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Determination of fixed carbon of blended briquettes of sawdust, maize stalks and coffee husks a case study of tea industry in Kericho County, Kenya

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ABSTRACT

The tea industry in Kericho is among the main consumers of firewood for its intensive thermal energy demand used in industrial steam boilers. There have been growing concerns about firewood depletion and tea factories have begun transitioning to alternative fuels to power their boilers. Briquettes made of biomass residues are among the promising solutions; however, they are not yet widely adopted and implemented. This study has identified the possible source of briquettes to fire boilers that will utilize agricultural by-products produced within Kericho. The blended briquettes have arrived at the best ratio by determining the physical and combustion properties of blended briquettes of sawdust, maize stalks, and coffee husks. Blended briquettes have gained attention as a sustainable alternative to traditional fuels due to their potential for reducing environmental impact utilizing agricultural and forestry residues and reducing the dependency of wood pellets. The combustion properties of the blended briquettes have also been examined, focusing on fixed carbon. The calorific value will be determined using calorimetric techniques to measure the amount of heat energy released upon combustion. The ideal combustion parameters of blended briquettes were determined via numerical optimisation. Design-Expert® Software's optimization method is based on a technique created by Derringer and Suich (1980). Experiment design and analysis were done with Design-Expert® Software Version 10-Stat-Ease. The response surface methodology was utilized to investigate the fixed carbons blended briquettes manufactured from coffee husks, maize stalks, and sawdust. The interaction of the parameters was also explored. The results of this study have blended briquettes developed from coffee husks, maize stalks, and sawdust, measuring 45mm by 45mm by 35mm. From the analysis of individual briquettes, Individual briquettes fixed carbons range between 8.58% and 13.08%. Sawdust gave 9.36%, coffee husks 8.58% and maize stalks at 13.08%. The quality of bio-briquettes improves as the fixed carbon value rises. Fixed carbon serves as a primary source of heat during combustion. The optimal mix ratio of coffee husks: maize stalks: sawdust is 2.3:1.1:1. This ratio gave a 6.986% fixed carbon. This has verified that blended briquette fuel has better combustion properties than individual briquettes. It is recommended that further research should be done to investigate the influence combustion properties and binders for uncarbonized briquette binders when varied above 10%. This should be adjusted to see if it impacts both the physical and combustion properties under investigation.

Keywords: Briquettes, Coffee Husk, Fixed Carbon, Maize Stalks Sawdust

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I. INTRODUCTION

Due to its high thermal energy requirement for use in industrial steam boilers, Kericho's tea sector is one of the major users of firewood (Suryani et al., 2022). The tea industry in Kericho is among the main consumers of firewood because of the intensive thermal energy demand used in industrial steam boilers (Suryani *et al.*, 2022). The production of briquettes from sawdust and other agro residues exemplifies the potential of appropriate technology for utilizing biomass residues which abound in large quantities in developing countries. Blended briquettes have unique physical and combustion properties. Densification of biomass waste materials has provided a great boost to the utilization of wood and agricultural waste for domestic and industrial fuel (Mitchual *et al.*, 2013).

Producing fuel briquettes with naturally available waste materials which are biodegradable is an asset. With the increasing energy needs and the continually growing population tend to result in a bunch of waste from agriculture and higher energy demands for use. The consumption of several agricultural products has regularly left the wastes and by-products being thrown away. Producing bio-briquettes from Agricultural waste has helped in addressing the increasing energy demand hence avoid dependency on forests (Sivakumar & Mohan, 2010).

In the tea industry fuel wood is required for the following uses i.e. for generation of hot air for withering, for generation of hot air for drying. Along with the growing concerns about firewood depletion, tea factories have begun transitioning to alternative fuels to power their boilers. The substitution potential has been assessed and arrived at the best ratio by determining the combustion properties of blended briquettes of sawdust, maize stalks, and coffee husks. In Kenya, the loss of primary forests reached 7.6% from 2002 to 2020, which was driven, among others, by the demand for cheap energy. The high demand for fuel wood by rural communities and industry has led to deforestation and the depletion of trees as a natural resource. Tea factories, which are firewood dependent, suffered additional expenditures in their production and, consequently, a decline in profits. Therefore, they seek to invest in alternative energy sources. Several studies have already investigated alternative energy sources for the tea sector (Petursson *et al.*, 2013).

The tea factories in Kenya recognized the potential of biomass residues to substitute firewood in their processes. Kenya has a promising bioenergy opportunity from crop residues, for example, sawdust's, maize stalks and coffee husks from ongoing agricultural production. Briquettes have been introduced in several tea factories through co-firing, i.e., mixing firewood and briquettes in the boilers (Deshannavar *et al.*, 2018; Suryani *et al.*, 2022).

Briquettes made from biomass residues could contribute to ensuring the sustainable supply of biomass energy (Ngusale *et al.*, 2014). Densification of agricultural residues and wood waste into fuel briquettes can provide a relatively high-quality alternative source of fuel, especially where solid wood fuel resources are scarce (Wamukonya & Jenkins, 1995)

Fixed carbon gives a rough estimate of the heating value of a fuel and acts as the main heat generator during burning. It also indicates the proportion of char that remains after volatile matter is extracted, which gives a rough estimate of the heating value of a fuel and acts as the main heat generator during burning (Akowuah *et al.*, 2012). The fixed carbon as reported in this study 74.20% to 75.13% is relatively higher than obtained by (Adegoke *et al.*, 2010). A good quality and efficient fuel briquette is dependent on lower volatile matter and ash content with a higher fixed carbon content (Asamoah *et al.*, 2016) in collaboration with the result of findings of this study. The percentage of fixed carbon content in briquettes is a critical factor that influences the calorific value of fuel (Thabuot *et al.*, 2015). As the composition of Carbon Content [CC] increases in the mixture ratio, the percentage of fixed carbon is increased. This is in agreement with the assertion of Onukak *et al.* (2017) who posited that "high fixed carbon implies high calorific value and hence an indication of easy ignition and proportionate increase in flame length. It also shows the percentage of char that remains after the volatile substance is removed (Adegoke *et al.*, 2010; Akowuah *et al.*, 2012; Emerhi, 2011). It provides a general estimate of a fuel's heating value and functions as the major heat generator during combustion. A good quality and efficient fuel briquette depend on lower volatile matter and ash content and a higher fixed carbon content (Asamoah *et al.*, 2016) in collaboration with the results of this investigation.

II. CONCEPTUAL FRAMEWORK

The experiment was used to investigate the effect of briquettes made from a mixture of coffee husks, sawdust, and maize stalks and molasses as the main variables. The ration of individual component will be guided as per the design of experiment. Molasses was kept at constant of 10% for all the samples produced. Preformed fabricated mold was used to develop the samples before analysis being done. Briquettes were studied primarily for their physical and combustion qualities which included measurements of fixed carbons of blended briquettes. Sawdust were be acquired from sawmills, whilst coffee husk and maize stalks are collected as a by-product of agricultural output. Molasses were purchase from accredited agro vets shops.

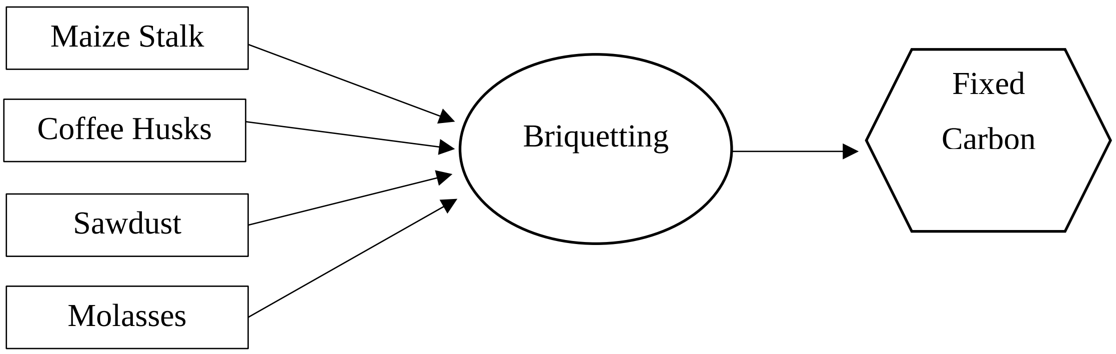

Figure 1
Conceptual Framework

Figure 1 demonstrates the conceptual foundation of the study. Sawdust, maize stalks, and coffee husk are the independent variables employed in the creation of briquettes, which were sundried and pulverized to a diameter of 2mm. The dependent variables obtained from blended briquettes included fixed carbon. The process included the use of prefabricated mold and slight application of pressure by the process of briquetting.

1.1 Statement of the Problem

Most tea companies utilize wood biomass to power industrial boilers. However, with a rising number of factories and increasing energy demand, it is necessary to investigate sustainable alternative energy sources due to the loss of forest cover. Kenya produces hundreds of tons of agricultural waste each year. While the energy potential of most of these agricultural residues has been assessed, others have not. Converting these leftovers into a densified form helps reduce deforestation by substituting wood burning, thereby decreasing the demand for wood.

This study examined the physical and combustion qualities of blended briquettes formed from sawdust, maize stalks, and coffee husks, assessing their feasibility as alternative industrial energy sources and determining their combustion characteristics for use in steam boilers.

1.2 Research Objectives

The following specific objectives guided this study:

i. To develop blended briquettes from sawdust, maize stalks, and coffee husks
ii. To optimize ratios of sawdust, maize stalks, and coffee husks to produce blended briquettes.
iii. Assess the physical and combustion qualities of blended briquettes.

III. METHODOLOGY

3.1 Introduction to Briquetting

Briquetting is the process of compacting residues into a product with a higher density than the initial raw materials. It is also called densification (Oladeji, 2015).Bio-briquetting is a process for increasing the density of biomass by compressing the original free particles using mechanical force. Bio-briquetting has several advantages, including creating a bond within the particles to form a solid fuel, lowering the moisture content of the biomass, increasing the net caloric value per unit volume by removing volatile matter, producing uniform size and quality fuel, making transportation and storage easier, and addressing the residue disposal problem.

Blended briquettes, which have unique physical and combustion properties due to the densification of biomass waste materials, have significantly boosted the use of wood and agricultural waste as residential and industrial fuel in industrial boilers (Mitchell *et al.*, 2020).

The benefits of employing biomass bio-briquettes as a source of heat include cost-effectiveness and sustainable energy. It also has low sulfur levels and hence cannot contaminate the environment. Biomass briquettes have a larger caloric value than individual briquette sources. The ash concentration of bio-briquettes is lower than coal at 2-10%, resulting in uniform combustion. Densified briquette products are easy to carry and store, and the fuel generated is uniform in size and quality, so there is a good possibility of ongoing energy supply. Finally, it contributes in the reduction of deforestation by offering an alternative for fuel wood for both households and industries (Bajwa *et al.*, 2018; Gbabo *et al.*, 2015).

There are several methods available for densifying biomass. Screw press briquetting is the most popular densification method suitable for small-scale applications. The raw material from the hopper is conveyed to and compressed by a screw in screw press briquetting. This process produces denser and stronger briquettes compared with other types (Bhattacharya *et al.*, 2002).

In addition, a hand-operated biomass briquetting mold was made from locally accessible materials to produce the charcoal briquettes for final examination. Briquettes containing binding materials such as cow dung, wheat flour, and paper pulp were previously used. These briquettes were evaluated for calorific value and compressive strength by altering the amount by volume of binder (Kumar *et al.*, 2016).

3.2 Materials

The determination of fixed carbon was determined by blended briquettes of sawdust, maize stacks, and coffee husk waste required the following materials. The blended briquettes used eucalyptus sawdust, coffee husks, and maize stalks as raw materials. They were selected, sun-dried to reduce moisture content, and weighed according to experiment runs. The procedure was followed in preparation for materials. The eucalyptus sawdust, coffee husks, and maize stalks were sun-dried at an average relative humidity and temperature for ten days. Then the materials were grounded to give a particle size of less than 2mm using a crusher machine. Finally, the sample was measured using a 2mm stainless steel mesh. The samples were measured using the digital scale as per the design of the experiment into six different samples

and labelled. The molasses were then added into the sample as the process of mixing by hand until we attained a uniform Mixture. The mixture was fed into the prefabricated mold. The fabricated mechanical mold with a plunger was used to form square briquettes. The same was done for all the remaining samples and labelled. The formed briquettes were dried in direct sun for fourteen days. The briquettes were stored in air-tight containers to avoid reabsorption of wet humidity.
Determination of combustion properties of Briquettes

Moisture Content: The moisture content of raw biomass was determined by calculating the loss in weight of material using the hot air oven dying method at 105°C to 110°C for one hour and up to constant weight loss. Its contents were removed from the oven, allowed to cool at room temperature, and reweighed. This process was repeated until the weight after cooling became constant, and this was recorded as the final weight. The sample's moisture content was determined using the equation below (Inegbedion, 2022).

$$Moisture\ Content\ (\%) = \left(\frac{w2-w3}{w2-w1}\right)100 \text{ .... Equation 2-1}$$

Where:

w_1 = weight of crucible, g
w_2 = weight of crucible + sample, g
w_3 = weight of crucible + sample, after heating, g

2.4.2 Calorific Value of Briquettes

Biomass is the most important source to increase the production of energy based on renewable energy sources. The calorific value of biomass is an indication of the energy chemically bound in it and the combustion process; it is converted into heat energy. Calorific value is the most important property of a fuel which determines its energy value. The calorific value of the briquettes was determined using a bomb calorimeter. 1.5g of the briquette sample was burnt completely in oxides of oxygen. The liberated heat was absorbed by the water and calorimeter. The heat lost by burning briquette was the heat gained by water and calorimeter. The calorific value (CV) of the fuel was calculated from the measured data using the equation below.

$$Calorific\ Value\ (\%) = \left(\frac{BFxt-2.3\ lenthg\ wire}{w}\right) \text{ .... Equation 2-2}$$

Where: BF = Burn Factor.
Δt = Change of temperature (t2 – t1)
t2 = final temperature.
t1 = initial temperature.
W = mass of the sample used and BF = constant = 13,257.32

Determination of Volatile Matter. The dried samples in the crucible were covered with a lid and placed in a muffle furnace maintained at 925 ± 20°C for 7 minutes. The crucible was cooled first in the air, then inside a desiccator, and weighed again. Loss in weight was reported as a volatile matter on a percentage basis.

$$Volatile\ Matter\ (\%) = \left(\frac{w5-w6}{w5-w4}\right)100 \text{ .... Equation 2-3}$$

Where;

w4 = weight of the empty crucible, g
w5 = weight of empty crucible + sample, g
w6 = weight of the crucible + sample after heating, g

2.4.5 Determination of Fixed Carbon

The percentage of fixed carbon (PFC) is given by the equation below

$$PFC\ (\%) = 100\% - (PMC + PVM + PAC) \text{ .... Equation 2-4}$$

Where:

PFC - Percentage of Fixed Carbon
PMC - Percentage of Moisture Content
PVM - Percentage of Volatile Matter
PAC - Percentage of Ash Content

3.3 Design of Experiments

Experiment design and analysis were done with Design-Expert® Software Version 10-Stat-Ease. The response surface methodology was utilized to investigate how burning affects the physical properties of mixed briquettes manufactured from coffee husks, maize stalks, and sawdust. The interaction of the parameters was also explored, and a total of six runs were done with different weight. The t-test or Analysis of Variance [ANOVA] was used to analyze the data. The impact of each potential factor combination on the response variable is investigated.

Table 1

Design of Experiments for Blended Briquettes.

		Factor 1	Factor 2	Factor 3	Response 1
Std	Run	A: Sawdust	B: Coffee Husks	C: Maize Stalks	Fixed Carbon
		Grams	Grams	Grams	
2	1	350	150	250	
3	2	150	350	250	
9	3	250	150	150	
5	4	150	250	150	
16	5	250	250	250	
1	6	150	150	250	
4	7	350	350	250	
11	8	250	150	350	
7	9	150	250	350	
14	10	250	250	250	
12	11	250	350	350	
8	12	350	250	350	
10	13	250	350	150	
15	14	250	250	250	
13	15	250	250	250	
6	16	350	250	150	

IV. FINDINGS & DISCUSSION

4.1 Combustion and Physical Properties of Sawdust, Coffee Husk, and Maize Stalks

This study was conducted to investigate the combustion qualities of briquettes made from sawdust coffee husks and maize stalks. Molasses was used as a binding agent and the amount of pressure applied was constant for all briquettes produced. Molasses was utilized as a binder throughout all trials and capped at 10%. The usage of these sorts of briquettes is environmentally friendly since it emits less carbon into the atmosphere, reduces the health risk connected with the use of wood fuel, and reduces deforestation and its associated issues. From the analysis of individual briquettes, the fixed carbons range between 8.58% and 13.08%. The quality of bio-briquettes improved as the fixed carbon value increases. Because fixed carbon functions as a key source of heat during burning. Low fixed carbon lowers the calorific energy of the briquettes. The more the fixed carbon, the better the charcoal produced, as the related calorific energy is high (Veeresh & Narayana, 2012). All the individual briquettes produced energy levels as per the analysis done below hence a clear indication that the process of preparation and analysis was ok.

Table 2

Individual Briquettes Sample Analysis

Sample	Fixed Carbon (%)
Saw dust	9.36
Coffee husks	8.58
Maize stalks	13.08

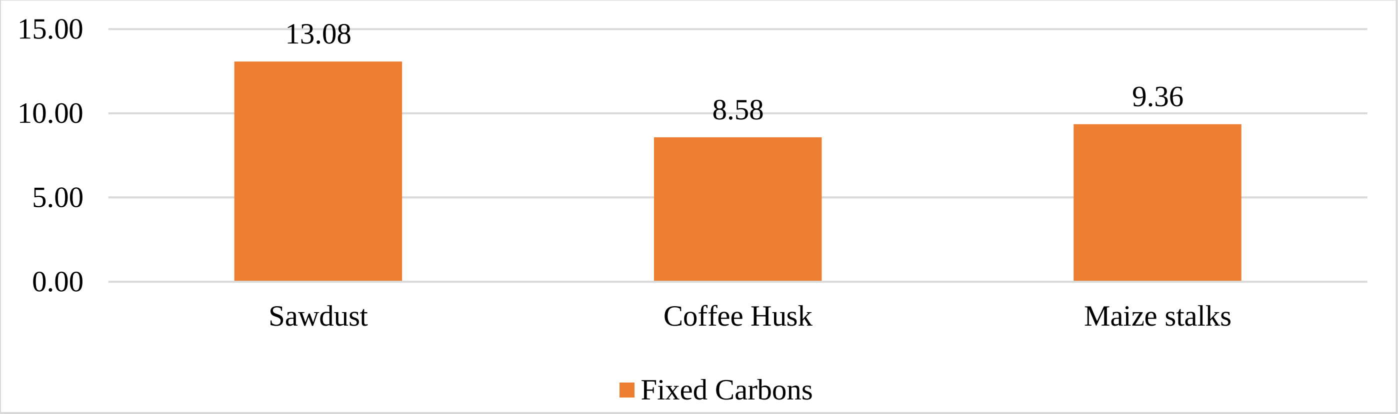

Figure 2

Graphical Representation of Individual Briquette Properties

Table 3

Design of Experiments Weight Calculation

		Factor 1	Factor 2	Factor 3	Response
Std	**Run`**	**A: Sawdust**	**B: Coffee Husk**	**C: Maize stalks**	**Fixed Carbon**
2	1	350	150	250	4.75
3	2	150	350	250	7.32
9	3	250	150	150	12.36
5	4	150	250	150	6.4
16	5	250	250	250	11.54
1	6	150	150	250	12.11
4	7	350	350	250	5.06
11	8	250	150	350	2.22
7	9	150	250	350	8.89
14	10	250	250	250	11.32
12	11	250	350	350	5.08
8	12	350	250	350	6.03
10	13	250	350	150	3.59
15	14	250	250	250	12.09
13	15	250	250	250	11.51
6	16	350	250	150	8.04

Fixed carbon represents a fuel's thermal value and serves as the primary heat source during combustion. It also displays the proportion of char left after the volatile ingredient is eliminated. It provides a general approximation of a fuel's heating value and works as the primary heat generator during combustion (Akowuah *et al.*, 2012). The fixed carbon observed in this study (2.2% to 12.11%) is relatively higher than the 5.75% to 8.28% as reported by (Adegoke *et al.*, 2010; Emerhi, 2011). A good quality and efficient fuel briquette depends on lower volatile matter and ash content and a higher fixed carbon content (Asamoah *et al.*, 2016), in collaboration with the results of this investigation. The percentage of fixed carbon content in briquettes is an important factor in determining the calorific value of fuel (Thabuot *et al.*, 2015). The amount of fixed carbon increases in proportion to the CC composition in the mixed ratio. This is compatible with the assertion of who said that high fixed carbon implies high calorific value and thus an indication of easy ignition and proportionate increase in flame length (Onukak *et al.*, 2017).

The percentage of fixed carbon content in briquettes is an important factor in determining the calorific value of fuel (Thabuot *et al.*, 2015). The amount of fixed carbon increases in proportion to the composition in the mixed ratio. This is compatible with the assertion of Onukak *et al.* (2017) who said that "high fixed carbon implies high calorific value and thus an indication of easy ignition and proportionate increase in flame length.

4.2 Effects of Mix Ratios on the Fixed Carbons on Blended Briquette using Reduced Cubic Model

Table 4

Anova for Reduced Cubic Model for Fixed Carbon.

Source	**Sun of squares**	**df**	**Mean square**	**F value**	**P Value**	
Model	**176.4**	**12**	**14.7**	**133.96**	**0.0009**	**Significant**
A Sawdust	0.3721	1	0.3721	3.39	0.1628	
B Coffee Husks	8.73	1	8.73	79.55	0.0030	
C Naize Stalks	18.71	1	18.71	170.41	0.0010	
AB	6.50	1	6.50	59.24	0.0046	
AC	5.06	1	5.06	46.12	0.0065	
BC	33.81	1	33.81	308.06	0.0004	
A^2	7.71	1	7.17	70.28	0.0036	
B^2	34.02	1	34.02	309.91	0.0004	
C^2	33.32	1	33.32	303.57	0.0004	
A^2B	0.2556	1	0.2556	2.33	0.0244	
A^2C	10.42	1	10.42	94.93	0.0023	
AB^2	8.82	1	8.82	80.35	0.0029	

The model's F-value of 133.96 shows that it's statistically significant, with only a 0.09% chance that such a high F-value could just be random noise. When P-values are less than 0.0500, it indicates that the model terms are significant. The key terms in this model include B, C, AB, AC, BC, A^2, B^2, C^2, A^2C, and AB^2. If any values exceed 0.1000, it suggests that those model terms are n0t significant.

4.2.1 Fit Statistics

Coefficient of variance (C.V.) is an indicator of the reliability of the experiment. A C.V. value whose percentage is less than 10% is reproducible. The C.V. % for this experiment is 4.13%, and it is reproducible. The R^2 value of 0.9981 lies in the acceptable range of 0.75 – 1.0 (Mukhopadhyay *et al.*, 2013) and indicates that 98.81% of variation of the results can be explained by this model. Adequate Precision is the signal-to-noise ratio. A ratio greater than 4 is desirable. Your ratio of 33.954 hence this model can be used to navigate the design space.

4.2.2 Final Equation in Terms of Coded Factors

$Fixed\ Carbons = 11.62 - 0.3050A - 1.48b - 2.16C + 1.27AB - 1.12AC + 2.91BC - 1.39A^2 - 2.92\ B^2\ \ -2.89C^2 +2.28A^2C-2.10AB^2$ ………………………………………………………………………… Equation 4-1

The equation in terms of coded factors can be used to anticipate the response for specific levels of each factor. By default, high levels of the components are coded as +1, while low levels are written as -1. The coded equation is useful for determining the relative impact of the elements by comparing their coefficients.

4.2.3 Final Equation in Terms of Actual Factors

$\text{Fixed Carbons} = -12.79594 + 0.261387 \cdot \text{Sawdust} - 0.2133681 \cdot \text{Coffee\_Husks} + 0.220781 \cdot \text{Maize\_Stalks} + 0.000999 \cdot \text{Sawdust} \cdot \text{Coffee\_Husks} - 0.001254 \cdot \text{Sawdust} \cdot \text{Maize\_Stalks} + 0.000291 \cdot \text{Coffee\_Husks} \cdot \text{Maize\_Stalks} - 0.000799 \cdot \text{Sawdust}^2 + 0.000233 \cdot \text{Coffee\_Husks}^2 - 0.000289 \cdot \text{Maize\_Stalks}^2 + 3.57500\text{E}{-07} \cdot \text{Sawdust}^2 \cdot \text{Coffee\_Husks} + 2.28250\text{E}{-06} \cdot \text{Sawdust}^2 \cdot \text{Maize\_Stalks} - 2.10000\text{E}{-06} \cdot \text{Sawdust} \cdot \text{Coffee\_Husks}^2$ ……………….Equation 4-2

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels are specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor, and the intercept is not at the centre of the design space.

4.3 Interaction Graphs

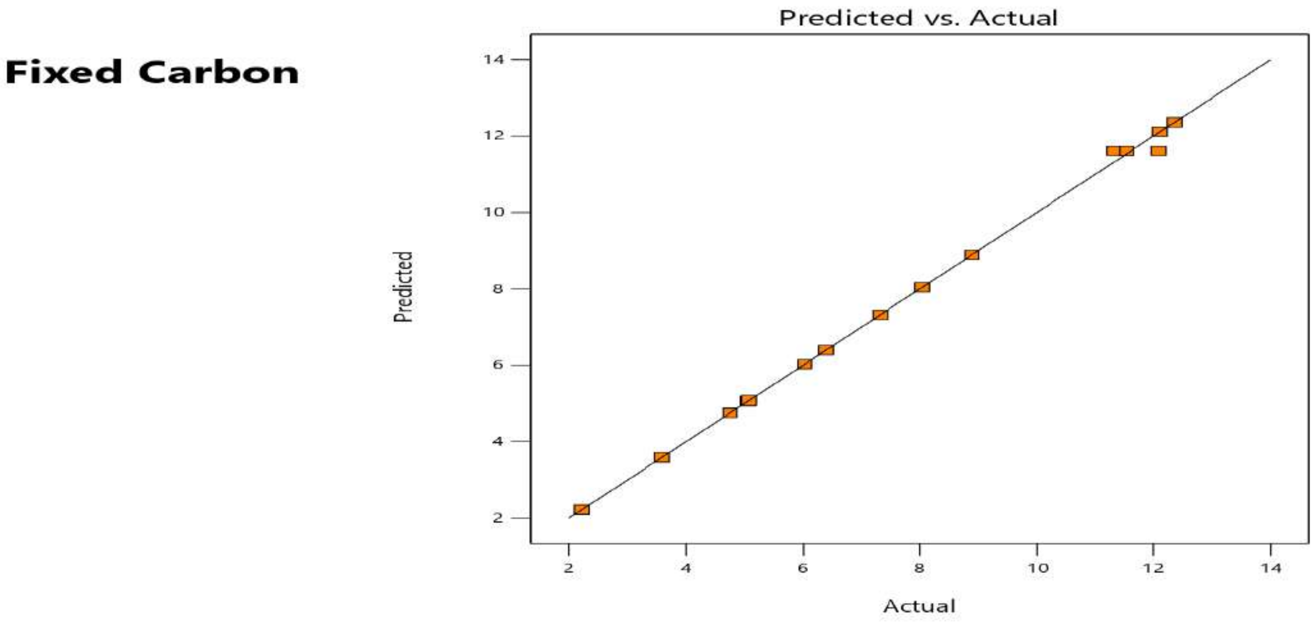

Figure 3
Predicted vs Actual Fixed Carbon of Blended Briquettes

Figure 4 depicts the expected fixed carbon values plotted against the experimental results. The observed good agreement (R2 = 0.9981) between actual and expected fixed carbon suggests that the model is substantial and sufficient to represent the experimental results in the area under consideration. Also, the graph shows that most points are split evenly by the 45-degree line, therefore the projected values are near to the actual ones. The data does not have values that deviate significantly from the diagonal line.

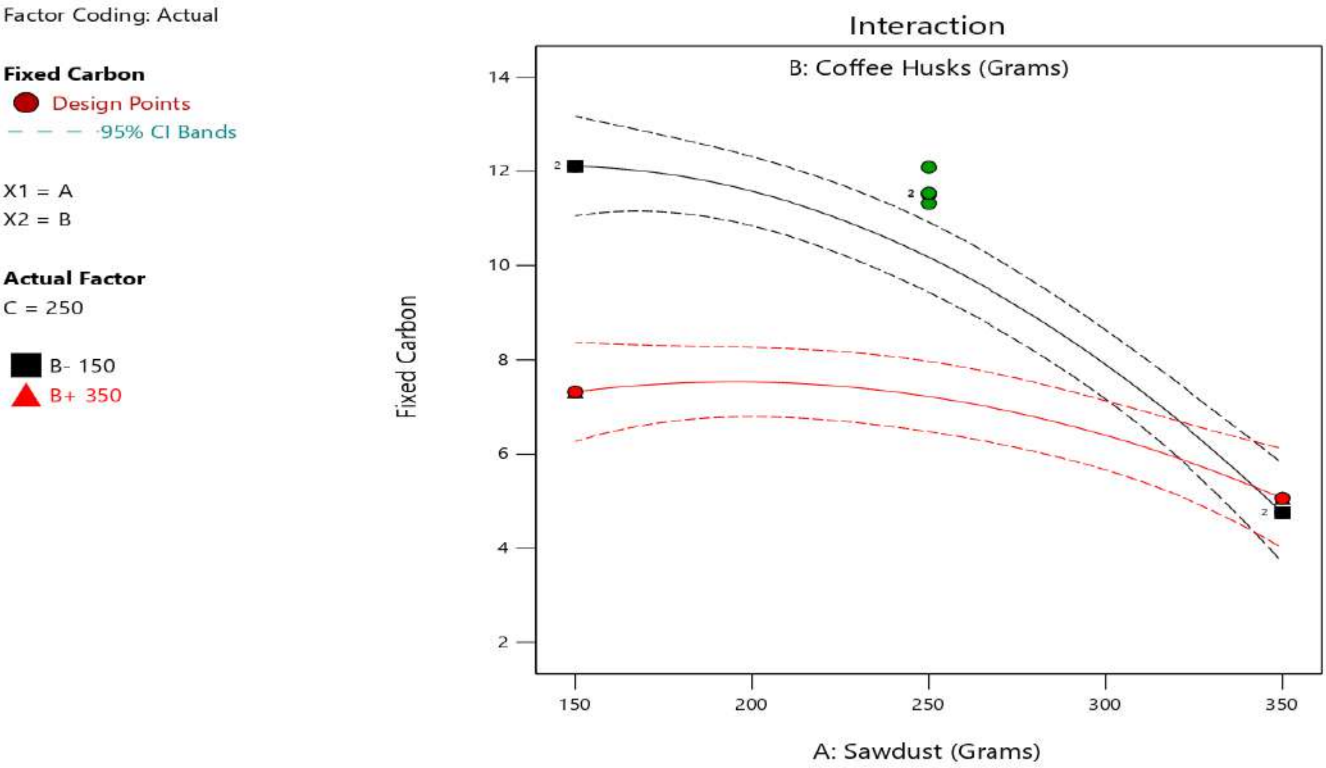

Figure 4
Interaction between Coffee Husk and Sawdust

Figure 5 depicts the interaction of coffee husks and sawdust in the measurement of fixed carbon. The graph shows that the lines linking the data points indicating different amounts of coffee husks are not parallel across the levels of sawdust. The lines also intersect, which strongly shows an interaction effect, implying that the relationship between sawdust and coffee husks and the response variable is different at different levels of the other factor.

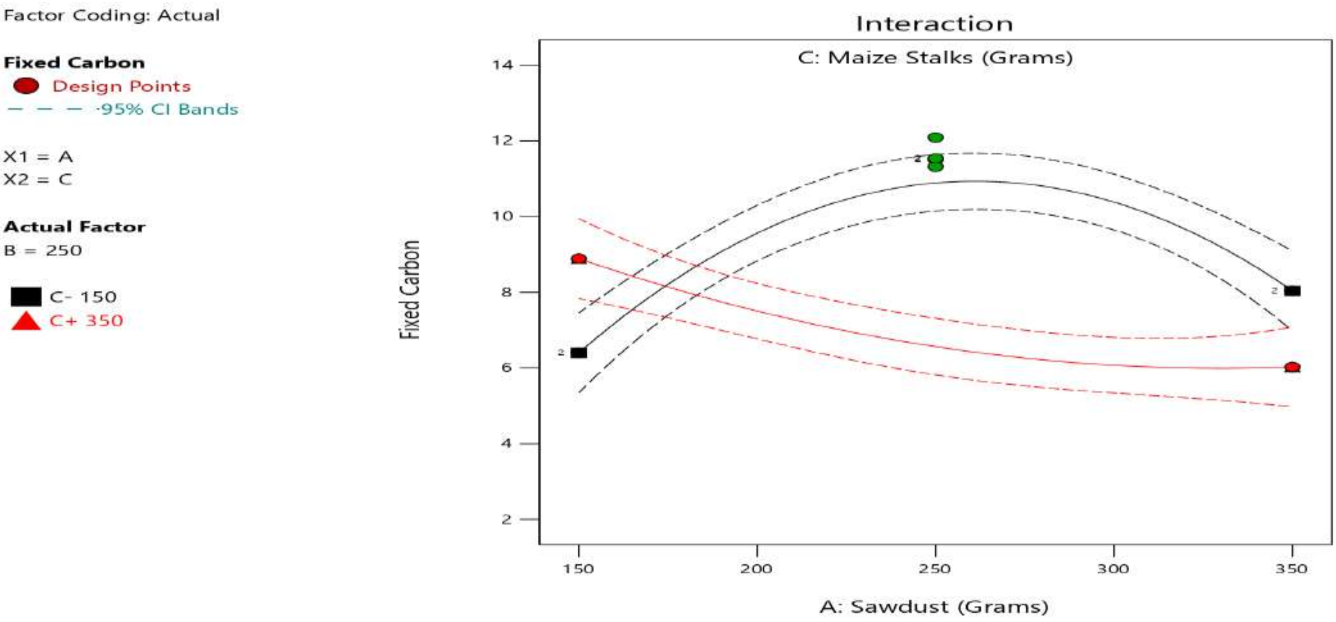

Figure 5
Interaction between Maize Stalks and Sawdust

Figure 6 depicts the interaction of maize stalks and sawdust in the study of fixed carbon. The graph shows that the lines linking the data points indicating different amounts of coffee husks are not parallel across the levels of sawdust. The lines also intersect, indicating a strong interaction effect. This means that the relationship between sawdust and coffee husks and the response variable varies depending on the level of the other factor.

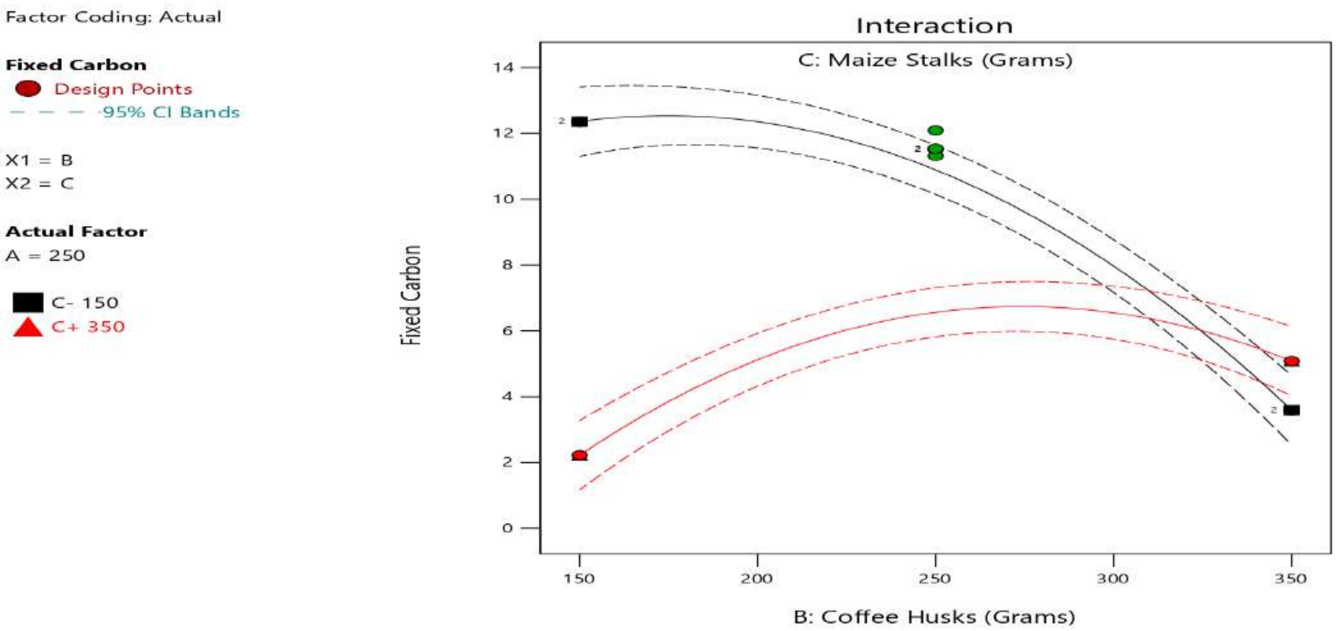

Figure 6

Interaction between Maize Stalks and Coffee Husks

To investigate fixed carbons, the two-factor interaction plots maize stalks and coffee husks to see if there is a difference between the two means, the interaction graphs. Figure 7 depicts the interaction of maize stalks and coffee husks in the study of fixed carbon. The graph shows that the lines linking the data points indicating different amounts of coffee husks are not parallel across the levels of sawdust. The lines also intersection, indicating a strong interaction effect. This means that the relationship between sawdust and coffee husks and the response variable varies depending on the level of the other factor.

4.4 Optimization of Combustion Properties of Blended Briquettes

The ideal combustion parameters of blended briquettes were determined via numerical optimisation. Design-Expert® Software's optimization method is based on a technique created by Derringer and Suich (1980), as described in (Meyers, 2009).The parameters was designed to fall within the maximum range for fixed carbon The ramping results, shown in Figure 8, were produced using the optimization criteria and a response desirability of 0.894. Figure 8 shows the desirability bar graph of the input variables of the fixed carbon while the optimization criteria is presented in Table 5. The starting points for optimization and solutions from optimization are presented in Appendix I and Appendix II respectively.

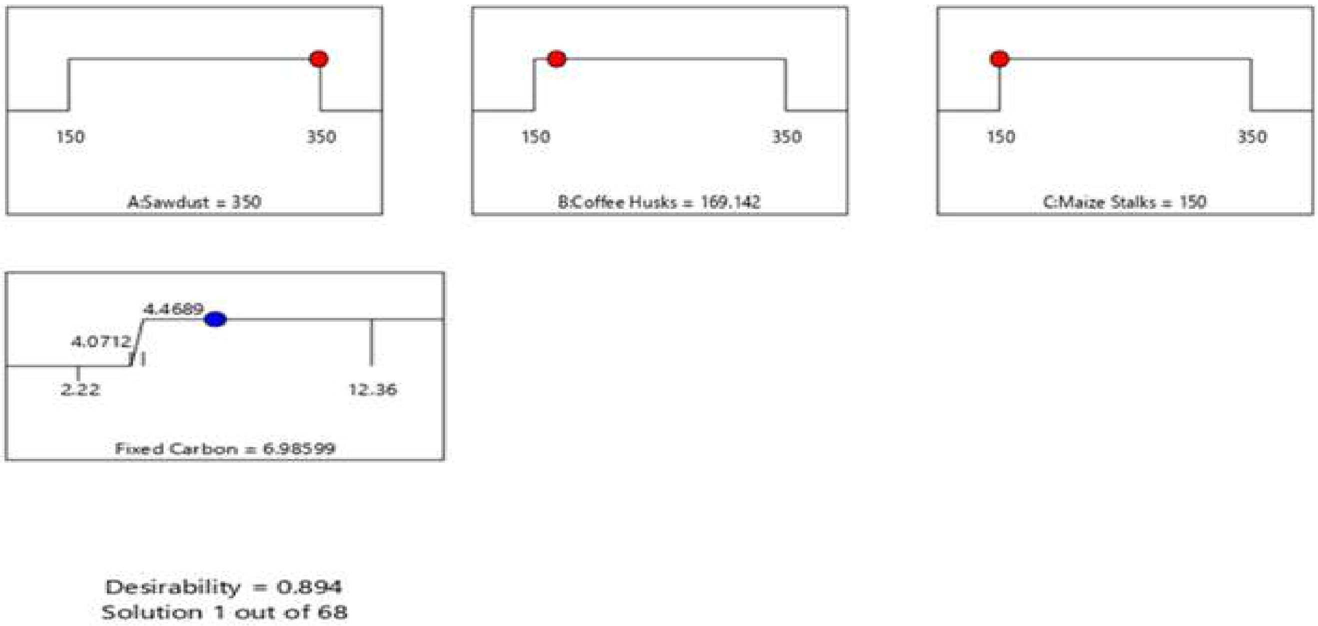

Figure 7
Numerical Optimization for Combustion Properties

Table 5
Optimization Matrix.

Name	**Goal**	**Lower Limit**	**Upper Limit**
Fixed Carbons	Maximum	2.22	12.36

The optimum blended ration was a combination of sawdust, coffee husk and maize stalks at a ratio of 350 grams, 169 grams and 150 grams with a result of 6.986 fixed carbon and a desirability of 0.894 as per Figure 8. The optimization of fixed carbon was capped at maximum because it approximates a fuel's thermal value and acts as the major heat source during combustion with the lower and upper limits being 2.22 and 12.36 respectively as shown by table 5.

V. CONCLUSION

Blended briquettes were developed from coffee husks, maize stalks, and sawdust, measuring 45mm by 45mm by 35mm.From the analysis of individual briquettes, Individual briquettes fixed carbons range between 8.58% and 13.08%. Sawdust gave 9.36%, coffee husks 8.58% and maize stalks at 13.08%. The quality of bio-briquettes improves as the fixed carbon value rises. Fixed carbon serves as a primary source of heat during combustion. The optimal mix ratio of coffee husks: maize stalks: sawdust is 2.3:1.1:1. This ratio gives a fixed Carbon of 6.986%. This has verified that blended briquette fuel has better combustion properties than individual briquettes made from coffee husks, maize stalks and sawdust.

VI. RECOMMENDATIONS

In the current investigation, the un-carbonized briquette binders were held constant at 10%. This should be adjusted to see if it impacts on fixed carbon. The current finding can be used as the basis for further investigation and optimization of briquette blending in the future, because the effect of modifying individual components has been known. Further research should be done to determine the effect of change in particle size, and change pressure in formation of blended briquettes as per the design of experiments to analyze the effect of fixed carbon on the blended briquettes.

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APPENDICES

Appendix I: *Optimization Starting Points.*

	Coffee Husks	Maize Stalks
350	250	350
250	250	250
150	250	350
250	350	150
250	150	150
150	150	250
150	350	250
150	250	150
250	350	350
350	250	150
350	150	250
350	350	250
250	150	350
333.669	163.375	222.676
289.438	271.777	213.02
282.378	180.005	202.639
328.314	175.409	166.055
163.131	296.348	294.634
260.817	269.458	333.59
172.253	242.558	202.305
285.651	272.199	198.035
179.943	179.152	328.919
196.63	256.544	270.77
298.871	155.343	157.475
299.68	348.135	327.782
233.407	179.096	175.012
156.741	324.434	348.374
245.946	194.051	204.247
181.44	262.106	155.274
167.289	307.197	155.638
284.454	217.76	209.325
225.378	258.481	226.475
191.743	184.878	241.661
167.127	312.835	317.604
344.869	165.973	324.246
229.92	159.155	286.586
289.278	272.05	168.625
255.159	178.086	169.941
202.228	331.195	314.796
344.72	224.598	229.752
234.133	325.984	344.435
255.88	207.111	241.925
219.866	273.631	200.97
190.038	347.237	236.993
262.211	187.688	299.83
171.955	259.954	164.039
339.097	295.187	215.335
190.043	193.664	195.562
242.814	302.512	159.641
269.693	167.453	197.836
260.999	177.163	290.778
208.876	268.809	169.109
179.687	312.495	242.34
348.828	208.575	208.814

259.226	204.17	294.432
267.403	176.537	298.917
179.673	166.191	287.208
284.833	191.505	246.638
235.451	254.859	161.396
240.985	195.14	259.17
236.828	247.841	225.92
195.089	236.776	218.968
193.993	261.073	327.571
312.671	165.279	194.19
196.75	174.944	312.953
219.679	191.204	237.74
174.293	227.806	268.953
292.977	150.484	242.881
299.409	189.84	219.63
176.097	280.69	307.363
218.725	279.823	228.984
263.647	217.611	315.679
326.701	195.049	192.709
322.721	232.438	235.035
169.179	214.587	257.795
302.174	254.31	200.722
189.522	278.389	284.752
304.738	239.478	170.827
318.879	230.148	225.92
302.54	234.299	328.587
321.09	248.822	276.633
168.92	280.916	198.878
332.369	193.397	264.337
188.409	153.968	218.915
293.117	262.129	296.209
252.286	157.412	291.645
168.1	342.318	162.503
203.17	262.426	247.375
242.159	231.199	236.248
253.664	306.141	198.894
290.836	319.399	164.208
225.071	222.287	330.578
225.728	234.645	322.899
276.624	270.27	266.812
230.468	230.487	212.346
318.904	165.682	313.302
188.14	215.983	329.005
312.2	168.674	221.725
325.543	190.494	227.895
160.202	189.462	176.961
299.527	170.09	318.145
186.193	175.425	187.79
258.767	269.941	250.059
308.076	183.18	286.939
240.183	330.781	265.883
273.094	169.91	188.993
203.485	341.923	295.721
333.108	234.704	342.039
336.928	328.974	263.227
217.153	162.098	216.55
162.195	317.035	223.776
205.454	245.61	244.907
311.211	320.184	218.825

Appendix II: *Optimization Solutions of Fixed Carbons.*

Number	**Sawdust**	**Coffee Husks**	**Maize Stalks**	**Fixed Carbon**	**Desirability**	
1	350.000	169.142	150.000	6.986	0.894	Selected
2	349.999	168.124	150.000	6.931	0.894	
3	349.999	168.771	151.148	6.993	0.893	
4	349.271	168.170	150.000	7.003	0.893	
5	349.998	165.267	150.000	6.771	0.892	
6	350.000	168.219	152.861	7.002	0.890	
7	349.350	164.117	150.001	6.767	0.890	
8	349.999	162.555	150.001	6.611	0.890	
9	347.720	166.234	150.001	7.044	0.889	
10	350.000	155.352	150.000	6.151	0.885	
11	345.162	163.133	150.000	7.112	0.883	
12	350.000	152.744	150.000	5.972	0.883	
13	350.000	151.133	150.001	5.858	0.882	
14	349.985	165.695	160.552	7.009	0.879	
15	345.808	151.719	150.000	6.333	0.876	
16	350.000	192.404	150.000	7.961	0.862	
17	349.999	150.000	167.583	6.014	0.861	
18	350.000	198.545	150.000	8.128	0.854	
19	342.512	150.001	165.561	6.730	0.852	
20	350.000	311.287	150.000	4.469	0.849	
21	350.000	316.359	157.154	4.469	0.845	
22	349.999	304.751	150.001	5.029	0.840	
23	347.427	313.009	150.000	4.469	0.840	
24	350.000	223.245	150.003	8.417	0.828	
25	350.000	329.947	179.400	4.469	0.827	
26	350.000	229.268	150.000	8.395	0.823	
27	350.000	238.664	150.000	8.288	0.817	
28	350.000	239.816	150.000	8.268	0.816	
29	350.000	270.990	150.000	7.241	0.813	
30	350.000	261.621	150.001	7.652	0.811	
31	350.000	150.000	209.181	5.866	0.808	
32	150.000	349.992	199.239	4.469	0.765	
33	150.000	350.000	200.136	4.532	0.765	
34	150.000	348.884	198.379	4.469	0.762	
35	151.471	349.935	198.401	4.469	0.762	
36	150.000	350.000	203.904	4.793	0.761	
37	152.298	349.642	197.720	4.469	0.759	
38	150.000	347.501	197.308	4.469	0.759	
39	154.311	349.999	196.919	4.469	0.755	
40	150.000	349.997	217.050	5.639	0.748	
41	350.000	150.000	238.518	5.161	0.747	
42	158.123	350.000	194.870	4.469	0.746	
43	150.000	350.000	222.270	5.947	0.742	
44	164.940	349.997	191.232	4.469	0.730	
45	150.000	350.000	233.294	6.546	0.730	
46	166.519	350.000	190.401	4.469	0.726	
47	150.000	331.896	185.311	4.469	0.719	
48	348.220	150.000	248.504	4.936	0.719	
49	170.000	349.999	188.580	4.469	0.718	
50	175.154	350.000	185.936	4.469	0.707	
51	290.295	150.000	150.000	10.676	0.702	
52	150.000	350.000	267.340	7.953	0.686	
53	150.040	313.776	171.580	4.469	0.678	
54	150.000	350.000	277.224	8.237	0.671	
55	350.000	157.861	270.395	4.648	0.659	
56	269.689	150.000	150.000	11.701	0.641	
57	150.000	291.125	154.800	4.469	0.639	
58	150.145	287.763	152.188	4.469	0.634	

59	150.002	286.400	151.331	4.469	0.633	
60	259.084	350.000	165.117	4.469	0.632	
61	222.767	350.000	167.298	4.469	0.627	
62	251.823	350.000	164.476	4.469	0.625	
63	228.802	350.000	166.055	4.469	0.623	
64	150.006	243.717	150.000	6.730	0.565	
65	157.656	254.384	150.000	6.771	0.564	
66	150.000	349.999	338.949	8.730	0.547	
67	159.106	219.569	150.001	8.617	0.522	
68	213.928	185.020	152.267	12.378	0.502	