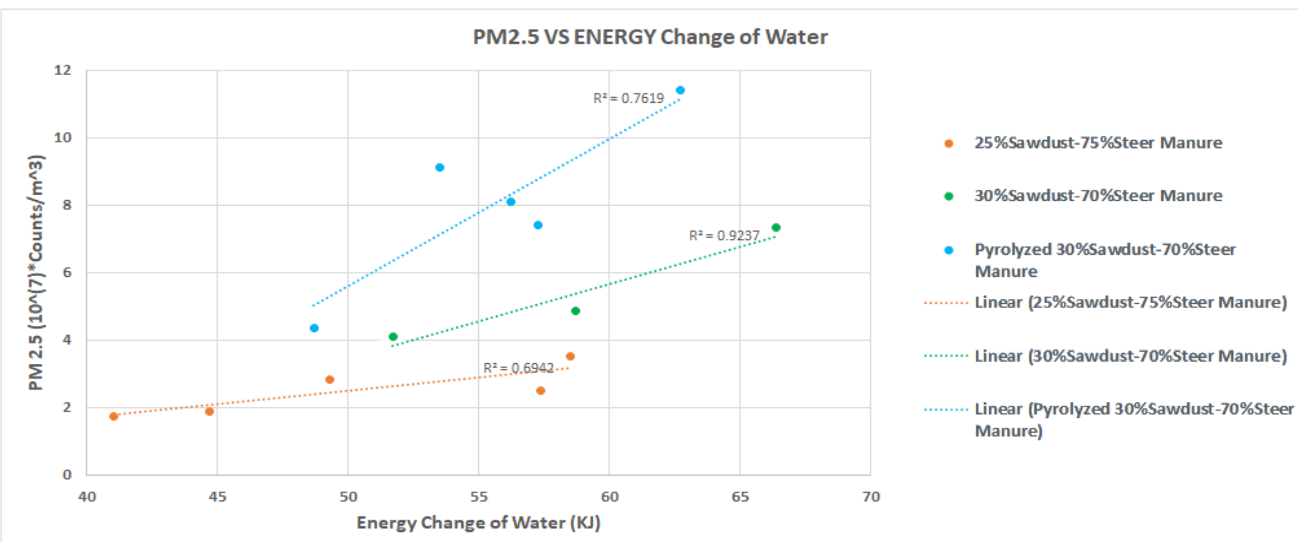

Figure 4: Production of PM2.5 according to Energy Change of Water

From Figure 4, it can be assumed that there is a relationship between the emissions of PM 2.5 and the energy change of water, since the two variables show a linear regression. The data of 25% sawdust - 75% steer manure was used to set an equation to compute the emission of PM 2.5 with the variable of energy change of water and temperature change of briquettes. The data analysis tool in Excel helps set the equation to determine how the energy change affects the emissions of PM 2.5. Table 2 provides the coefficients of X variable 1 and X variable 2. The equation generated is as follows:

$$y=39386.7606x1+546.944018x2-11021990.5,$$

Where y is the amount of emission of PM 2.5, x1 is the temperature change of briquettes and x2 is the energy change of water.

The R squared was found to be 0.906479, showing a strong correlation between the two variables. Furthermore, the p-value of each variable was more than 0.05, indicating weak evidence against the set-up equation. Therefore, this equation can accurately explain the relationship of emission of PM 2.5, temperature change of briquettes, and the energy change of water. From the coefficients, the temperature change has a higher coefficient, meaning it variable could heavily affect the results of PM 2.5 emissions, while the energy change of water has lower influence.

Table 2: Results for Equation Generated from Field Testing

	Coefficients	T Stat	P-value
Intercept	-11021990.5	-1.03971	0.407668
X Variable 1	39386.7606	2.130582	0.166837
X Variable 2	546.944018	2.31085	0.147051

3.0 Summary of Engineering Work

3.1 Schedule Modification

A Gantt chart was created to organize the team plans throughout the semester.

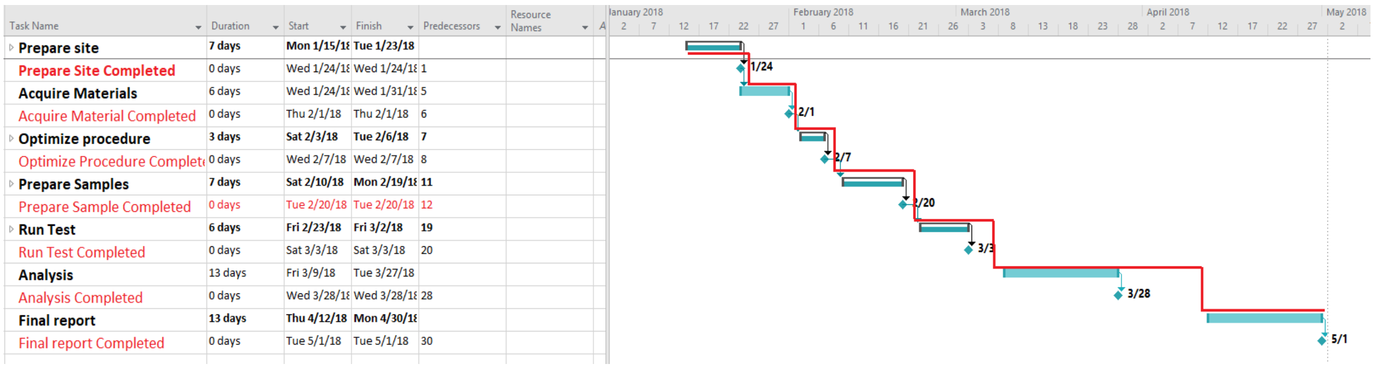

Figure 5: Original Gantt chart of Project Schedule

The site was completed on time, in which the team cleared the area from debris, grass and big chunk of rocks to assemble the tent. The next part is acquiring material such as sawdust from AP Sawmill (Flagstaff, Arizona) and steer manure from Grantham Ranch (Williams, Arizona). This part took more than what was expected because of the prototype testing and due to failure testing. Failure testing includes other equipment not functioning which eventually decreases the amount of briquettes that were made and formed. Other materials were given from Dr. Baxter and Professor Reibolt which are particulate profiler and thermocouple. Design briquettes was late because the briquettes that were formed won't mix well which resulted breaking up. Therefore the team searched alternatives ways of how to make the briquettes stick together. Research showed that starch binder is best way to mix and stick briquettes together. The next step it to run test once all materials are acquired. Due to failure of technical equipment, the testing took more than what is shown in the schedule. These technical issues were from thermocouple in which it did not read all the channels that were installed and particulate profiler which does not read all the pm sizes. The last task is analyzing data which was on time. Once all the tests run smoothly and exported to excel then the team can analyze the tests which is shown in excel format.

Table 3: Updated Schedule

Task	Projected start Date	Projected End Date	Actual Start Date	Actual End Date
1.0 Preparing Site	1/115/18	1/23/18	1/15/18	1/23/18
2.0 Acquiring Material	1/24/18	1/31/18	1/24/18	2/16/18
3.0 Design Briquettes	2/03/18	2/20/18	2/17/18	3/11/18
4.0 Running Test	2/23/18	3/02/18	3/13/18	4/21/18
5.0 Analyze Data	3/13/18	3/28/18	4/5/18	4/23/18

4.0 Summary of Engineering Costs

The most cost of this project contribute to the 10X10 tent. If the team had access to an indoor environment, this amount of cost could be saved. The calculated total cost was $132.93.

Table 4: Original Estimating Cost of Materials and Equipment

	Quantity	Unit	Unit Cost	Total
Sawdust	10	Pounds (lbs)	$2/lbs	$20
Steer Manure	2	Bag (CF)	$1.47/bag	$2.94
10x10 Tent	1	N/A	$109.99	$109.99
			Total Cost	$132.93

5.0 Conclusion

In conclusion, all data test results were plotted in one graph to examine the amount of particulate matter emission with the water energy concentration. Results shows that the pyrolysis briquettes boils water with the shortest time and has the highest particulate matter emission compared to the dry briquettes. Also, the pyrolysis briquettes has the most water energy concentration in which it resulted in boiling water with the shortest amount of time. While the least particulate matter emission was shown to be the 75% steer manure - 25% sawdust dry briquettes.

6.0 Recommendations

After finishing with the testing and analysis, the team has three recommendations for future testing which are as follows:

1. Improve testing enclosure
2. Use composted steer manure
3. Test more pyrolyzed ratios

Improving the testing enclosure will help to prevent wind interference that could affect the data as discussed in accordance with Figure 3. The team recommends doing this by placing the Jiko Stove within a closed container such as two-foot tall glass cylinder. Additionally, using composted steer manure instead of raw manure because it has a high amount of organic matter. During pyrolysis, organic compounds are burned off and only the carbon is left, which is the most important for combustion. With the higher organic content of the composted manure, there will be more carbon and should theoretically burn better. Lastly, because only one ratio was pyrolyzed and tested, it was difficult to conclude the effectiveness of the pyrolysis. Therefore, the team recommends testing three different pyrolyzed ratios similarly to what was done for the dry briquettes.

7.0 Reference

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Appendix A

Table A-1: Collected Data for Each Test of 20% Sawdust-80% Steer Manure Briquettes

20%Sawdust-80%Steer Manure			
PM2.5	Change of Water Temperature	Change of Briquettes Temperature (°C)	Energy Change of Water (J)
83368421	16.2	3.2	16958.97
237227067	18.9	24.7	19785.465
89215037	29.8	-15	31196.13
81527820	12.7	-7.2	13294.995
68697745	29.8	69.7	31196.13

Table A-2: Collected Data for Each Test of 25% Sawdust - 75% Steer Manure Briquettes

25%Sawdust - 75%Steer Manure			
PM2.5	Change of Temperature	Change of Briquettes Temperature (°C)	Energy Change of Water (J)
2.840301	47.1	353.7	49.306635
1.8821052	42.7	140.7	44.700495
2.5070674	54.8	185.7	57.36738
3.5290228	55.9	283.1	58.518915
1.734737	39.2	123.4	41.03652

Table A-3; Collected Data for Each Test of 30% Sawdust-70% Steer Manure Briquettes

30%Sawdust-70%Steer Manure			
PM2.5	Change of Temperature	Change of Briquettes Temperature (°C)	Energy Change of Water (J)
173028569	49.9	172.6	52.237815
4.8439101	56.1	274.9	58.728285
4.1094735	49.4	259.9	51.71439
7.3335338	63.4	173.3	66.37029
143193987	61.5	237	64.381275

Table A-4: Collected Data for Each Test of Pyrolyzed 30% Sawdust-70% Steer Manure Briquettes

Pyrolyzed 30%Sawdust-70%Steer Manure			
PM2.5	Change of Temperature	Change of Briquettes Temperature (°C)	Energy Change of Water (J)
11.4105265	59.9	252.6	62.706315
7.4117293	54.7	127.2	57.262695
8.0938347	53.7	114.2	56.215845
9.099549	51.1	17.7	53.494035
4.3344361	46.5	111.5	48.678525

Appendix B

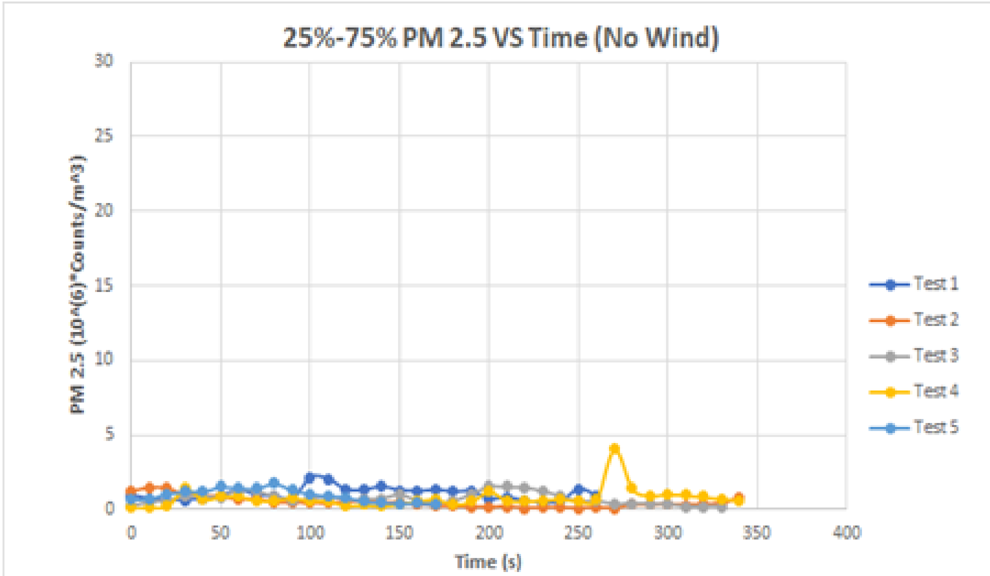

Figure B-1: Emission of PM2.5 for 25%-75% ratio

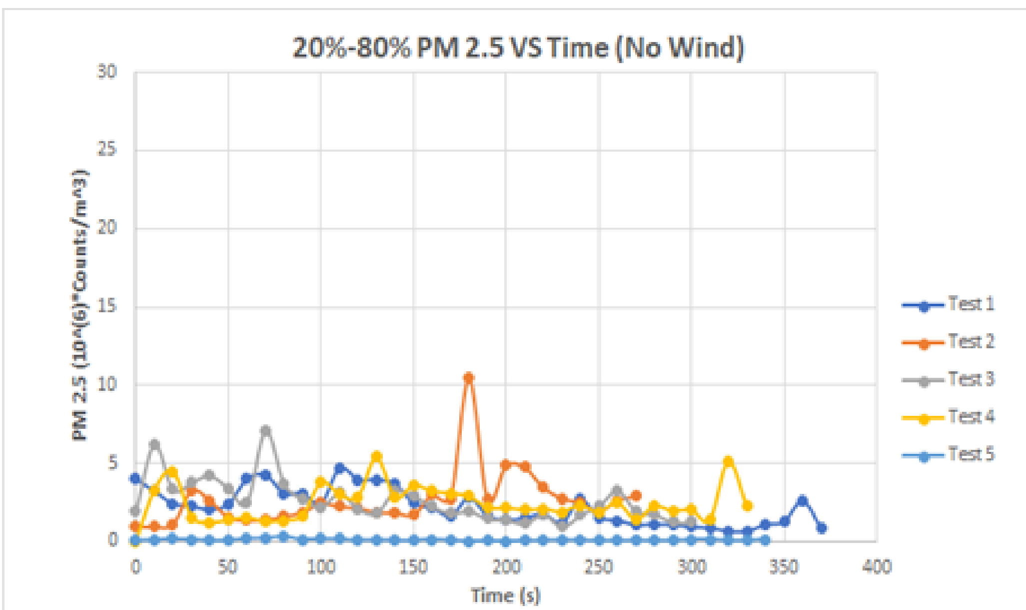

Figure B-2: Emission of PM2.5 for 20%-80% ratio

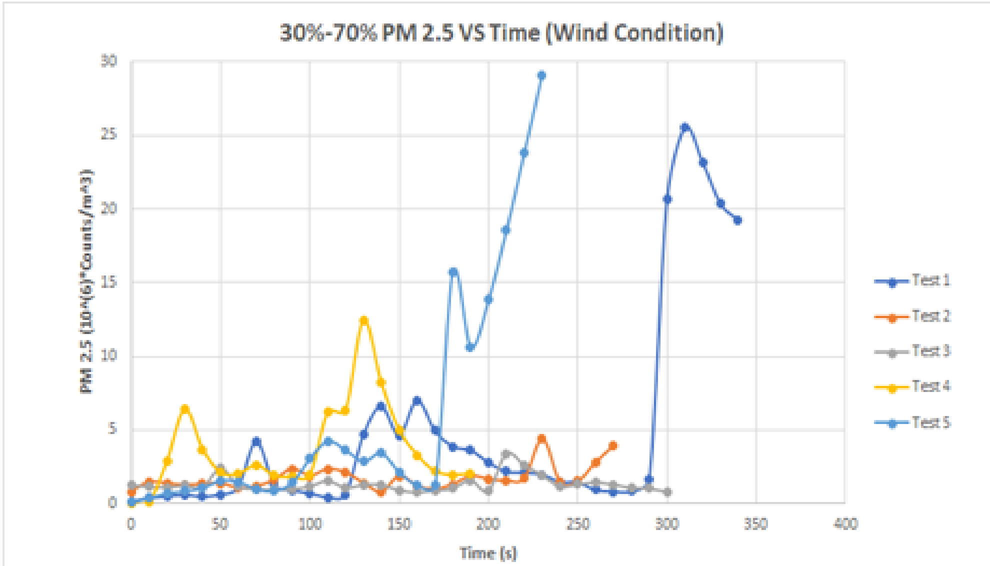

Figure B-3: Emission of PM2.5 for 30%-70% ratio

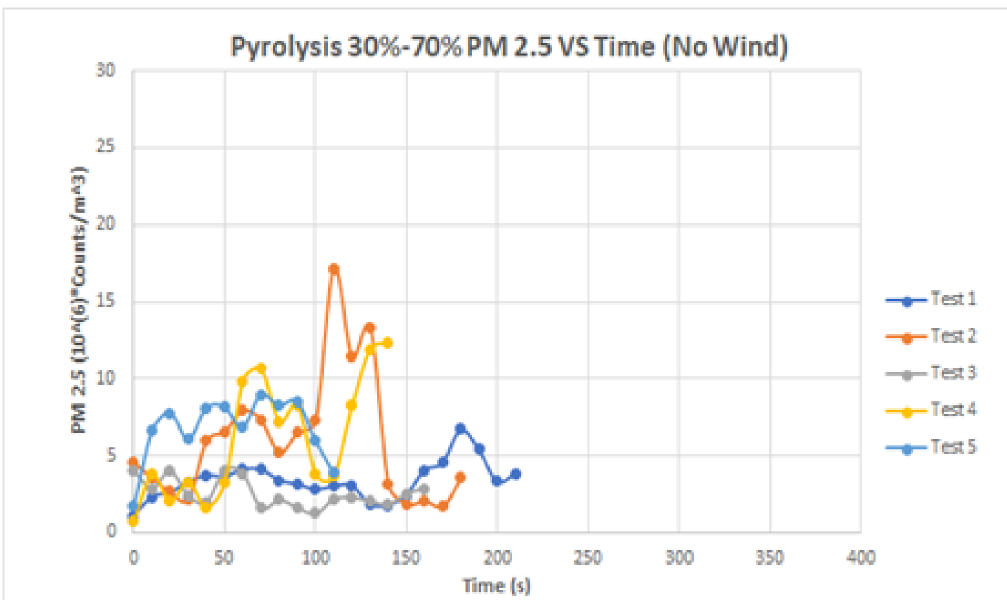

Figure B-4: Emission of PM2.5 for pyrolyzed 30%-70% ratio