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# Productive use of coffee husks

## How to make briquettes from coffee husk in Karagwe, Tanzania

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# Abstract

In the Tanzanian district of Karagwe the NGO KADERES is working with agricultural development. In relation to this they produce fair trade coffee obtained from local farmers. Coffee husks are created as a waste product from the plant and are currently not used for any purpose. Instead they are left outside the factory. The propose of this project is to find a way to create briquettes from these husks. On a technical level, there is two ways in which to produce briquettes; the carbonize-first and the densify-first method.

The carbonize-first method, is a technically more simplistic method and is the one most commonly used in East Africa. In this method, the coffee husks are first carbonized into charcoal using a charcoal kiln. The charcoal is then grinded and mixed with hot water and a chemical binder, usually a form of starch like cassava flour. The starch in this process binds the charcoal particles together, meaning that the binding of the briquettes is created chemically. The mixture is then pressed through an extruder that increase the density of the mixture, creating briquettes. The mixture is then dried until it reaches a sufficient moisture content.

The densify-first method is more high-tech. In this method the coffee husks are densified through a physical process. The lignin in the coffee husk welds them together, when enough pressure and temperature is applied. This is done using a briquetting press followed by a cooling belt with a preheating step preceding these two steps. There are two main types of briquettes presses, namely piston presses and screw presses. Both with pros and cons where piston presses are efficient if the bulk density is high. For densification to be optimal, the coffee husks need the right physical and chemical properties. Otherwise additional steps before densification are required. If the particle size is too big the husks needs to be crushed, if the moisture content is to high they need to be drayed and if unwanted material is in the biomass then sieving is needed.

Both the densify-first and the carbonize-first methods have their positive and negative sides. The carbonize-first method is adaptable for low to mid-range production within a price range suitable for Tanzania. The process can moreover use other biomasses then coffee husks under the same process. The efficiency is however low compared to briquettes made using the densify-first method. This method on the other hand, while creating better briquettes, is also more expensive in regards to the initial investment and requires equipment not found in the region. As such this study proceeds from this theoretical background to a methodologic section that aims to study which method is the best and what unit operations that are needed for that method.

The properties of the husk that where studied was their size, their bulk density and their moisture content. The particle size was measured in relation to height, width and length. The result indicated that the husks are bigger then the optimal size for the densify-first method and that crushing equipment is needed. The bulk density was measured using a one litre container. This was done both by shaking the husks to decrease the amount of air in the container and by not shaking the husk. The result indicated then when the husks where shaken the bulk density was high enough for a piston press to be used.

The moisture content was measured using a microwave. The husks where put into a container and their initial weight was measured. The husk where dried in a microwave oven for two minutes and additionally 30 seconds at the time until no more loss of weight was recorded. There was then assumed that this means that there was no water left in the husk. The result from the experiment

indicated that the husks were dry enough for briquetting whiteout the need for drying. This however, requires that the husks are kept dry and not exposed to rain.

A simple cost analysis based of the two methods was also done. This using data from other plants in East Africa as sources of reference. This analysis showed that the carbonize-first method had a lower cost of initial investment, but a higher cost of production then the densify-first method due to the need for cassava flour and water in the process. The densify-first method requires advanced machinery that has to be imported, but there is no major cost of production. Using a local sales price for briquettes the analysis showed that there is profit to be made from both methods.

A possible problem that could arise is the lack of a market for the briquettes, some plants is the region have been force to close down due to lack of sales. As this is a technical report and not an economical one, it’s of key importance that a proper economic analysis is made before plant construction start. This report can only conclude what is technically possible and needed, not if its economically viable.

With this information obtained the report concludes that a densify-first method is the better process. As a method it creates better briquettes for a lower cost of production then one made using the densify-first method. The initial cost is more expensive, but this will be worth it in the long run. The report further recommends that this method uses a crusher, a cooling belt and a preheater along with the briquetting press. A screw press is preferred over a piston press, due to several reasons. There are however presses made explicitly for coffee husk, so they are most likely the best.

# Table of content

# 1. Introduction

In the north-western part of Tanzania bordering Rwanda to the west and Uganda to the north is the district of Karagwe. The district is home to around 400,000 people, people that mostly live of sustenance farming. The main crops include staple foods such as beans, maze and cassava. The most important crop, however is coffee, a crop that is usually grown for cash alongside the staple crops. Even though coffee is of such local economic importance, its cultivation has not reach its full potential. An average harvest of coffee in Tanzania gives around 300 kg/hectare, compared to 2500 kg/hectare in countries with more developed agriculture. A difference most likely due to the region's economic environment making in difficult to invest in agricultural development (Ingenjörer utan gränser p. 1).

The local NGO "*Karagwe Development and Relief Service*", or KADERES for short, are working with the local farmers in the district to bring them out of poverty and to make their agriculture more efficient. Their main areas of focus are to educate farmers in agricultural technology, to be an incubator for local entrepreneurs and to work with the implementation of cultivation of coffee beans. In a step to increase the sales prices of coffee KADERS have in cooperation with external financiers constructed a factory for processing the raw bean into a sellable product. In the process, that the factory uses, unwanted material is separated from the beans and then the beans are washed, peeled and sorted leaving coffee husks as a by-product. (Ingenjörer utan gränser p. 2).

In 2014 the NGO Engineers Without Boarders started a cooperation with KADERES with three projects in mind. The projects where (1) to find a way to utilize the coffee husks that are created as an industrial bi-product, (2) to build tank for fresh water and (3) to develop a centre for education and development (Ingenjörer utan gränser p. 3-4). This paper will deal with the utilization of the coffee husks. Currently the husks are left outside of the factory for a significant amount of time, resulting in a negative environmental impact. This is also a waste of a resource that could be of economic value. On a theoretical level, several usages for the husk could be constructed, but KADERES and Engineers Without Boarders have concluded the production of briquettes is best suited for the local circumstances. As such the aim of the report is to find a method to use the coffee husks, that are created as a bi-product from the factory, to create briquettes.

The purpose of creating briquettes is to use them as an energy source for both personal and industrial use in the region. Currently firewood and charcoal are the most commonly used energy sources. Sources which 90 % of rural sub-Saharan Africa depend on (Falcão, M. P, 2008 p. 1). These are fuel sources that causes environmental degeneration when produced, as firewood and often charcoal requires trees to be cut down, in order to be made (Falcão, M. P, 2008 p. 1). As such, the production of briquettes from coffee husks will help to create a greener energy source that can be used by the local community.

## 1.2. Aim, propose and research questions

The purpose of the study is to find a method to convert the coffee husk at the KADERES factory in Karagwe into briquettes. Moreover; the purpose of this study is to study how this can best be achieved under local circumstances. As such the main questions that this paper aims to answer are:

- What unit operations are optimal for producing briquettes from coffee husks?
- What process parameters are important and how are they optimized?
- How should the process be adapted for local conditions?

# 2. Background

## 2.1 Coffee production in Tanzania, Karagwe and KADERES coffee factory

Today Tanzania stands for 1 % of the worlds coffee production and the crop stands for around 20 % of the nation's export, meaning that the produce is an important part of the national economy. Sixty-one million kilos where produced in 2011, even considering the low yield of production. Of this the region of Kagera, of which the district of Karagwe is a part, produced twenty-one million kilos in 2011/12, mostly produced by small scale farmers (Goebel, Jürgen, 2014 p. 4-5). KADERES factory is located in the town of Kayanga and has a capacity to produce 2000 kg of coffee/hour. It was built for a cost of 1.3 billion dollars of which 1.1 billion dollars was obtained externally. The coffee is supplied from 4 500 small farmers and the aim is that the factory should be able to produce 10 billion kilos yearly at full capacity. This goal is not yet reached (Goebel, Jürgen, 2014 p. 9).

## 2.2. The composition and the environmental consequences of coffee husks

Coffee husks are rich in organic material and consists mostly of cellulose, hemicellulose, pectin and lignin. It also contains amounts of other substances. (Nguyen et al., 2013 p. 77). Two of these chemicals, caffeine and tannin, can have negative environmental impacts, especially if nearby water sources are exposed to them, as this can cause health problems such as irritation of the skin, problem with breading and stomach problems. The lack of oxygen in the water that follows exposure can moreover cause problems for aquatic organism and for the local aquatic ecosystem (Padmapriya R,. et al., 2013 p. 4-5).

## 2.3. What are briquettes

Briquettes are produced through a densification process into which biomass consisting of solid particles are pressed together in order to increase the density while agglomerating the material so that it remains in a compact state (Grover & S.K. Mishra, 1996 p. 7-8). The product also needs to be bigger than 30 mm, otherwise the product is defined as pellets (S. Eriksson & M. Prior 1990). The purpose of the densification is to improve "*the handling characteristics of the materials for transport, storing etc.*" as well as to increase the volumetric calorific value which strengthens their use in energy production. Briquetting can be done through several processes but can, in regards to "*the basis of compaction*", be divided into high, medium and low pressure briquetting, where low pressure briquetting needs a binder to bind the particles together and in high pressure briquetting this occurs due to pressure and temperature. (Grover & S.K. Mishra, 1996 p. 7-8). Briquetting can also be divided into the categories of "*the briquetting-carbonization (BC) option*", (high pressure) and "*the carbonization-briquetting (CB) option*" (low pressure) (S. C. Bhattacharya et al. 1990 p. 499). They are also called the "*densify-first*" and the "*carbonize-first*" methods (T.H. Mwampamba et al., 2013 p. 161-164), a terminology that will be used in this report.

## 2.4. Carbonize-first briquetting

### 2.4.1. General process for low pressure carbonize-first briquettes in East Africa

Carbonize-first briquetting is the method most commonly used in East Africa and its central methodological component is that the briquettes are compacted using a binder (T.H. Mwampamba et al., 2013 p. 161-164 & George K. Ngusale et al., 2014 p. 751-752). In the literature several description of this method can be found (T.H. Mwampamba et al., 2013 p. 161-164 & George K. Ngusale et al., 2014 p. 751-756 & Bonale, Wondwossen, 2009 p. 82-95). Moreover, a visit to the Tanzanian NGO ARTI-energy in Dar-es Salaam on the 27th of September 2016 was done in order to observe their method of briquette making. ARTI produces charcoal briquettes from agricultural waste. This waste is then carbonized in a charcoal kiln. The charcoal is then grinded and filtrated into smaller pieces and then mixed with water and cassava flour. That step is followed by densification, in which the charcoal-water-cassava mixture is pressed in an extruder after which they are sundried until they reach a water content of below 14 %, which takes around a week (ARTI-energy). A flowchart of the process is presented in *Figure 1*.

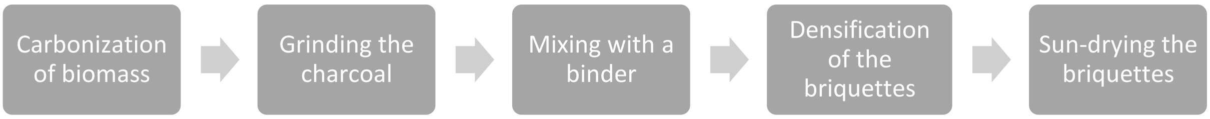


*Figure 1: a flow chart over the carbonize-first process bases on ARTI-energy and T.H. Mwampamba et al. (2013 p. 161)*

This method finds support in the literature. T.H. Mwampamba et al. describes that the key compounded of this process is that briquettes are made from "*biomass that is carbonized before being densified*" (2013 p. 161). A similar flowchart to the one above is described by G.K. Ngusale et al. except that they don't have the grinding step and have added the preparation of raw biomass as a step (2014 p. 751). This step is excluded due to the reason that the husks already are at the factory. The other papers mentioned give a similar overview of charcoal briquette production using the carbonize-first method. The steps will now be described in more detail.

### 2.4.2. Carbonization of biomass

Carbonization is as its core a process in which an organic substance is turned into carbon and this is often done by pyrolysis, a process in which carbonization is done at high temperatures in an environment that lacks oxygen and this can be done in what is called a charcoal kiln. These kilns can be constructed in several ways but the key principle is that the biomass is packed in such a way that most oxygen can mostly enter only from two opposite facing ends. In some models smaller holes in other ends lets in small amounts of oxygen. At one end there is a chimney and at the other there is an ignition source (V. Siemons & Baaijens, 2012 p. 133-134 & ARTI-energy).

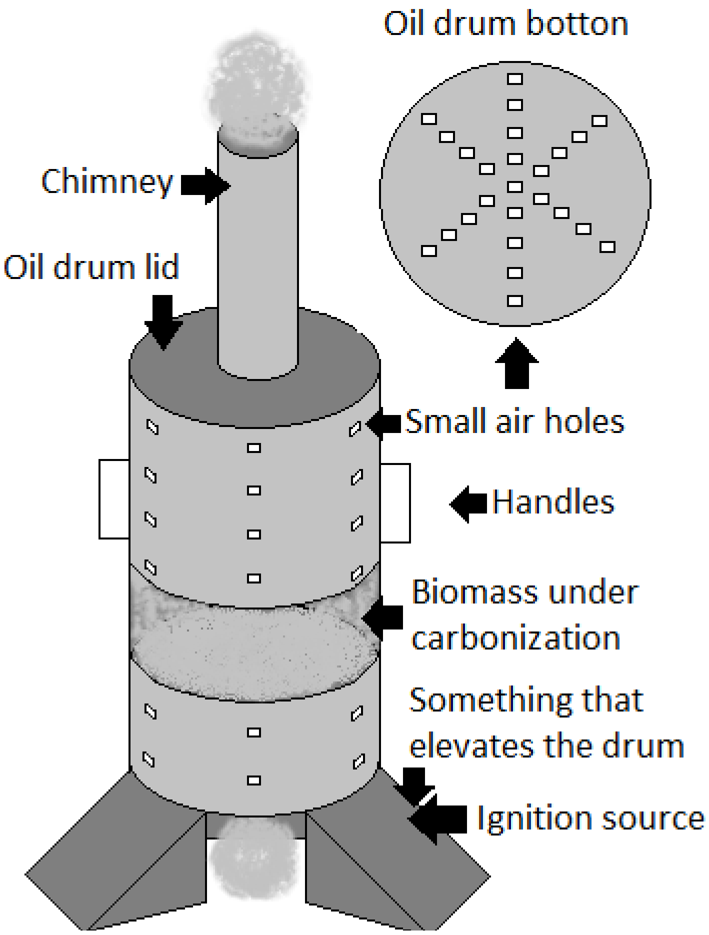


*Figure 2: A charcoal kiln based ARTI-energy design*

When that ignition source is ignited, it causes a high-temperature gas to spreads through the biomass spreading heat through it. This does not cause ignition of the biomass due to the lack of oxygen, except some burning at the edges, if some oxygen is allowed in. The gas is then released through the chimney as smoke. The carbonization of the biomass starts as a spontaneous chain reaction due to the heat. As the carbonization is an exothermic reaction that releases energy, the release continues to carbonize the biomass until all of it is carbonized. This process also results in other chemicals being produced. In the case of wood as biomass these products are "*water vapour, methanol, acetic acid and more complex chemicals*" such as "*form of* *tars*“ and “*hydrogen, carbon monoxide and carbon dioxide*”. (Food and Agricultural Organization of the United Nations, 1983 & ARTI-energy).

Charcoal kiln can be designed in several different ways. ARTI-energy’s model is constructed from two oil drums of which one work as the main part of the kiln. The lid of that oil drum is fitted with a chimney from the other one, handles are attached and small holes are created on to the button. The kiln is put above a fireplace that is then ignited. When smoke can be seen in the chimney the kiln is put on the ground to finalize the carbonization. See *figure 2*. Other types of kiln are available, for instance what is called mounded kilns or brick kilns. These kilns exist in several types, but the key difference from oil drum kilns is that they are of bigger size, immobile and that the airflow can be regulated (Food and Agricultural Organization of the United Nations).

### 2.4.3. Grinding and binding of the charcoal

For the briquettes to be manufactured a binder needs to be added. The reason being that the charcoal and water itself cannot bind the charcoal together as charcoal lacks plasticity (Food and Agricultural Organization of the United Nations). Several different types of binding agents can be used, ranging from paper and clay to mangos (Abia Katimbo et al., 2014 p. 147-148 & George K. Ngusale et al., 2014 p. 754). The most efficient binding agent is starch (Food and Agricultural Organization of the United Nations) and it can be added as both flour and as grinded down plants from crops of high starch content, such as entire cassava tubers (ARTI-energy).

A common biding agent in East Africa is cassava flour due to its high starch content and locally cheap price. The flour is added to water and the mixture is heated up to around 100 C$^o$ in order to facilitate the mixing. ARTI uses four kilos of cassava and 20 litres of water per 40 kilos of charcoal (ARTI-energy). Different proportions can however be used, for instance 1 litres of water per 153 grams of cassava flour and 2 kilos of charcoal (Abia Katimbo et al., 2014 p. 147-148). There is no mentioning of grinding the charcoal in the literature, but according to ARTI-energy the charcoal needs to be grinded into smaller pieces, which might require filtration, before the binder is added. The reason being that lumps of charcoal cannot be bound together (ARTI-energy).

### 2.4.4. Densifying and drying the briquettes

When the mixture is done, it needs to be added to a charcoal extruder. These extruders press the mixture together using mechanical force to increase the density (ATRI-energy). There are several types of extruders, both manual and electric ones with different capacities (George K. Ngusale et al., 2014 p. 754-756). This process should be done in connection with the mixing (ARTI-energy). The final step is to dry the briquettes, a process that is done by letting the briquettes dry in the sun. This is done until they have reached a moisture level of under 14 %. This process can also be done in a drying-oven. (ARTI-energy).

## 2.5. Densify-first briquetting

### 2.5.1. General process for densify-first briquettes

The principle of densify-first briquetting is that instead of adding an external binder, the biomass contains the binder itself. Under high pressure and temperature that internal binder binds the briquettes. This means this method can only be used for material that contains such an internal binder. The material that act as that, in most briquetting process that uses a densify-first process, is lignin. Lignin works as a “*thermo plastic polymer*” where the material softens when 100 C$^0$ is reached and it starts “*flowing at higher temperatures”* which causes the biomass to “*weld*” together (S. Eriksson & M. Prior 1990 & Grover & S.K. Mishra, 1996 p. 8-9).

The unit operations that a densify-first process requires varies depending on the chemical characteristics of the acquired biomass. Unit operations that can be used are sieving, drying, crushing, preheating, densification, cooling and packing. Of these operations, it's possible that the preheating, densification, cooling and packing steps are the only ones needed. If not, there are three different process that are "*generally required*" before preheating. The biomass can be sieved and dried, sieved and crushed or dried or crushed (Grover & S.K. Mishra, 1996 p. 12-14). These briquettes will however not be charcoal briquettes, but these briquettes can be transformed to charcoal briquettes using a brick kiln (T.H. Mwampamba et al., 2013 p. 164). A flow chart of the process can be outlined as shown in *Figure 3* (if the packing step is excluded):

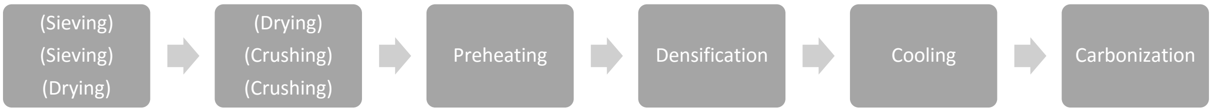


*Figure 3: a flow chart over the densify-first method bases on Grover & S.K. Mishra (1996 p. 12-14).*

#### 2.5.1.1. *Important parameters*

In order to produce good quality briquettes, it's important to optimize the parameters of the feed. One parameter of key importance is the size of the biomass. In general material of 6-8 mm in size "*with 10-20 % powdery content*" gives the best briquetting result. If high enough pressure is applied larger particles can be used, this can however jam the machine and will produce briquettes of lesser quality. If a screw press is used (described later), then particles below 1 mm are not suitable. Another important parameter is the moisture content of the biomass. If the moisture content is too high, (usually when it is exceeding 10 %) then the briquettes might be poor and easily break. The optimal moisture content depends on the type of briquetting used. The effect of temperature, both on the biomass and the die are also important (Grover & S.K. Mishra, 1996 p. 12-14).

### 2.5.2. Sieving, drying the crushing

These unit operations are needed in order to change the biomass so that it contains material of optimal size and moisture content for densification. The purpose of sieving is to separate the biomass from unwanted material, such as stones or larger pieces of wood when sawdust is used as the main biomass. This is a process that can be done in several ways, including with a vibratory screen. Draying is needed if the materials water content is to high, as such it's not needed for some biomass, like coffee husks in most instances, but is of fundamental importance for other types of biomass. Dryers exists in several models, ranging from flash dryers to cabinet dryers. As the biomass before densification needs to be of optimal size the biomass might need to be crushed in order to obtain that optimal size. There are several types of crushing equipment, but hammer mills can efficiently be used. They crush the material by repeated blows by small hammers that are moved by an engine (Grover & S.K. Mishra, 1996 p. 12-18).

### 2.5.3. Preheating

Preheating can be essential for optimizing the briquetting process and is a unit operation in which the temperature of the biomass is increased before densification. The reason being that this "*relaxes the inherent fibre in the biomass*" which increases its softens. This in turn decreases the power consumption for the process as well as increases its production rate. Moreover, as binder less briquetting requires high temperatures under high pressure this would require the entire temperature increase to be done through mechanical friction if preheating was not used (Grover & S.K. Mishra, 1996 p. 13-14, 22-23). There are several different types of preheaters. In one common type the biomass is let through a pipe that is surrounded by a shell. In this shell, hot gas or oil is passed through in order to heat up the biomass, a process that uses electricity. This type of machinery requires a significant electricity input and as such biomass driven stoves can be used to heat up the biomass in order to save the cost of electricity (Grover & S.K. Mishra, 1996 p. 23-26 & S.C. Bhattacharya et al., 2002 p. 3-6)

### 2.5.4. Densification

Densification can be done through several types of machinery. The three most common types are mechanical piston presses, hydraulic piston presses and screw presses. Piston presses work by feeding the die into a pipe that contains a piston. The pipes cross sectional area is decreased and when the piston is pressed, it forces the die in the that area to increase its density and create briquettes. With each stroke more die is added and there is still material left from the previous stroke. The difference between a hydraulic and mechanic piston press is the way the piston is being moved. In a mechanical piston press "*the piston gets its reciprocating action by being mounted eccentrically on a crank-shaft with a flywheel*" where "*the shaft, piston rod and the guide for the rod are held in an oil-bath*". In a hydraulic piston press the energy comes from an electric motor linked to a "*high pressure hydraulic oil system*". The mechanical piston press capacity, will moreover depend on the bulk density of the material. A high bulk density corresponds with high capacity where wood with a bulk density of 150 kg/m$^3$ have a capacity index of 100. See *Figure 4 for* a piston press (S. Eriksson & M. Prior 1990).

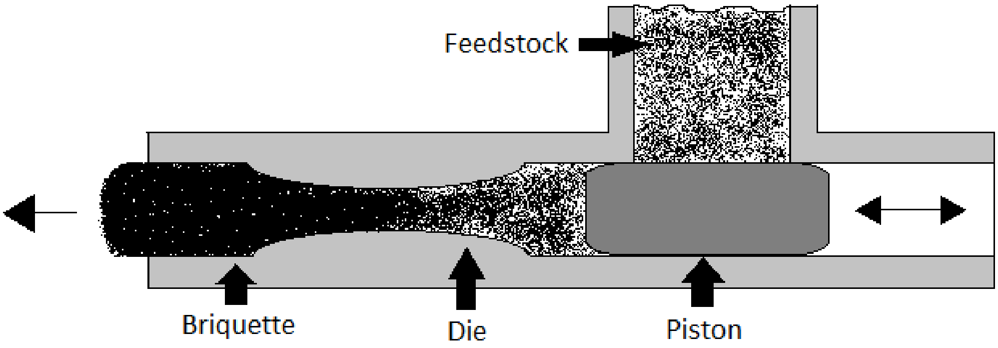


*Figure 4: A piston press based on S. Eriksson & M. Prior (1990).*

Screw presses work in a similar fashion. The die is entered through the feedstock into the machine. Inside the machine there is a screw that forces the die forward while the area of the die is decreasing. This forces the density of the die to increase until it forms briquettes. *Figure 5* illustrates one type of screw press, one with a conical screw, but the principle is the same for all screw presses. The process can be done with or without heating the die. The die is often heated by a heated wire, usually an electric one, that have been constructed to surround the die. These types of presses also give the final briquettes holes in the middle (S. Eriksson & M. Prior 1990).

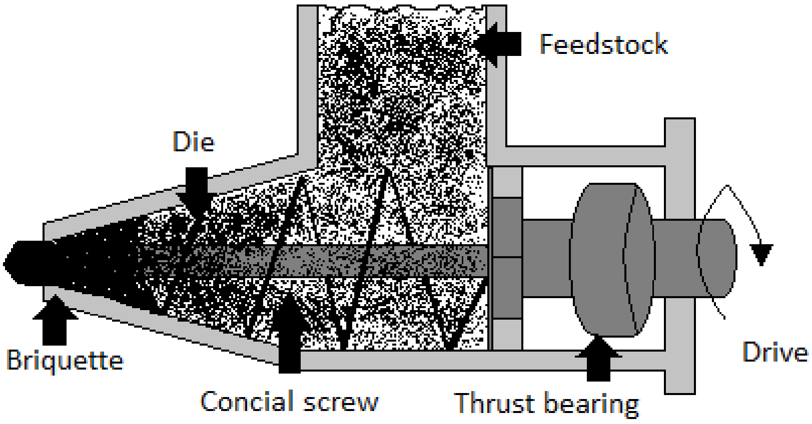


*Figure 3: A screw press based on S. Eriksson & M. Prior (1990).*

Both the piston and the crew presses have their respective advantages and disadvantages, depending on the local circumstance and the biomass being briquetted. Piston presses has the disadvantages that the briquettes produced have worse "*combustion performance*" then briquettes produced using a screw press. These briquettes, moreover, cannot be carbonized to charcoal, nor are they "*suitable in gasifiers*", which ones made from a screw press are. Screw press briquettes are also homogenous in size and form and are done in a continues process. Screw presses have a lower maintenance cost then piston presses, but it wears out quicker and requires more power. The optimal moisture content also varies, 10-15 % for piston presses and 8-9 % for screw presses (Grover & S.K. Mishra, 1996 p. 10-11).

### 2.5.5. Cooling and carbonization

When the briquettes have been densified they can have surface temperature of above 200 C$^0$, and as a result they need to cool down, a process which can be done by letting the briquettes travel on a conveyer belt of appropriate length (Grover & S.K. Mishra, 1996 p. 20). These briquettes could later be carbonized in a brick kiln or in more industrialised carbonization equipment (T.H. Mwampamba et al., 2013 p. 163). The main difference between carbonized and non-carbonized briquettes are that the non-carbonized ones create far more smoke when used.

### 2.5.6. Mass and energy balances

Below is a mass and energy balance chart describing the densify-first briquetting method, excluding the carbonization step. The balances are taken from “*Biomass Briquetting: Technology and Practices*” by P.D Grover and S.K. Mishra (1996 p. 30-33) and it have been somewhat modified in regards to nomenclature. The balances are moreover from a process which uses preheating and have a furnace powered by the biomass as an energy source for preheating and draying. See *figure 4* for the chart over the balances and *table 1* for its nomenclature, including ones used in more detailed descriptions of the balances. Feed processes includes sieving, crushing and drying. *Equation 1* described the mass balance for the entire system, *Equation 2* the mass balance of the feed processing, *Equation 3* the material loss at the feed processing, *Equation 4* the moisture loss at the feed processing, *Equation 5* the mass balance for the pre-heating, *Equation 6* the moisture loss for the pre-heating, *Equation 7* the mass balance for the briquetting and cooling, *Equation 8* the moisture loss for the briquetting and cooling, *Equation 9* the energy needed for draying and *Equation 10* the energy needed for pre-heating.

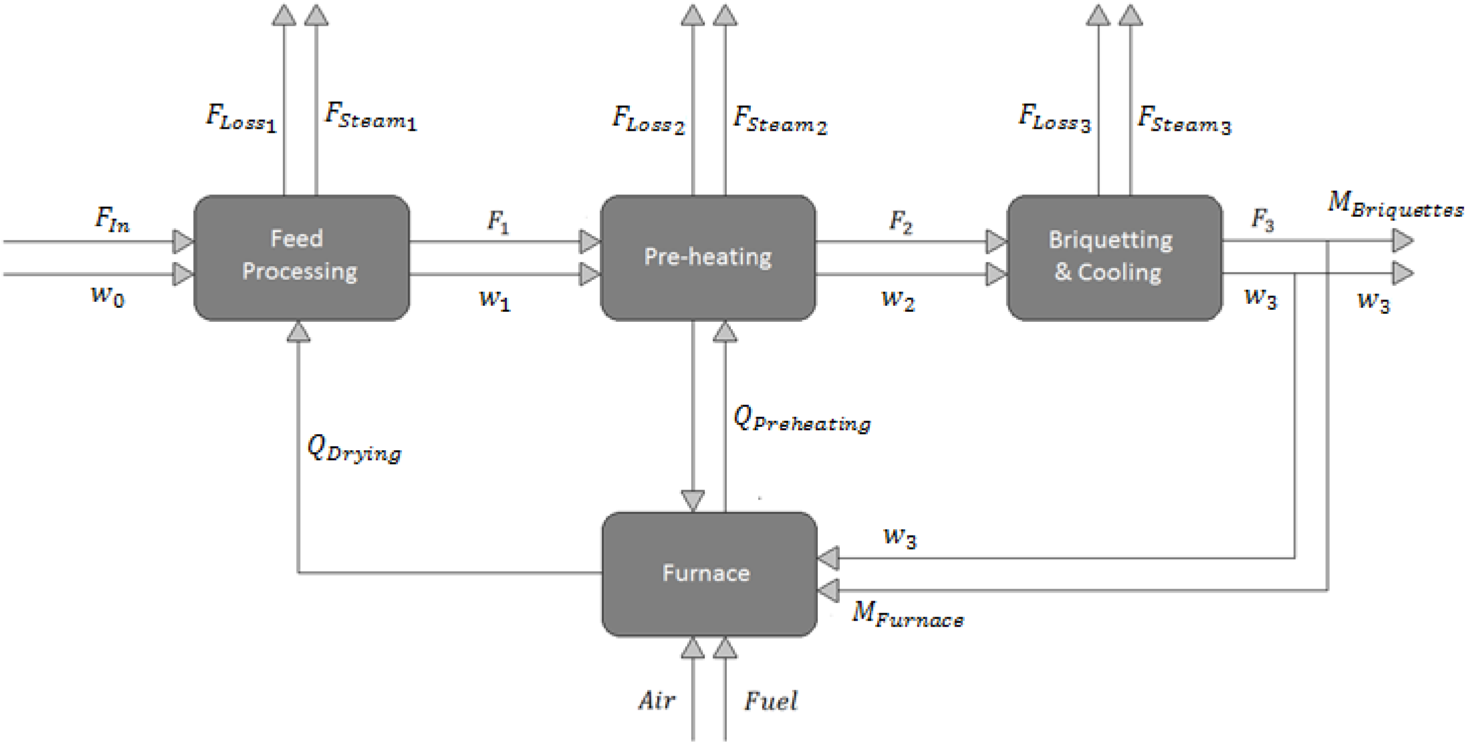


*Figure 4: A mass and energy balance chart over the densify-first process*

Table 1: The variables used in figure 4, their explanation and unit

| VARIABLE | EXPLANATION | UNIT |
|---|---|---|
| $\boldsymbol{F_{In}}$ | Feed rate with w moisture content | kg/h |
| $\boldsymbol{F_{1,2,3}}$ | Feed from different components | kg/h |
| $\boldsymbol{F_{Steam_{1,2,3}}}$ | Moisture losses from components | $kg_{water}/h$ |
| $\boldsymbol{F_{Loss_{1,2,3}}}$ | Material losses from components | $kg_{dry\ weight}$ /h |
| $\boldsymbol{M_{Furnace}}$ | Mass of briquettes used in furnace | kg/h |
| $\boldsymbol{M_{Briquettes}}$ | Mass of briquettes produced | kg/h |
| $\boldsymbol{w_{0,1,2,3}}$ | Moisture content to and from different components | $kg_{water}/kg_{dry\ weight}$ |
| $\boldsymbol{Q_{Drying}}$ | Energy used in draying | kJ/h |
| $\boldsymbol{Q_{Preheating}}$ | Energy used in preheating | kJ/h |
| $\boldsymbol{T_{0,1,2}}$ | Temperature at different components | $C^{O}$ |
| $\boldsymbol{C_{P_{biomass}}}$ | Specific heat capacity for biomass | kJ/(kg* $C^{O}$) |
| **A, B** | Constants taken from P.D Grover and S.K. Mishra (1996 p. 30-33) | kj/kg |

*Total mass balance*

$$F_{In} - \sum_{1}^{3}(F_{Steam} + F_{Loss}) - M_{Furnace} = M_{Briquettes} \tag{1}$$

*Feed processing system (sieving, drying and crushing)*

$$F_{In} = F_1 + F_{Steam_1} + F_{Loss_1} \tag{2}$$

$$F_{Loss_1} = 0.01 * \left(F_{In} - F_{Steam_1}\right) \tag{3}$$

$$F_{Steam_1} = w_0 * F_{In} - 0.1 * \left(F_{In} - F_{Steam_1}\right) \tag{4}$$

$$If\ w_0 \leq 0.1\ no\ drying\ is\ required\ and\ F_{Steam_1} = 0$$

*Preheating*

$$F_1 = F_2 + F_{Steam_2} + F_{Loss_2} \tag{5}$$

$$F_{Steam_2} = F_1 * w_1 - \left(F_1 - F_{Steam_2}\right) * w_2 \tag{6}$$

*Densifying and cooling*

$$F_2 = F_3 + F_{Steam_3} + F_{Loss_3} = M_{Furnace} + M_{Briquettes} \tag{7}$$

$$F_{Loss_3} = 0.011 * \left(F_2 - F_{Steam_3}\right) \tag{8}$$

$$F_{Steam_3} = F_2 * w_2 - \left(F_2 - F_{Steam_3}\right) * w_3 \tag{9}$$

$$F_3 = M_{Furnace} + M_{Briquettes} \tag{10}$$

*Furnace*

$$Q_{Drying} = F_{In} * (1 - w_0) * 0.3 * (T_1 - T_0) + F_{In} * w_0 * (T_1 - T_0) + A * F_{Steam_1} \tag{11}$$

$$Q_{Preheating} = F_1 * C_{P_{biomass}} * (T_2 - T_1) + F_{Steam_2} * B \tag{12}$$

## 2.6. Coffee husk and briquetting

The high content of organic material results in that briquettes created from coffee husk have a high-energy content. As such it can be used as an energy source on equal footing with other fuels such as coal and firewood. They also have a lower moisture level then fire wood and a higher density making them more efficient. Experimental data, moreover, indicates that coffee husks have a moisture content of 10 %, a bulk density of 196 kg/m$^3$ and a minimum heating level of 18.39 MJ/kg (Suarez et al., 2003 p. 961-962). Coffee husk is a material that have been shown to work as a biomass for briquetting. However, data does not exist for all the different methods of briquetting described. No usage of piston presses for coffee husk briquetting have been found but usage of screw presses are mentioned in the literature (S. Eriksson & M. Prior 1990). Making charcoal briquettes from coffee husk have been tried, even if no example from ARTI-energy exist (ARTI-energy). An alternative carbonization method in Nairobi, still under developed, have been able to carbonize coffee husks without "*no major wastage*" (George K. Ngusale et al., 2014 p. 751-756).

## 2.7. Statistics

Statistics analysis is used in a scientific study to analyse how the obtained data can be organized and analysed. The mean value of a sample is a fundamental statistical tool and is calculated as shown in *Equation 13*:

$$\bar{x} = \frac{\sum x_i}{n} \tag{13}$$

Where $\bar{x}$ is the mean for the sample, $x_i$ is the value of each measurement and $n$ is the sample size (Douglas Lind et al., 2011 p. 60). Another important statistical toll is the standard deviation of the sample. This deviation could be described to give the spread of values from the calculated mean. The most common way the calculate the standard deviation can be seen if *Equation 14:*

$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n - 1}} \tag{14}$$

Where s is the standard deviation for the sample and the rest are the same as in *Equation 1* (Douglas Lind et al., 2011 p. 83-84). The standard error of the mean, moreover, is also a common statistical tool. This is a value that estimates "*the stranded deviation of a sampling distribution*" and is described in *Equation 15*:

$$SE_{\bar{X}} = \frac{s}{\sqrt{n}} \tag{15}$$

Where $SE_{\bar{X}}$ is the standard error of the mean and the rest the same as in *Equation 1* and *Equation 2* (Douglas Lind et al., 2011 p. 730). The interpretation of the equation is that when the sample size increase that level of error for the standard deviation and mean deceases. All the formulas are for a sample of a population (Douglas Lind et al., 2011 p. 58-60, 79-84). They can also be calculated from total population, a value that is more difficult to obtained, but will give a more secure value. If the population is theoretically known, that a one sample t-test can be done. For this test two hypotheses are postulated. $H_0$ that there is no significant difference between the sample and the population and $H_1$ is that there is. The hypothesises are tested using *Equation 16*:

$$t = \frac{\bar{x} - \mu}{s} * \sqrt{n} \tag{16}$$

Where t is the t-value, $\mu$ is the mean of the population and the rest are the same as in previous equations. The t value for a specific confidence interval can be given from a table, where it depends of the degree of freedoms which is defined as n – 1. Were n is the sample size. If the following is true, $|calculated\ t| \leq |table\ t|$ then $H_0$ is true (Statistical Solutions).

### 2.8. Cost analysis

A cost analysis is an analysis in which the economic viability of a plant, in terms of its cost and profitability is done. In the short term the probability of a briquetting plant is the difference between total sales and the cost of production plus the cost of raw materials. This does however not take into account the initial investment of the plant. In the long term the investment is important and its used to analyse the pay-back period (Grover & S.K. Mishra, 1996 p. 39-40). Below follows this reasoning in mathematical terms with the basis in economic theory. The investment will be considered as a fixed cost (it does not depend on volume, even if a larger process requires more investment) and the cost of production will be a variable cost (that will depend on volume). *Table 2* shows the nomenclature of the variables used. *Equation 17* shows the total cost of production, *Equation 18* the profitability and *Equation 19* the pay-back period (P. Skärvad & J. Olsson, 2015 p. 245-246 & Grover & S.K. Mishra, 1996 p. 39-40). The nomenclature is translated.

*Table 2: The variables used in the cost analysis and their explanation*

| ***VARIABLE*** | ***EXPLANATION*** |
|---|---|
| $TC$ | *Total cost of production* |
| $FC$ | *Fixed cost of production* |
| $VC$ | *Variable cost of production* |
| $Q$ | *Quantity of production* |
| $S$ | *Sales price* |
| $P$ | *Profit (short term)* |
| $T$ | *Time to cover investment* |

$$TC = FC + VC * Q \tag{17}$$

$$P = S * Q - VC * Q \tag{18}$$

$$T = FC/P \tag{19}$$

It is also important to have a grasp of the approximated size of the economic variables in an analysis, namely what cost are included in the initial investment and cost of production. In other words, their cost centres. Below follow the cost centres for the investment and cost of production for a briquetting plant as presented by P.D Grover and S.K. Mishra, see *table 3* (1996 p. 39-40). Their presentation include water, which here is change to additional material to include other materials as well.

*Table 3: The different cost centres for the initial investment and cost of production for briquette making*

| **Investment** | **Cost of production/hour** |
|---|---|
| Machinery and installation | Power |
| Land | Manpower |
| Building | Additional material |
| Total investment | Maintenance |
| Working capital | Administration |
| | Deprecation |
| | Subtotal |
| | Financial cost |

# 3. Method and material

## 3.1. Analysing the chemical properties of the coffee husks

The aim of the study is to find the best method for creating briquettes from the coffee husks. This process was separated into four steps. First the chemical properties of the coffee husk, that are relevant when it comes to designing the process, were studied. As some unit operations are only necessary if the biomass does not have the correct parameters, these parameters for the coffee husk were studied in order to design a process that was technically optimal. The chemical properties needed for this and that were measured was the size of the coffee husks, their moisture content and their bulk density.

### 3.1.1. The particle size

The particle size was determined by measuring the size off 100 pieces of coffee husk. As the coffee husks were not uniform in size they were measured in regards to length, height and width. Length was defined as the distance from the button to the top of the husks, if it could be identified. Otherwise the length was defined as the dimension in which the coffee husks were the longest. Width was how wide the husk were from side to side, or the second longest dimension if the sides couldn't be identified. The height was then defined as the dimension that was not yet measured.

The coffee husks existed in different forms and sizes, from small crumblike pieces to bigger ones. Only particles of significant size were measured and very small ones were therefore excluded. The reasoning being that the aim of determining the size of the coffee husks was to analyse if they needed to be crushed before preheating. As such; the question of relevance was if too many large particles existed? Therefore, it was only relevant to study husks that were of such size that they could cause this problem. The material needed for this experiment was ruler were the back of an excess card was used. In *Figure 5* the experimental setup as well as the husk measured are shown

*Figure 5: the experimental setup for measuring the particle size and the husks measured.*

For all these test the mean, the standard deviation and the standard error were also calculated. Worth noting is that this did not give the standard error for the entire population of coffee husks, only the standard error of the husks in the sample. For the standard error of the population to be calculated the standard deviation for the entire population would have needed to be acquired, which was not possible to do in this study.

### 3.1.2. The bulk density

The bulk density was measured by weighing a one litre container and calculating it as the mass/volume. A tetra pack was used as the one litre container. The top of the pack was cut open using a scissor. Only three of the side were cut, leaving the top left on the tetra pack open. Coffee husks were then manually put into the container until it was full. The bulk density was first measured by putting the husks into the container and this was repeated ten times. The bulk density was then measured after the container was shaken, this was also repeated ten times. This using a scale. The experimental setup is shown in *Figure 6*.

The purpose of the shaking was to study if there was any significant amount of air between the husk, in the first test, and if shaking would decrease the space between the husks. This is a step that is usually done when bulk density is measured and gives a better indication of the true bulk density. For both tests the mean, the standard deviation and the standard error was also calculated. As a table value of the bulk density exist a t-test was calculated in order to see if there was any statistically significant difference between that value and the measured value. This at a significance of 5 %.

*Figure 6: The setup for measuring the bulk density.*

### 3.1.3. The moisture content

The water content was measured using the microwave method. In this method, a microwave is used to dry the husks. The husks were put in a container that does not lose weight when put into a microwave. The container was weighed and its weight was named C, then the container was filled with coffee husks and was weighed again. The container was only filled to such an extent that the husks could be manually mixed without husks being lost. This weight was named A. Then the container was put into a microwave together with a glass of water. This to not damage the microwave when there was no more moisture in the husks. After two minutes at high power, the container was weighed. Then this continued every 30 seconds until there was no more weight for the sample. "*No more weight loss*" was defined as when five measurements in a row didn't show a change in weight. Then the weight was measured and labelled B. After each weighting the husk were mixed to prevent carbonization. If this happed the test was rerun. After mixing, the container was weighed again to

*Figure 7: the experimental setup for measuring the moisture content in a microwave.*

make sure no husks had been lost in the process. A gram scale was used. The moisture content was then defined using *Equation 20* where w is the moisture content:

$$w = \frac{(A - C) - (B - C)}{A - C} * 100 \tag{20}$$

This process was done three times to give a more reliable result. This method was done in a microwave due to it being the material that was available. Usually the moisture content is measured using an air dryer (or an oven if such a dryer is not available), a process which can be considered more precise, but also takes a lot longer to do. The experimental setup can be seen in *Figure 7*.

## 3.2. The total amount of coffee husks and briquettes

The total amount of coffee husk available was also obtained, this was the second step. This was done by visiting the factory and via the factory manager get an idea of the amount of husks produced. Using mass and energy balances the amount of briquettes produced, from the obtained amount of coffee husks, was calculated for the densify-first method. This was not possible for the carbonize-first method as no balances for it have been described. This process is also less fine-tuned then the densify-first method and no balances could be found in literature. Moreover, no data on the efficiency of the carbonization and other unit operations for that method was found. And if data would have been found this would say very little about the end result due to the process less then fine-tuned nature.

## 3.3. Practical issues

Thirdly, the local environment for briquette making was analysed. What does the market look like? What kind of problems does other briquetting plants in East Africa have? This in order to analyse if it was reasonable to continue working on implementing a briquetting plant at the KADERES factory. The reason that East Africa and not only Tanzania is referred to in this study was because of the limited application of briquetting technology in Tanzania. The countries in the region can be assumed to be in an economically similar situation regards to briquette making.

## 3.4. Cost analysis

The fourth and final step of the study was to do a cost analysis of the densify-first and carbonize-first methods. The purpose of which was to analyse which method was best from an economical perspective. The analysis was started by finding information regarding the cost places as presented in *Table 3*.

### 3.4.1. The initial investment

Firstly, the initial investment for the two methods was calculated. The cost of the equipment for both the carbonize and the densify-first processes were found. This was done by finding information of the investment cost from other briquetting plants in East Africa. The capacity and these plants was then found. A linear correlation between cost and capacity was then assumed and used to conclude what the initial investment for the KADERES plant was. This in light of the information presented in this study. These costs were then summarized.

### 3.4.2. The cost of production

Secondly, the cost of production was analysed. The size of the cost places was based on similar numbers from other plants in East Africa. For the carbonize-first method the price of the cassava flour and the water needed was based on local data about their price, this based on the recipe from ARTI-energy. As the coffee husks already existed in the factory, the cost of raw material was excluded from the study.

### 3.4.3. Sales and profitability

The sales price from other plants in East Africa (Tanzania, Uganda, Kenya, Rwanda & Burundi) were used as the basis for the sales. The profitability of the densify-first and carbonize-first method were then calculated using *Equation 16*. If a strong difference between different plants using the same methods where found, the profitability was calculated for both. The pay-back time was then calculated using *Equation 17*. The cost and sales price were calculated in USD. If a different currency was used, it was converted to USD. If the report was old, the currency was converted from the year the report was written. This applies if the report was written before 2010.

Worth noting is that this analysis was not intended to give a clear picture of the economic condition regarding the process. It only gave the picture in broad strokes. As the profitability was estimated from other sources and by estimations, the numbers cannot be assumed to be correct. A more detailed economic analysis, then the one in this report, with an economic focus would be needed to make it more exact. This analysis showed at most if there is economic value in any of the methods and if one is better by a significant margin.

## 3.5. Assumptions

For the result of the study to be valid, some assumptions, both technical and economical were needed to be made. Below follow the assumptions made in this study.

- There is a 1 % material loss for $\Upsilon_1$ and a 1.1 % loss for $\Upsilon_3$
- There is a 2 % moisture loss during preheating and a 5 % loss during densification
- There is around a 50 % heat loss between the furnace and the heater
- The furnace has a combustion efficiency of 90 %
- There was only loss of material in the carbonization if the carbonize-first method is used.
- The economic environment for briquette is the same in all East African countries
- Economic report from other East African plants could be used to make economic assumptions
- There is a linear correlation between production capacity and production cost
- There was no inflation in USD
- There wasn't inflation in any currency since 2010

## 3.6. Material

The following material were used in the experiments:

For measurement of particle size:

- A ruler (the back of an excess card)

For measurement of bulk density:

- A scale (from Scout-Pro that rounds off to the closest gram)
- A one-litre tetra pack (from He-House)
- A pair of scissors

For measurement of moisture content:

- A microwave oven
- A large plastic container
- A drinking glass
- Water from a water tank

# 4. Result

## 4.1. The chemical properties of the coffee husks

### 4.1.1. The particle size of the coffee husk

In *tables 4,5,6* the length, weight and height of 100 coffee husks are presented, as well as their mean size, their standard deviation and their standard error. The 100 husk were on average 11.32 mm long, 7.71 mm wide and 4.53 mm high. With standard deviations of 1.74, 1.69 and 1.31 respectively. The standard errors were moreover 0.174, 0.169 and 0.131 for length, with and height.

*Table 4: The length of 100 coffee husk and the mean, standard deviation and standard error for the husks in mm*

| **The length of the coffee husks (mm)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 12 | 9 | 10 | 11 | 10 | 15 | 14 | 12 | 13 | 9 |
| 11 | 13 | 13 | 10 | 8 | 16 | 9 | 12 | 8 | 12 |
| 10 | 12 | 12 | 11 | 10 | 11 | 11 | 10 | 10 | 12 |
| 10 | 12 | 11 | 10 | 13 | 19 | 14 | 12 | 12 | 11 |
| 10 | 9 | 11 | 10 | 10 | 10 | 13 | 11 | 10 | 14 |
| 11 | 11 | 9 | 10 | 13 | 12 | 8 | 13 | 10 | 12 |
| 10 | 10 | 12 | 11 | 10 | 10 | 11 | 11 | 13 | 12 |
| 13 | 12 | 12 | 10 | 10 | 13 | 10 | 10 | 11 | 11 |
| 10 | 11 | 10 | 12 | 14 | 13 | 11 | 9 | 13 | 13 |
| 12 | 15 | 10 | 11 | 12 | 12 | 10 | 12 | 11 | 12 |
| | | | | | | | | **Mean:** | 11.32 |
| | | | | | | | | **Standard deviation:** | 1.74 |
| | | | | | | | | **Standard error:** | 0.174 |

*Table 5: The width of 100 coffee husk and the mean, standard deviation and standard error for the husks in mm*

| **The width of the coffee husks (mm)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 7 | 8 | 6 | 8 | 5 | 10 | 7 | 10 | 6 | 7 |
| 7 | 5 | 6 | 6 | 8 | 3 | 6 | 6 | 8 | 6 |
| 7 | 10 | 9 | 7 | 7 | 6 | 8 | 9 | 8 | 8 |
| 10 | 6 | 7 | 7 | 8 | 5 | 12 | 7 | 12 | 6 |
| 8 | 10 | 8 | 9 | 7 | 6 | 9 | 9 | 9 | 8 |
| 10 | 10 | 9 | 8 | 8 | 8 | 9 | 5 | 9 | 8 |
| 8 | 9 | 6 | 10 | 8 | 8 | 6 | 6 | 6 | 7 |
| 11 | 7 | 11 | 9 | 10 | 11 | 6 | 9 | 6 | 10 |
| 6 | 6 | 8 | 7 | 6 | 11 | 7 | 6 | 7 | 8 |
| 6 | 7 | 7 | 8 | 7 | 7 | 8 | 7 | 8 | 9 |
| | | | | | | | | **Mean:** | 7.71 |
| | | | | | | | | **Standard deviation:** | 1.69 |
| | | | | | | | | **Standard error:** | 0.169 |

*Table 6: The height of 100 coffee husk and the mean, standard deviation and standard error for the husks in mm*

| **The height of the coffee husks (mm)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 5 | 6 | 1 | 3 | 5 | 6 | 5 | 5 | 4 | 4 |
| 5 | 2 | 5 | 7 | 5 | 3 | 3 | 5 | 5 | 4 |
| 6 | 3 | 7 | 5 | 5 | 3 | 5 | 6 | 7 | 3 |
| 6 | 4 | 4 | 4 | 5 | 4 | 4 | 5 | 5 | 2 |
| 4 | 5 | 4 | 5 | 5 | 5 | 6 | 7 | 4 | 5 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 6 | 4 | 4 | 5 | 6 | 3 | 5 | 3 | 4 | 4 |
| 4 | 5 | 4 | 6 | 6 | 5 | 6 | 4 | 2 | 5 |
| 2 | 4 | 2 | 4 | 3 | 4 | 4 | 6 | 5 | 6 |
| 5 | 3 | 9 | 4 | 5 | 4 | 4 | 6 | 5 | 5 |
| 5 | 5 | 5 | 4 | 3 | 4 | 5 | 4 | 4 | 2 |
| | | | | | | | | **Mean:** | 4.52 |
| | | | | | | | | **Standard deviation:** | 1.31 |
| | | | | | | | | **Standard error:** | 0.131 |

### 4.1.2. The bulk density of the coffee husk

The bulk density of the coffee husk when not shaken is shown in *table 7* and the bulk density of the coffee husks when shaken are shown in *table 8*. The average bulk density when not shaken was 126.6 g/l and the average bulk density when shaken was 167.4 g/l. The standard deviations were 4.37 when not shaken, 3.72 when shaken and the standard errors were 2.38 when not shaken and 1.18 when shaken.

*Table 7: The bulk density of the coffee husks when not shaken in g/l and the mean, standard deviation and standard error for the bulk density.*

| **Bulk density of the coffee husks (not shaking & g/l)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 123 | 124 | 132 | 123 | 132 | 129 | 124 | 119 | 127 | 130 |
| | | | | | | | | **Mean:** | 126.3 |
| | | | | | | | | **Standard deviation:** | 4.37 |
| | | | | | | | | **Standard error:** | 1.38 |

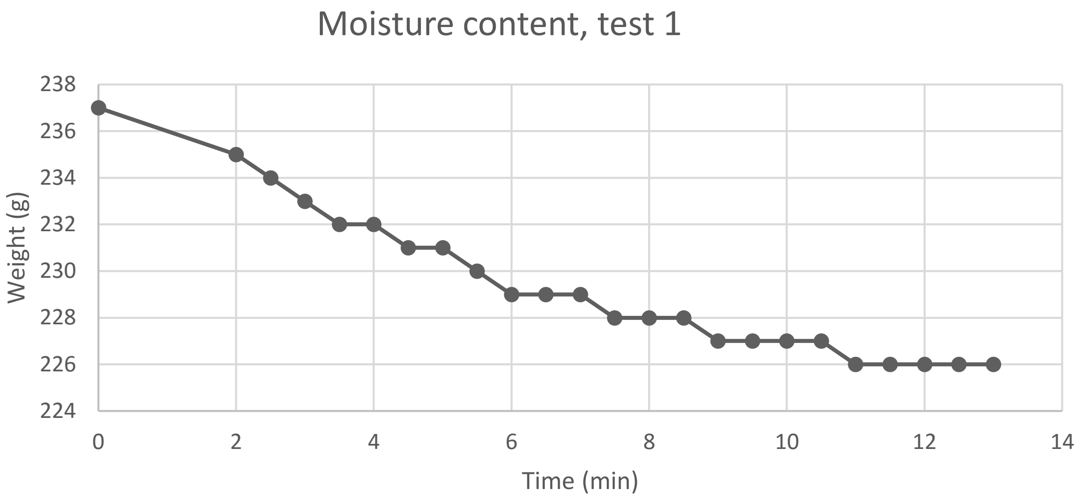
*Table 8: The bulk density of the coffee husk when shaken in g/l and the mean, standard deviation and standard error for the bulk density.*

| **Bulk density of the coffee husks (shaking)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 165 | 172 | 169 | 163 | 165 | 167 | 175 | 168 | 165 | 165 |
| | | | | | | | | **Mean:** | 167.4 |
| | | | | | | | | **Standard deviation:** | 3.72 |
| | | | | | | | | **Standard error:** | 1.18 |

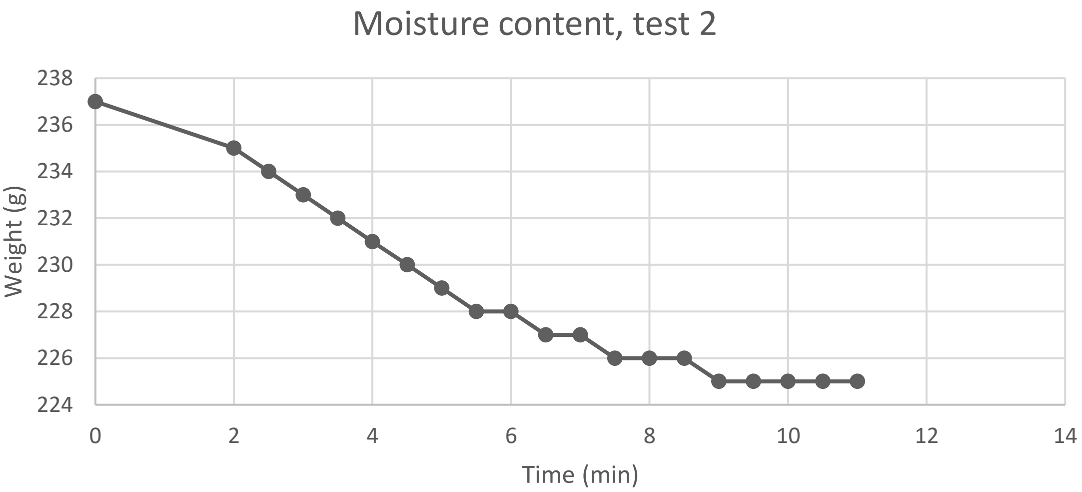
The t-value for the bulk density when not shaken was -50.44 and the t-value for the bulk density when shaken was -24.31. A n-value of 10 gave 9 degrees of freedom and a t-value of 2.26 which indicated that hypothesis $H_1$ was true and that there was a significant difference between the sample and the table value at a 5 % significance level.

### 4.1.3. The moisture content of the coffee husk

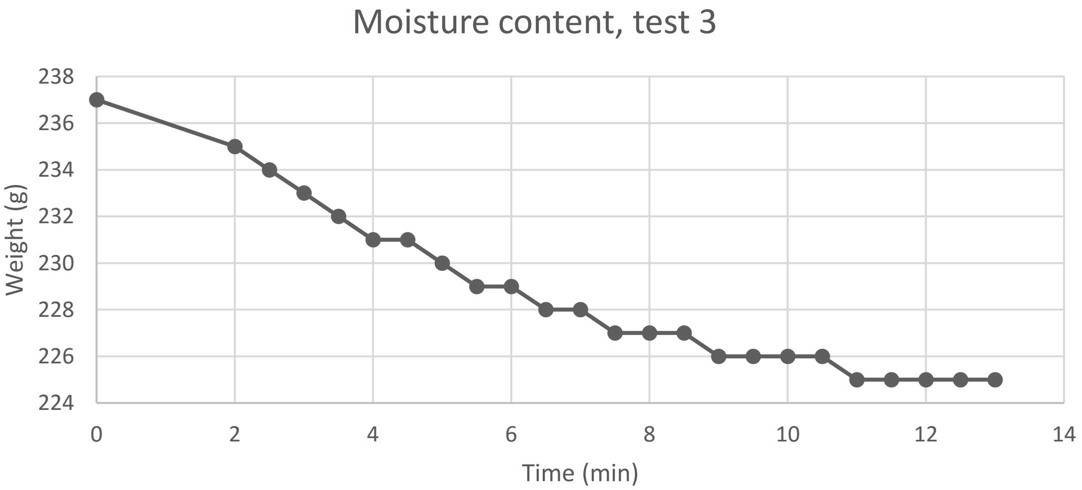
*Graph 1*, *Graph 2* and *Graph 3* shows how the weight of the coffee husks decreasesd with the time they were dried in the microwave oven. All three tests showed the same result. In all tests the weight of the container was 96 grams and the starting weight was 237 grams (the highest possible amount of husks without losing husk during mixing). In test one the weight decreased to 226 grams after 13 minutes giving it a moisture content of 7,80 %. In test two and three the weight decreased to 225 grams after 11 and 13 minutes which gave those tests water contents of 8.51 %. In average the water content was calculated to 8.27 %.



*Graph 1: The weight (g) over time in microwave (min) under high efficiency, test one.*



*Graph 2: The weight (g) over time in microwave (min) under high efficiency, test two.*



*Graph 3: The weight (g) over time in microwave (min) under high efficiency, test three.*

## 4.2. Total production of coffee husks and briquettes

The total amount of coffee husks produced per year are 4 000 000 kg. A number approximated by the plants manager. If the operation is running 300 days a year and is in operation 10 hours a day that this gives an hourly production of around 1 333 kg. As the water content is 10 % there is no moisture loss and a 1 % material loss. This gave the following vales in *Equation 2 and 4:*

$$F_{Loss_1} = 0.01 * (1333 - 0) = 13.33\ kg/h \rightarrow F_1 = 1333 - 13.33 = 1319.67\ kg/h$$

During the preheating step, the moisture content drops 2 %, from 8.27 % to 6.27 %. This gave the following calculations using *Equation 5* and *6:*

$$F_{Steam_2} = 1319.67 * 0.0827 - \left(1319.67 - F_{Steam_2}\right) * 0.0627 \rightarrow F_{Steam_2} = 109.1367 - 82.7395 + 0.0627F_{Steam_2} \rightarrow 0.9373F_{Steam_2} = 27.3972 \rightarrow F_{Steam_2} = 29.2299\ kg/h$$

$$F_2 = 1319.67 - 29.2299 = 1290.4401\ kg/h$$

During the densification and cooling step, the moisture content drops to 5 %, from 6.27 %. There will also be a material loss of 1.1 %. This gave the following calculations using *Equation 7*, 8 and 9*:*

$$F_{Steam_3} = 1290.4401 * 0.0627 - \left(1290.4401 - F_{Steam_3}\right) * 0.05 \rightarrow F_{Steam_3} = 80.9106 - 64.5220 + 0.05F_{Steam_3} \rightarrow 0.95F_{Steam_3} = 16.3886 \rightarrow F_{Steam_3} = 17.2512\ kg/h$$

$$F_{Loss_2} = 0.011 * (1290.4401 - 17.2512) = 14.005\ kg/h$$

$$F_3 = 1290.4401 - 17.2512 - 14.005 = 1259.1839\ kg/h$$

This showed that the flow out from the cooling process is around 1305 kg (0.989*1319.67). The last step was to calculate how much briquettes are needed for the furnace. There is no drying so $Q_{Drying}$ = 0. The preheating raises the temperature from 30 to 100 $C^0$ causing a two percent loss in moisture. The calculation was done using *Equation 12* with the consent B = 560 (P.D Grover and S.K. Mishra, 1996 p. 30-33)

$$Q_{Preheating} = 1319.67 * 0.37 * (100 - 30) + 29.2299 * 560 = 50548.197\ kJ/h$$

A combustion efficiency of 50 % results in that 50548.197/0.5 = 101096.394 kJ/h of energy is needed. Theoretically the combustion efficiency is 90 % which results in that 101096.394/0.9 = 112329.327 kJ/h is needed. The lower heating value is 18390 kj/kg which means that 112329.327/18390 = 6.108 kg/h of briquettes are needed for the furnace. The amount of briquettes produced was then calculated using *Equation 10*;

$$M_{Briquettes} = 1259.1839 - 6.108 = 1253.0759 \approx 1253\ kg/h$$

## 4.3. Practical issues – how are briquettes made in East Africa

It was difficult to get data regarding briquetting in Africa as it is a technical process still under development on the continent. In a study from 2013 seven large to medium scale briquetting operations were found in East Africa. All of these operations used charcoal dust or different types of agricultural waste as the main biomass as well as the carbonize-first method. These operations varied from NGO:s that deliver equipment and education to local "*social-enterprises*" (such as ARTI-energy) and private companies (T.H. Mwampamba et al., 2013 p. 161-166). An operation using the densify-first method for briquetting without carbonization, that used coffee husk as biomass, exist in Uganda that produces 2 000 tonnes of briquettes a year, briquettes that are sold for 0.28 USD/kg (KMEC Engineering).

A significant problem regarding briquetting in East Africa is that the initial investment can be significant using the densify-first method and that the carbonize-first method is not suitable for large upscaling (T.H. Mwampamba et al., 2013 p. 161-166). A similar problem is a noted by S. Eriksson & M. Prior (1990). There also seems to be a problem with the market for briquettes. Of the four main private companies found to produce briquettes, two have halted production. One due to low sales (there is no comment on the other). Another practical issue is the obtaining of the machinery. For the carbonize-first method, most of the equipment can be found locally. However, if more advanced equipment, like piston presses are needed, those needs to be important from China or India. This also includes spare parts. Screw press can be found locally, but it's possible they need to be imported as well (T.H. Mwampamba et al., 2013 p. 161-166).

## 4.4. Cost analysis

### 4.4.1. Investment – what would it cost to build a densify and a carbonize-first plant?

The investment cost for the carbonize-first method will depend on the equipment used. The less advanced the machinery is, the cheaper the price is (Ferguson, Hamish, 2012 p. 9-14). A factory in Uganda with an annual capacity of 720 000 kg of charcoal briquette had fixed cost in machinery worth around 22 300 USD in 2009 (Tumwesige, Vianney, 2009 p. 9, 15). This gave an hourly production rate of 800 kg/hour. Let's say that twice the machinery is needed then the cost will be 44 600 USD. A roller press with a capacity of 15 000 kg/hour can however be bought for 19 000 USD.

The machinery for the densify-first method as mentioned previously has to be imported. The prices for the machines found varied and they do not include the price of transportation. A piston press from India important to Rwanda with a capacity of 750 kg/hour cost 60 000 USD in 2003 (Challenge Fund, 2003 p. 23). As the total hourly production was 1 333 kg/hour two such machines would be needed giving it a total cost of 120 000 USD. As its not known if this included the other machineries needed or the transportation it's not exact but will be presented in the table as a rough approximation. There is no land cost, as the land for the plant already exists. Moreover, the cost of the building in the carbonize-first plant in Uganda was 11 000 USD, we assume that the same price for both methods. (Tumwesige, Vianney, 2009 p. 9, 15). For a summery see *Table 9*.

*Table 9: The cost of investment for the carbonize-first and the densify-first methods, divided into machinery and installation, land and building. Summed and in total investment and with working capital added.*

| **Investment** | **Carbonize-first** | **Densify-first** |
|---|---|---|
| Machinery and installation | 44 600/19 000 | 120 000 |
| Land | 0 | 0 |
| Building | 11 000 | 11 000 |
| Total investment | 55 000/30 000 | 131 000 |
| Working capital | - | - |

### 4.4.2. Cost of production – what does it cost to produce the briquettes?

For the carbonize-first method the plant in Uganda was used as a reference. The data was for the cost per year, so it was calculated into hours. The maintenance cost was around 2 300 USD/year, the staff cost (including office personal) was around 41 100 USD/year, the packaging cost was around 14 500 USD/year, the utility cost was around 12 600 USD/year and additional costs were around 11 300 USD/year (Tumwesige, Vianney, 2009 p. 9, 14). If 1.666 (1 333/800) times the production is used then the hourly cost is 1.27 USD/hour for maintenance, 22.82 for staff and 22.16 USD for other costs. The cost for raw materials is excluded.

Moreoever, the cost of cassava and water were needed. As 1 333 kg of briquettes are available per hour this requires 133.3 kg of cassava flour and 533.2 litres of water per hour. Numbers calculated using the recipe for charcoal briquettes used from ARTI-energy. One kilo of cassava flour costs between 50 and 200 Tanzanian shilling (Agricultures Network) per kg giving it an hourly price of between 66 650 shillings/hour to 266 600 shillings/hour. In dollars this is between 30.46 and 121.84 USD/hour (XE Currency Converter). 1 cubic meter of water costed on average 500 Tanzanian shillings using public utilities, a price a lot higher from other sources and it may very within the country (Dr. Dirk Pauschert et al., 2012 p. 8), giving it a price of 0.30 USD/hour (XE Currency Converter).

For the densify-first method, a rapport with data regarding a briquetting plant in Rwanda from 2003 was used as the basis for the cost analysis. In a pilot study using a 750 kg/hour piston press important from India the cost of production was as follows in Frw (Rwandese francs): salaries, 6.85 Frw/kg, maintenance 1.23 Frw/kg, packaging 2.47 Frw/kg, utilities 2.4 Frw/kg, transport 1.17 Frw/kg and raw material 8.8 Frw/kg (Challenge Fund, 2003 p. 20). In 2003 1 USD was around 545 Frw compared to around 805 today (Trading Economics), which gives the values seen in table 10, where salaries are under manpower, utilities are the sum of power and additional material, the rest are included under others and material is excluded. The numbers were also multiplied by 1 333 and 1.778 (1333/750). As a reference, it cost 500 Indian rupees to produce one tonne of briquettes in 1996, according to P.D Grover and S.K. Mishra. Of which half was the cost of raw material (1996 p. 40). For summery see *Table 10.*

*Tabell 10: The cost of production for the carbonize-first and the densify-first methods, divided into power, manpower, additional material, maintenance, administration, deprecation and other costs. Summed and in subtotal and with financial cost added.*

| **Cost of production/hour** | **Carbonize-first** | **Densify-first** |
|---|---|---|
| Power | No information | 10.44 USD |
| Manpower | 22.82 | 29.79 USD |
| Additional material | 30.76/122.11 | See power |
| Maintenance | 1.27 | 5.35 USD |
| Administration | 0 | 0 |
| Deprecation | - | - |
| Other costs | 22.16 | 15.83 USD |
| Subtotal | 77.01/168.36 | 61.41 |
| Financial cost | - | - |

### 4.4.3. Sales – how does the East African market for briquettes look like?

The answer can be considered to depend on the end product. As non-carbonized briquette produced from coffee husk sells for 0.28 USD/kg in Uganda and a similar price can be assumed to roughly exist in Tanzania, at least in Karagwe. The Rwandan company sold them for 45 rfw in 2003 (Challenge Fund, 2003 p. 20) ARTI-energy sells charcoal briquettes for 600 Tanzanian shillings (ARTI-energy), which is currently 0.2742 USD/kg (XE Currency Converter) and a similar product can be assumed to be sold for the same price. The Ugandan company sold charcoal briquettes for 0.31 USD/kg in 2009 (Tumwesige, Vianney, 2009 p. 9).

### 4.4.4. Profitability – who much profit can the production give?

For the profitability, a sales price of 0.28 USD/kg was used as both types of briquettes have been sold for that price. For the carbonize-first four different profitability's were calculated using both prices for cassava and for both prices of equipment. If cheap cassava and equipment is used, the total cost is 261 030 USD for the first year, the profit is 888 690 USD and the pay-back time is 0.0338 years or 12 days. If expensive machinery and cheap cassava is used, the total cost for the first year is 286 030 USD, the profit is 888 698 USD, the pay-back time is 0.0619 year or 23 days. Is cheap machinery and expansive cassava is used the total cost for the first year is 535 080 USD, the profit is 614 640 USD and the pay-back time is 0.0488 year or 18 days. Then if expensive machinery and cassava is used then the total cost for the first year is 560 080 USD, the profit is 614 640 USD and the pay-back time is 0.0894 years or 33 days. For the densify-first method, the total cost is 315 230 USD the first year, the profit is 935 490 USD/year and pay-pack time is around 0.14 % of a year or 51 days. Worth noting is that the pay-back time for P.D Grover and S.K. Mishra was 2.5 years (1996 p. 40)

# 5. Discussion

## 5.1. Evaluation of the technical results

The results in regards to the size of the coffee husks gives an indication that they are too large to be directly briquetted without grinding. This aspect will be discussed later in the report. For now, the statistical aspect of the result in regards to particle size will be discussed. In regards to length, width and height the standard deviations indicates that the size of the husks don't deviate highly from the mean values. At most there is a statistically relevant deviation of 1.74 mm in length. Moreover, the standard error indicates that the sampling distribution doesn't deviate a lot, most likely due to the high n-number. Worth noting is that the standard deviation would most likely be higher if small pieces of coffee husk would have been included in the study.

The value of the bulk density is shown to deviate a lot depending on if the coffee husks are shaken or not shaken. This indicates that when they are not shaken there is a lot of air still left in the container. As there is a big difference between the table value and the measured bulk density this might indicate that there is still a lot of air left in the container. And shaking it even more might increase the bulk density further, so the real bulk density might be higher than the measured values. There is moreover, a minor standard deviation in the result; this however cannot be interpreted to have any practical relevance, as it would not affect the differences between measured bulk density when shaken, compared to not shaken density values.

The value of the moisture content is almost the same in all three measurements. The first one is only one gram of from the other two. This indicates that the measured values are valid. One problem is that this value creates a difference in moisture content of 0.71 %, meaning that a small difference can create a large difference in value. As all three test are so close, this cannot be considered a major problem. This difference can furthermore be explained by the fact that the scale used was only exact to a gram level. This means that there can theoretically be an almost one-gram difference within one measured value. So the differences within the initial value of 237 grams, can be so large that they create a difference in the final measurement. If a scale that would measure milligrams would be used, then the values might have been closer.

## 5.2. Technical assumptions

The study made five technical assumptions. Four of these were in relation to the energy and mass balances. They are taken directly from the literature, namely P.D. Grover & S.K. Mishra. As such they are considered reasonable. Of course different types of equipment could give different material and heat losses as well as different combustion efficiencies. It is however difficult to get any values better than the ones found, as others would have needed to be guessed. The fifth is that "*there is only loss of material in the carbonization using the carbonize-first method*". This assumption is probably not exactly true. Other unit operations will most likely result in some material loss. These losses however are arguably small compared to the loss during carbonization and they cannot be estimated and as such just assuming loss during carbonization works in the context of this study.

## 5.3. Economic assumptions

The study made five economic assumptions in order to reach a result. They can broadly be subdivided into three general areas. The first is in relation to inflation, where it was assumed that no inflation has happened since 2010 or in USD. The reason for the first one is that the economic situation between countries can change the currency conversion significantly. For instance, the Rwandan francs have gone from around 500 Rrw/USD in 2003 to around 800 Rrw/USD at the moment this report is being written. A difference that would have changed the result. 2010 is simply the cut-off date for which I assumed this is no longer relevant. I also assumed that the inflation in USD will have no impact, something that might make older data look cheaper.

Secondly it was assumed that there is a linear correlation between production capacity and production cost. This is an assumption done within business studies. In economics however, it is assumed that the margin of utility exists. Meaning that the more there is off something the less worth it is. As this would be too complicated of an assumptions for a non-economic report, the assumption made within business studies was made.

The last assumptions was that the economic situation for briquette production is the same in all East African countries (Rwanda, Tanzania, Uganda, Kenya and Burundi). Even if they are different countries with different polices, they are strongly integrated economically and can in relation to this report be assumed to function similarly in terms of economics. As Karagwe is close to both Rwanda and Uganda, the area is economically close to both countries and as such a huge difference in the economic situation is unlikely. This also has support by T.H. Mwampamba et al., who analyses briquettes making in the region as a whole, as well as by S. Eriksson & M. Prior whom makes a general argument of the briquetting market in all of sub-Saharan Africa.

## 5.4. Can briquettes be made from coffee husk?

Before it is discussed what method is the best, and how its best implemented, it has to be concluded if briquettes can be made from coffee husks. This has been shown to be possible using both methods. Coffee husk made using a screw press have been made and even if no explicit mentioning of piston press usage was found, they may work as well. When it comes to carbonize-first briquettes the question is a bit more complex. Briquettes can be made from coffee husk and this have been tested. The problematic step here is the carbonization step. The ARTI-energy design might have a problem in that the holes in the button might be too big. Something that will result in that the coffee husks, being quite small, might fall down through the holes. It cannot be concluded that this is a problem, as it hasn't been tested. It is however likely and as a result this indicates that a different type of carbonization kiln is needed and that a good one needs to be obtained if the carbonize-first method is concluded to be the best one for KADERES. Carbonization using a specific kiln (like the one in Nairobi) have shown to work however.

## 5.5. Carbonize-first or densify-first – which ones fits the KADERES?

Using the cost analysis from the result it can be concluded that the best method for KADERES is the densify-first process. The reason is on one level economical, but it's also practical. The carbonize-first method is adapted for small-scale and mid-scale operations and as such is not suitable for KADERES. This as the charcoal kilns and the charcoal extruders (that are available on the local market) do not have the capacity needed for a large-scale briquetting operation. As such a high number of kilns and extruders needs to be enquired. This will result in a lot of area, a large building and a large workforce to be manageable. Moreover, the amount of cassava flour and water needed, will not only be expensive, but can also be harmful for the local economy. It's only a speculation, but buying that much cassava flour in a small rural Tanzanian town will most likely increase its local price, which can have a negative on local needs for of the crop as a staple food. A similar argument can be made in regards to water, if there is a limited water supply then using halve a cubic meter per hour might not be the most positive thing.

From the cost analysis the argument could be deepened. The profitability of the densify-first method is higher than for the carbonize-first method and this is true even if "*cheap*" cassava flour is available. The problem with the densify-first method is that the initial investment is a lot higher. This however, is based on a report about a plant in Rwanda from 2003. Cheaper machines (by a far margin) can be found online. I don't know if these ones can be exported to Tanzania, but if they can the investment cost might be significantly lower then presented in this study.

It's important to point out, again, that this is not an economic report. The only thing that the cost analysis aims to do is to study if it's worth looking into implementing one of the methods, this from an economic perspective. The result shows that a profit can be made from both methods, but that the densify-first one is most likely more profitable. The result, however, does not seem that reasonable, the profit margin is extremely high and the bay-back time is very low. As a reference the pay-back time was calculated to be 51 days for the densify-first, this compared to 2.5 years for one in India. One reason is most likely that there is no cost of raw material, a cost that makes out half of the production cost for the Indian plant. Another one is that it's possible that the machinery has gotten cheaper since they made their analyses in 1996 (the same could apply for the Rwandan plant).

All of this is however speculation and a proper economic report is needed before a plant is build. The only conclusions that this report can be considered to have brought is that it's technically possible to create briquettes from coffee husks and that it looks like it's a good economic investment. Worth noting is that the densify-first method has the disadvantage that its adapted to use for one type of biomass. So as long as only coffee husks are used it is the best method. If other material should be used to create briquettes, then the carbonize-first method is better.

## 5.6. What equipment is needed for the densify-first method?

As its concluded that the densify-first method is the most preferable one, the next step is to analyse what unit operations and, as a consequence, what equipment is needed for the briquetting process. Densification and cooling are necessary parts for briquetting so a briquetting machine and a cooling belt are needed. Preheating is theoretically shown to decrease the energy need for the process and as such can be considered a "*necessary*" unit operation. The particle size of the husks indicates that some husks are too big for optimal briquetting. This as the optimal range is 6-8 mm in size and the mean husk was 11.32 mm long. As such it can be concluded that a girder is necessary in order to optimise the briquetting process. What is optimal will depend on the specific equipment however, this within the mentioned range.

The moisture content was measured to be around 8.27 %. This is well below the 10 % at which drying is needed. As such this unit operation cannot be concluded to be necessary. This is however under the assumption that the husks remain dry. If they are exposed to rain, the moisture content will go up and the husk needs to be dried. As such it is of key importance to build a roof over to process to make sure the husk remains dry before briquetting occurs. Sieving is also a step that might be needed. In the bag of coffee husks used in this study, other material could be found. Very little other material, but some nevertheless. This means separation might be needed as a unit operation. The presence of other material could be due to the storing process so I would recommend checking husks that have just been processed in the coffee plant if they contain other material. A carbonization step might also be needed. This as carbonized briquettes create less smoke when used. The unit operation will be needed if that decrease in smoke increases the demand for the briquettes on the local market. If so a carbonization kiln is needed.

A bulk density of 150 g/l (same as 150 kg/m$^3$) gives a capacity of 100 % for a piston press. As the measurement for coffee husks when shaken are higher than this, this indicates that the coffee husks have a good capacity for being used in a piston press. This does not mean that that is the best type of press. A screw press can create briquettes that can be carbonized, have good combustion performance, are homogenous in size, can be used in gasifiers, are usually cheaper and are more optimal for the measured water content. They do however wear more, which will increase the maintenance cost. As such most factors indicated that a screw press is preferable to a piston press. There are however presses on the market labelled "*coffee husk briquetting presses*" and they can be used to make briquettes from coffee husks. And as that is their intended purpose that are most likely the best briquetting presses for coffee husks.

## 5.7. Sources of error

This refers to the technical aspects of the study and not the economical ones. One large source of error is the measurement of the bulk density. As a significant difference between the measurements when the husks were shaken and when they were not shaken where found it's possible that a lot of air remained in the former. If equipment used to shake the husks where used, instead of it being done manually, it's possible that the bulk density would be higher. As the husks will be entered into an extruder they will be pressed so that the air between husks decreases. This means that the density might be higher when the extruder is used. The material however needs to be grounded, which will change the bulk density. So for the practically of the operation this is of little significance. There is also the possibility that the scale is not calibrated and will give results that are consistently wrong.

In regards to the measuring of the coffee husk several problems of measurement are worth noting. One is that the measurement cannot be rationalized to give a value on the average size of the coffee husk, as smaller ones where excluded. It's also possible that larger husk where selected even with this exclusion in mind.  The reason being that as husks were taken up one by one it's easier to pick larger husks then small ones. As the purpose of the experiment was to study if crushing is needed, this has no bearing of the result. The reason being that if too many big husks exist, as the result indicates, then crushing is needed even if the average would indicate otherwise. It's also possible that the dimensions of some husk could have been mixed up, changing the average. This is however unlikely to have resulted in a large effect, due to the sample size.

When it comes to the coffee husks moisture content, the biggest source of error is that the coffee husks did not come directly from the plant. At the moment of study, the plant had not been operational due to lack of available coffee beans. Even if the husks where protected from rain, it's possible that, because of the moisture in the air, the measured moisture content moisture content is higher in the husks compared to just processed coffee beans. This is however not a problem as the moisture content was shown to be below 10 %.

Another problem is that some husks where removed during mixing and that this decreased the weight. This is something that would have created a higher water content value and could have affected the result. However, as the average water constant was 8.27 % and the highest measured water content was 8.51 % it's unlikely that sufficient loss in mixing (a loss that would have resulted in a water content value exceeding 10 %) occurred. This as losses in all three test to that extent is unlikely. The same conclusion can be drawn if some minor carbonization occurred, as significant carbonization in all three test would been needed for the real water content to exceed 10 %. Carbonization was furthermore checked for during each mixing so cannot be considered a major source of error. This as more water would have evaporated.

# 6. Conclusion

To conclude, the densify-first method was found to better for KADERES. The reason being the scale needed for the process, for which the carbonize-first method is not adapted. This due to the amount of water, cassava flour and manpower needed for it. The optimal unit operations are crushing, preheating, densification and cooling. It is also possible that sieving as well as carbonization might be optimal unit operations. This will depend, in the case of sieving, on if other materials are found in the bags of coffee husk. I did not find any but this needs to be looked into further. In the case of carbonization, if it’s found that carbonized briquettes are better for the local market then that unit operation is optimal. In regard to process parameter optimization, the preheating is theoretically optimal when the biomass reaches a temperature of 100 $C^O$ and the crushing is optimal when biomass particles are around 6-8 mm in size. It’s finally important to adapt the process to local conditions were a more detailed economic calculation is needed but from this study it can be concluded that its profitable and that the densify-first method is more profitable then the carbonize-first method.

# 7. Recommendations

So, to conclude the report here are the recommendations for how to proceed with the briquetting plant. The best method is the densify-first method, as long as only coffee husks are used. As a method it is more profitable then the carbonize-first method, will create better briquettes and will be more efficient in using the material. In has however, a larger initial investment. An investment that however will lead to a higher profitability in the long run. The unit operations that are needed are crushing, preheating, densification and cooling. It might be optimal to use sieving as an operation as well; this will have to be further studied by looking at husk just used in the plant. Before the plant is being constructed, it is recommended that a more detailed economic analysis of the plant cost and profitability is done. This preferably done by someone with experience in business. Finally, the equipment needed is best imported from suppliers in India or China. They will most likely have machinery adapted for coffee husk and knowledge of how the plant should be put together in practice.

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