Improved Parboiling Practices in Benin, West Africa

BREE 495 Engineering Design 3

Design 3 Report

Presented to

Dr. Vijaya Raghavan

By

Stéphanie Dumais

Stéphanie Mayer

Audrey Yank

April 2010

Department of Bioresource Engineering

Faculty of Agricultural and Environmental Sciences

McGill University, Macdonald Campus

1. Executive Summary

The international community has agreed that attaining food security is one of the major goals of the millennium. In West Africa, this target can be reached through securing the actual food supplies and reducing processing losses. Rice production is an important economical activity in Benin, but low efficiency processing does not make this production competitive on the market. Thus, parboiling activities in Benin are to be improved through the development of more efficient stove, of new parboiling equipment and of an alternate fuel. The main objective will be to improve the efficiency, to lower the cost and to ensure availability of material while being applicable to the parboiling activities in the village of the Département des Collines. The women of the coop in the village of Gobé, will be the main client for that project.

2. Acknowledgments

We would like to thank sincerely:

- The Africa Rice Centre (WARDA) for their generous contribution and support during this project.
- Our project supervisor Dr. Robert Kok for his constant advices, his dedication for the project and for sharing this experience with us.
- Professors Raghavan and Ngadi for having giving us the opportunity to participate in this project and to be part of this cause.
- Dr. Aliou Diagne and Simon Ncho for their time and devotion to this project.
- Our colleagues Serge Adjognon and Lidia Dandedjrohoun for their socio-economical contribution and for their presence which significantly help our integration in the Beninese community.
- Mrs. Annie Kouakou for her constant help and availability.
- Mrs. Solange for her patience and perseverance in helping us in our experiments and showing us how to build traditional clay stoves.
- The many workers at the Africa Rice Center for their generous number of hours spent helping us achieving our goals.
- The women in the villages of Gobé and Gbaffo that generously received us in their villages and took of their time to be part of this project.
- INRAB and the University of Abomey-Calavi for their collaboration.
- The drivers, cooks, friends and all the people that contributed to our welfare during our stay and to our integration in the Beninese culture.

This project wouldn’t have been possible without the implication of all those great people. We highly appreciate the time and effort they all have put in this project. They have all truly contributed to the project and they are a part of the success of the present study. We sincerely acknowledge everybody for making our stay in Benin an unforgettable experience.

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5. Introduction

5.1 General Situation

Rice has been selected by the United Nations as a primary crop to enhance food security in the world. Just after wheat and corn, rice is the third most important crop contributing to human food supply. It represents 30% of the world's total consumption in terms of the number of calories ingested per person (Kossou, 2008). In total, Africa represents a non negligible part of the international rice market. Effectively, with 9.6 million tonnes imported in 2008 at a total cost of approximately 2 billion dollars US, it represents more than one third of the total international rice trade (FAO, 2008). A large fraction of the African rice is produced in West Africa where the consumption is steadily increasing. More than 20 million farmers are involved in this culture that mobilizes up to four million hectares of land in the region (WARDA, 2005). Women are responsible for parboiling as well as the majority of the work related to rice culture. In the sub-Saharan region, 80% of the workers in charge of sowing and harvesting are women (ADRAO, 2008). This cereal occupies a central place in the African culinary culture.

5.2 Rice Situation in Benin

Rice consumption in Benin is quite representative of the West African situation. In rural areas, the average annual consumption of rice is about 6 to 20 kg per person. This average is even higher in urban areas with 10 to 30 kg per person per year (Kossou, 2008). As such, rice production in Benin is not sufficient to meet the overall demand. In 2000, the country imported more than 210,900 tonnes of rice whereas it only produced 53 441tonnes (Kossou, 2008). The actual production of quality rice and its related costs are two major constraints for the local rice to enter the national and international markets and to stay competitive. However, Benin as an important potential concerning rice culture that could be further developed. The climate varies from a tropical region in the south to a sub-Saharan one in the north, but overall, as a costal country, the climate is characterized with warn and generally humid weather with a rainy season during summer time. At the same time, these precipitations serve to fully irrigate the agricultural lands. There is a great substantial potential for rice production since Benin has available very adequate agricultural lands and water resources, both surface and subsurface (Kossou, 2008). This has been exploited to a certain degree over the past twenty years in order to improve the country's negative balance of payment and to decrease its dependence toward foreign importations. For instance, between 1990 and 2000 some governmental and non-governmental initiatives have led to an increase of Benin's rice production from 10,940 tonnes per year to 53,441 tonnes per year (Zossou, 2008). It is significant to note that this was mostly done by increasing the overall area under cultivation rather than by introducing new technologies. Here, the traditional methods of product processing, both in terms of parboiling and cultivation, can only respond to a local demand. The manual tools presently in use by the farmers cannot serve a larger scale market. The need to improve efficiency and resource management is crucial to stay competitive and to develop the production of better quality rice in greater quantities at a more beneficial price.

6. Location and Context

The realization of this project is part of the larger project entitled "Improving Rice Processing Strategies for Food Security in West Africa". The lather is conducted in collaboration between McGill University and the Africa Rice Center. Two of the main objectives of the Africa Rice Center are directly related to this project. The NGO seeks to ''develop new […] complementary technologies'' (Africa Rice, 2009) and to ''address key constraints in the major rice production systems'' (Africa Rice, 2009).

For that project, three months were spent at the The Africa Rice research center in Cotonou (May 15 2009 until August 15 2009) along with the consultant for this project, Robert Kok. Two undergraduate students, Serge Adjognon and Lidia Dandedjro-houn, from the University of Abomey-Calavi also cooperated on the projects by comparing the economic and social aspects of the established and proposed technologies.

The project was developed for the specific situation of women coops working on parboiling activities in the villages of Gobé and Gbaffo in the Département des Collines in central Benin. The first village, Gobé, is located in the region of Glazoué (coordinates: N 07° 59' 53.1"; E 002° 24' 25.9"). The second village, Gbaffo, is located in the region of Dassa-Zoumé (coordinates: N 07° 47' 06.9"; E 002° 16' 09.8"). The locations are shown in Figure 1. The coops with whom this project is associated are organized groups of women that share the parboiling equipment. In Gobé, there were fifteen women in the coop while in Gbaffo six smaller coops share one parboiling equipment for a total of 45 women using it. Parboiling is not the only activity those women do for living. Amongst other activities, some will produce flour from corn or others will dry and process peanuts. In both villages, a NGO is working with the women cooperative to enhance their knowledge on organization and their technical skills.

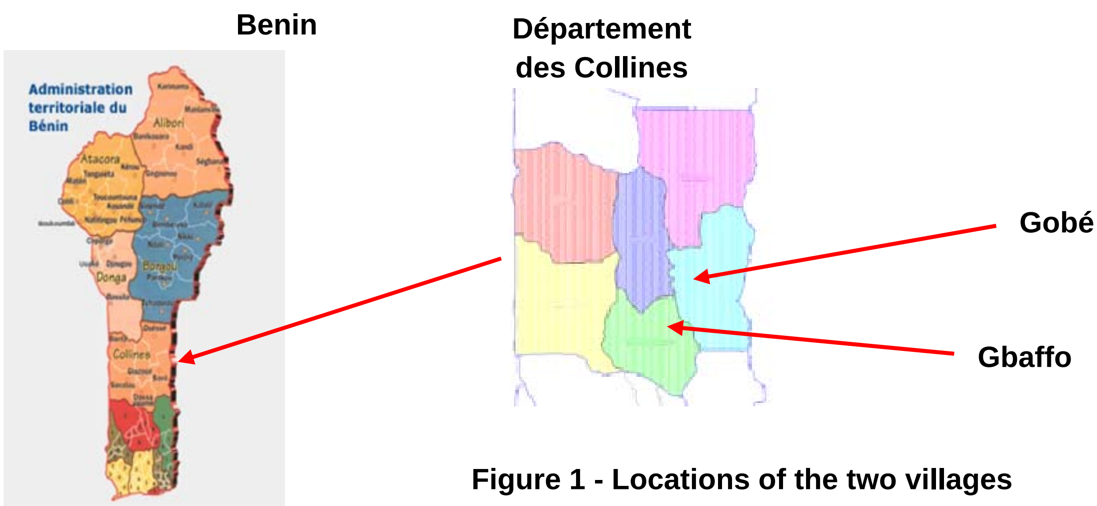


Figure 1 - Locations of the two villages

7. Background information

7.1 Rice Parboiling

Rice can be consumed parboiled or not, and as either white or brown kernel, the latter state being determined by how the rice is milled. Thus, if the bran is removed by polishing, the rice will be white, otherwise it remains brown. For cultural reasons most people in West Africa prefer and consume white rice and, also, they prefer it to be parboiled (this is not so in many other areas of the world). The preference for parboiled rice may also be caused by the facts that locally-produced, parboiled rice contains fewer broken kernels, generally is cleaner, and has a better nutritional value than non-parboiled rice. Thus, parboiled white rice has a higher protein and vitamin A content (Kossou, 2008) than non-parboiled white rice. This seems to be caused by nutrients being carried from the bran into the kernel during processing. As well, just like blanching, parboiling stops most biological activity in the rice so that germination, insect infestation, and fungal growth are largely inhibited (Zossou, 2008). Accordingly, parboiled rice can be stored longer before it begins to deteriorate (Zossou, 2008). In West Africa people also prefer the taste and texture of parboiled rice over its non-parboiled counterpart, although that attitude may be shifting as the result of new foods and food habits being introduced from East Asia, together with the rice.

Essentially, "parboiling" of rice means that the rice is slightly cooked before it is dried and stored. With reference to the two villages mentioned two main parboiling methods are of interest: the "traditional method" and the "currently-used method". In both the rice is first soaked in water and washed. However, in the currently-used method the washing is more extensive. In the traditional method, only a cauldron is used and the rice is half-boiled, half-steamed in place (Figure 2a). Because the rice needs to be stirred frequently in this method the cauldron cannot always be covered with a lid during processing. In the currently-used method an insert and a lid are used together with the cauldron (Figure 2b) and the rice is steamed in the insert and not boiled as such. In both methods the rice is then dried, but the drying is done more carefully in the currently-used method. In the final step of both methods the rice is milled to remove the husks and bran so as to obtain white, parboiled rice. The currently-used method is the one mainly used in the two villages of interest, but the traditional method is still employed extensively in other areas of Benin. More detailed descriptions of parboiling and its development are presented below.

Figure 2a
Traditional Method

Figure 2b
Currently-Used Method

7.2 Development of Parboiling

The traditional parboiling method is quite simple and is carried out in a cauldron only. To start, the rice is soaked in cold water for 12 hours, drained, and then simply placed in the cauldron (usually made of a cast aluminum alloy derived from recycled automobile parts). A relatively small amount of water is then added - enough to steam all the rice - and the cauldron is heated until the water in the bottom comes to a boil. The resulting steam partially cooks all the rice while it is being stirred regularly to ensure a reasonable homogeneity. This steaming is continued until the husks have opened slightly and the kernels are visible. A main disadvantage of this method is that the average rice quality is low since some of the rice will remain submerged during heating in the liquid water at the bottom of the cauldron and will therefore overcook. Also, some of the rice will burn on the hot cauldron bottom, resulting in discoloration of some kernels, leading to overall lowered quality and losses. Evidently, the traditional method is rather labour intensive because the rice needs to be stirred frequently. As well, the subsequent drying is mostly done in direct sunshine since some of the rice gets very wet during the procedure. This can lead to over-drying, cracking of the kernels, and further losses. If traditional parboiling is not done very carefully, there is considerable risk of obtaining rice with a poor color, a bad odour, and subject to fungal attack (especially when it is overcooked). Overall, the traditional method requires a lot of attention from the women and can lead to diseases and injuries due to extensive and intensive exposure to the cooking fire. It is not very energy efficient because the cooking is often done without a cover on the cauldron so that a considerable amount of steam escapes from the top of the cauldron.

At one point INRAB-PTAA, WARDA and Sassakawa Global 2000 worked together on the development of an improved parboiling method, with the objectives of increasing both the rice quality and the productivity of the parboilers. Accordingly, a first “improved” method was developed in 2003 and was reported upon by Houssou (2003). The currently-used parboiling method is the result of further improvements made to that first, improved method. Technical and socio-economic studies were subsequently carried out

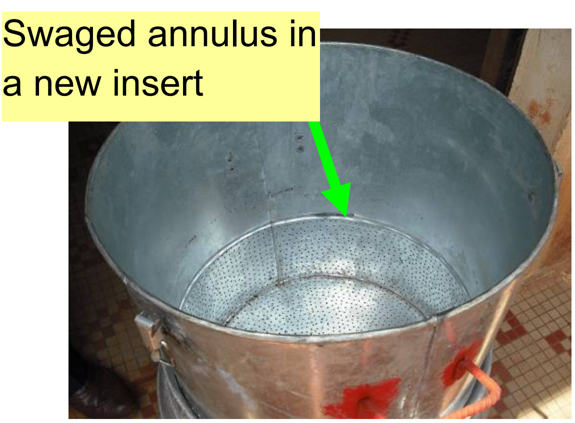


Figure 3a
Insert

Figure 3b
Insert and Cauldron

Figure 3c
Lid with Clamp

on the currently used method by Houssou (2005). Overall, the parboiling equipment and processing approach that, together, constitute the currently-used method result in the production of a better quality rice than the traditional method. However, the equipment cost is much higher (about twice as much), with various versions of the equipment being fabricated and used. No data seem to be available on overall resource consumption (water, fuel, labour) or productivity for either of the methods.

As mentioned above, in the currently-used method, instead of being partially boiled, the rice is entirely steamed in an “insert” (Figure 3a) which is named as such because it is partly inserted into the cauldron (Figure 3b). Thus, in this case, the cauldron serves as a boiler to generate very low-pressure steam. The insert is a funnel-shaped container whose bottom and lower side wall are perforated (up to 15 cm above the bottom plate) to allow steam to pass from the cauldron headspace into the rice mass. When the insert is put into the cauldron all the holes of the sidewall will be below the top rim of the cauldron, and the water level in the cauldron will be just below the bottom of the insert. The insert is usually made of galvanized sheet metal by means of rolling and soldering. Often, there is an annulus swaged into the bottom of the insert to support the insert on the collar of the cauldron and to seal that opening (Figure 3a) to a degree. The seal is frequently improved by the insertion of a cloth (Figure 4) into the gap. A number of local artisans have been taught how to fabricate the inserts by INRAB-PTAA, but other artisans have been shown how to do this by some different organizations.

Figure 4
Alternate Insert Design

Generally, the artisans attempt to imitate the original inserts, but sometimes change the design slightly, depending on the technology and materials available. For example, the insert distributed by INRAB-PTAA comes with a lid which is attached to the side with three clamps to reduce steam loss (Figures 3c). However, in the villages visited, the lid was not attached but was held down with rocks (Figure 4). Such simplifications may also be implemented to reduce fabrication costs.

In the currently-used method the actual parboiling step is less labour-intensive than in the traditional method and there is less direct exposure of the workers to the fire. As well, the rice is cooked more evenly and can be dried mostly in the shade. All this leads to a better quality product containing fewer broken and scorched and discoloured kernels. However, although the insert was designed for parboiling 40 to 50 kg of rice (Houssou, 2004) at a time, the village women have indicated that for the version of the insert that is available to them the rice will cook unevenly if the insert is used at this "rated capacity". Thus, the parboiled rice will vary greatly from the top to the bottom of the insert. Therefore, they are using their insert with a maximum of 30 kg of rice (the "functional capacity" in this case). They may parboil as many as six such batches in a day to obtain a total of 100 kg of milled rice in the end. The first batch takes more time because the fire must be started and the stove needs to heat up but subsequent batches take less time each, about 30 minutes per batch.

After milling the rice is sorted to remove broken and discoloured kernels. The fraction that is removed seems to vary with the rice variety and the details of the processing method but the quantity of kernels that needs to be removed seems quite high, even for the parboiled rice. Kernel discoloration may also be due to milling. A sample of unsorted rice parboiled at INRAB-PTAA in Porto-Novo is shown in Figure 5.

Figure 5
Rice after parboiling but before sorting

For the implementation of the new parboiling method WARDA, SG2000, Songhai and INRAB produced the video *Cashing In with Parboiled Rice* in which the currently-used method (equipment and procedures) are explained (including steps such as drying on a tarp instead of directly on the soil, etc.). After the village women had seen the video, they started to ask the NGO's for the new equipment and they formed cooperative groups so as to have joint access to it. Funded by VECO Bénin, the NGO's of the *Département des Collines* then distributed 61 sets of parboiling equipment in order to make the new technology available. However, although quite a few women were thus provided access to the equipment (slightly different from the equipment developed by PTAA), it was not made available free of charge to everyone, and many women could not afford to buy it. As a result of having seen the video but not having access to the equipment, a number of women then innovated parboiling methods based on the use of the cauldron only (as per the traditional method) but in which the rice was kept away from the water in the cauldron and exposed to the steam only (as per the currently-used method). Thus, many of the village women, as a result of having seen the video, were stimulated to innovate. Simply put, they started with the idea of the equipment used in the currently-used method and innovated different approaches to attain the same goal. In their various approaches they created a false bottom in the cauldron either with branches, metal wires, jute bags, etc. This false bottom is then covered with a cloth to retain the rice. Obviously, this approach is much simpler than the use of a large and expensive insert used in the currently-used method, but also has its drawbacks. Specifically, placing branches horizontally in a grid while they are only supported at their ends by the cauldron wall requires considerable time and care. Several support arrangements are shown in Figures 6a and 6b below (from Zossou, 2008).

Figure 6a (Zossou 2008)

Figure 6b (Zossou 2008)

Evidently, this approach is less convenient than using the composite equipment because the false bottom must be re-constructed for every batch of rice processed. As well, removal of the rice from the cauldron after the parboiling step is more time-consuming than in the insert-based method, since it needs to be done more carefully. Also, there is chance of rice being lost during this operation.

The currently-used method has some advantages but also some disadvantages. Specifically, the equipment is relatively expensive and, for some versions, it can only be used at half of its rated capacity. Although the quality of the rice produced is better than with the traditional method, it is difficult to determine whether it is a "better" method overall since no detailed data seems to be available on resource consumption (water, fuel, labour), nor on productivity (kg/hr), nor on value addition, nor on actual profitability to the parboiler. Generally, women seem quite ready to adopt the currently-used method as long as they are provided with the equipment free of charge. Their reluctance to invest may reflect an inherent lack of appreciation of the commercial possibilities, or it may reflect an intuitive understanding that the benefit/cost ratio is not very favourable.

Figure 7 - Washing the rice

Figure 8 - Cover cloth

7.3 Description of the currently-used parboiling method

The currently-used parboiling method involves a number of steps.

- The rice is first washed with water several times in a basin (Figure 7). Approximately 3 litres of water are used to wash 1 kg of rice (Zossou, 2008).

- The rice is then soaked in clean water for 18 to 20 hours (overnight). Either hot or cold water can be used for this. After soaking, the rice is washed again by taking handfuls of the grain and rubbing the kernels together.

- Next, the rice is drained in a basket, upon which it is put into the insert already sitting on top of the cauldron. The depth of the rice layer in the insert is usually about 30 cm. In both villages of interest, a cloth (usually raffia/jute) is put on top of the rice to reduce steam loss and to facilitate even steam distribution throughout the rice (Figure 8).

- Approximately 10L of water is then added to the cauldron to parboil about 25 kg of rice. This means that, at the beginning of parboiling, the water level in the cauldron will be just below the bottom of the insert so that the rice will not be in contact with the liquid. A simple lid is put on top of the insert and some rocks may be put on top of the lid to reduce steam loss (Figure 4). (In both Gobé and Gbaffo the lids did not seal against the insert very tightly and there were no sidewall fastenings present.)

- The cauldron is heated by means of the fire which is started underneath it, causing the water to boil. The resulting steam is forced through the perforations (side and bottom of the insert) and passes into the body of rice which is thereby heated. This is continued until the rice is steamed sufficiently, upon which it is removed from the insert. It was observed in Gobé that the steaming phase lasted about 30 minutes.

- After the steaming is completed, the rice is dried before being milled. To dry it, the steamed rice is first spread out on a tarpaulin in the sun for about an hour and a half, which brings the moisture content down to around 21% (Zossou, 2008). It is then moved into the shade for another sixteen hours of slower drying. In the end, before milling, the rice has a water content of 10% (Zossou, 2008).

- Milling is usually not done by the parboiler herself. Instead, she will transport the rice to the miller's where the husk and bran are removed, normally in one operation, and then transport it back home. The parboiler will pay the miller for this service, either in cash or in kind; generally, the husk and bran remain the property of the miller.

- After milling, the last step before marketing is sorting. Thus, the milled rice kernels have to be sorted to eliminate broken and discoloured kernels. This step is essential to obtain a rice of good quality which can be sold quickly.

A flowchart of the parboiling procedure is presented in Figure 9.

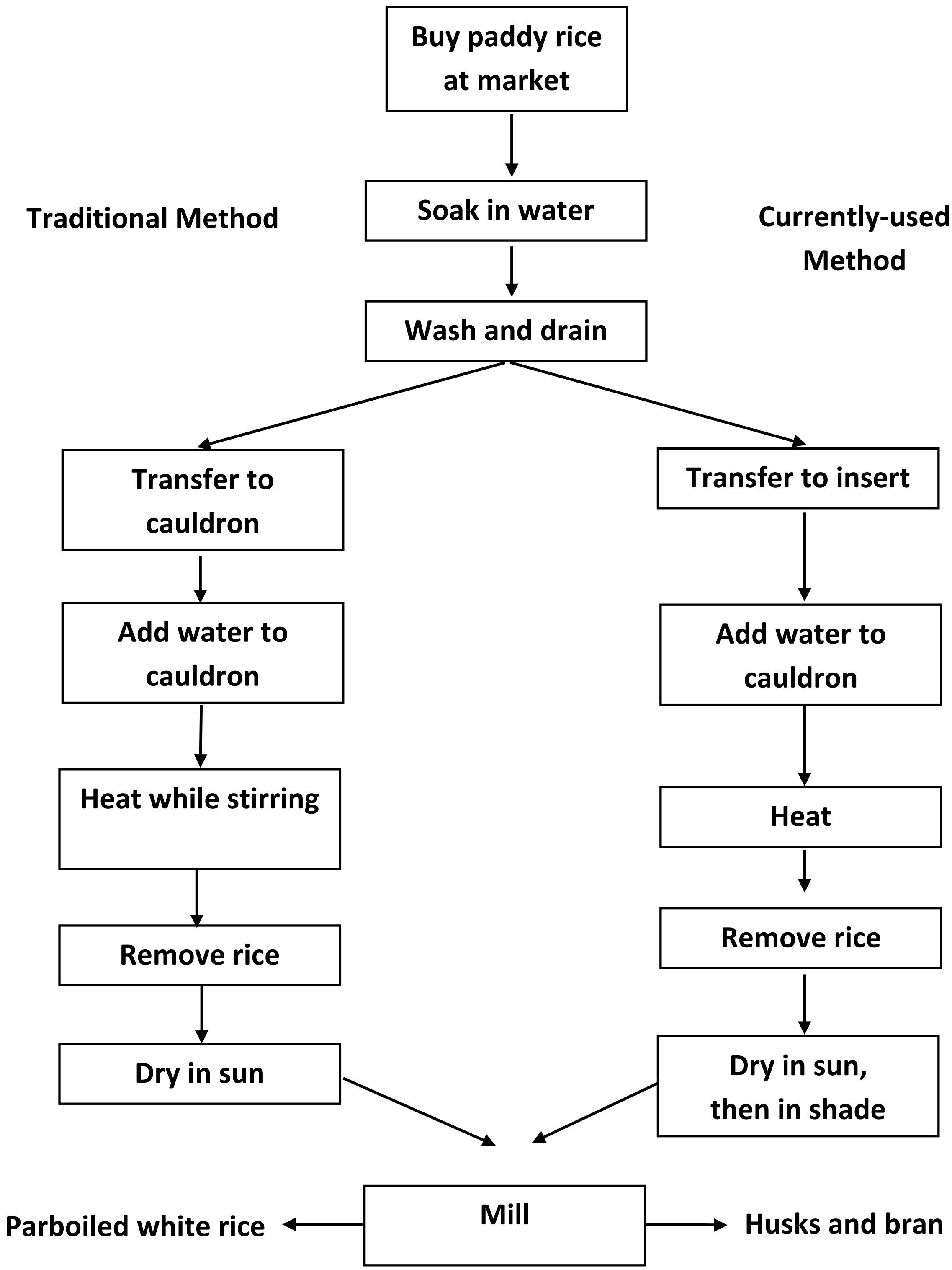


Figure 9
Flowchart of Parboiling

8. Problem statement

With only a low level of technology being available, the women face many challenges in their parboiling activities. These difficulties are of major concern when it is time to supply a growing demand, stay competitive by producing at an advantageous price and respect good rice quality criteria. The parboiling is also procedure which is inherently inefficient since the steam is produced by boiling water on an open wood fire. Further heat transfer is also quite inefficient, reducing productivity and leading to high wood consumption. Wood is becoming more difficult to obtain and its price keeps on increasing.

The different problems concerning the overall parboiling system can be gathered into three main topics: the traditional stove, the parboiling equipment and the energy source.

8.1 The Traditional Stove

The traditional stoves used in Benin for rice parboiling are similar to the popular traditional stoves of many developed countries in the world. The stoves consist of three clay supports set in a triangular form. An open fire, with wood as primary fuel, is then initiated under the cauldron to achieve various tasks. In fact, nearly three billion people in the world are using daily this cooking method despite its low efficiency (Hedon 2008). The fuel-efficiency of the three supports traditional stove is very small. Moreover, open air fire produces considerable amount of smoke. The non-effective combustion also burns much more wood than what would normally be required. The high demand forces the women and children to allocate a good amount of their time to wood collection which unable them to perform other activities such as going to school.

8.2 The Parboiling Equipment

During parboiling, the rice is steamed. To achieve this, the rice is added in a perforated insert which is then placed in the cauldron. The process reduces the rice losses and enhances the rice quality, but its high cost makes it inaccessible to many women. The insert is rather costly in the village environment, unreasonably so for its size, sophistication, and quality. It is made of galvanized metal sheets and its price is estimated at about 35,000 to 50,000 CFA ($85.00 to $125.00). Thus, women have created coops to share the equipment. Productivity is greatly lessened since in the villages, many women are sharing the parboiling insert. Furthermore, with important steam escape from different locations, the insert's energetic efficiency is low. This requires important quantities of wood to produce a fire sufficient for the process. Overall, the amount of fuel used per kg of rice being parboiled is larger than what it needs to be. This is due to two main factors, very low thermal efficiency of the system and large thermal losses from the equipment during processing.

8.3 The Energy Source

In Benin, wood is the main source of energy especially in rural areas for cooking purposes. It is estimated that 93% of Benin's rural population is using wood as main energy source (MMEE, 2006). The demand for wood is steadily increasing, and this trend is closely related to the increase in population in the country. In 2005, the mean annual population growth rate in Benin was 3.18% (DAT, 2007). This situation of deforestation brings wood to become less available. Various tree species are used as fuel and availability is mostly the prevailing factor during wood collection, with no strong tendencies towards variety. The wood is usually gathered directly from the surrounding forest, except during the rainy season when the women buy it at a local market. Increasing demand relative to supply is now causing the price of wood to increase. Women are preoccupied by the rising cost of wood but also by the longer walking distances to collect it. They will sometime use palm nuts and various wastes, such as old sandals as fuel supply. In addition to its high wood consumption, the production of parboiled white rice generates organic by-products. Both rice husks and bran are removed from the rice kernel during milling. This material is often considered a waste which tends to accumulate in heaps at the miller's facility. A certain amount of it is used as animal feed, but most of it is presently not utilized. Sometimes it is burned when too much accumulates in pile.

9. Objectives and Scope

9.1 General Objectives

The main objective of this overall project is to improve the energy efficiency of rice processing, more specifically small scale parboiling process. The reduction of fuel wood consumption is aimed to reduce the stress on the environment and the time allocated for wood collection by the women and children. The overall general cost of the process is wished to be reduced and therefore cheap and available material must be used. User friendly and thus easy to construct, repair and maintain innovations should be designed. The objective is to develop technical solutions that are realistic and easily applicable to the social and economic context of African villages in order to bear the extent of parboiling issues. More specifically, for this project three solution were defined: 1) develop a more efficient stove to be use for rice parboiling; 2) develop smaller, cheaper and more efficient parboiling equipment; 3) develop a method to use the by-products of rice milling as an alternative energy source. Finally, the results of the development should be ready to pass on to local fabricators and NGO's for implementation at the population level of the targeted villages, as well as in other villages after that.

9.2 Objectives and Scope - Improved stove

The thermal efficiency of the fuel, stove, cauldron and water_in_cauldron system is to be examined with the specific objective to substantially improve that efficiency through the further development of a modified stove. Thus, the amount of fuel consumed per kg of rice parboiled will be reduced. As well, the newly modified stove must meet the following criteria: 1) its real cost, including labour and time required for construction, should not be substantially higher than the stoves presently in use (with other words, materials should be cheap and the stove should be easy to construct and repair), 2) it should be constructed from materials with which the villagers are thoroughly familiar. The modified stove must allow the use of alternate fuels, such as briquettes made from the material left-over from rice processing, as well as wood. Overall, it is essential that the modified stove be readily acceptable to the local NGO's who will implement the design, and to the village women who are involved in parboiling. It will also be attempted to design the new stove so that it can accommodate different sizes of cauldron.

9.3 Objectives and Scope - Parboiling equipment

For this second improvement, the first objective is to develop equipment (an alternate insert) which will allow rice to be parboiled directly in a cauldron, without the large, currently-used insert being required. Obviously, the equipment should allow a woman to produce satisfactorily parboiled rice, and should have approximately the same functional capacity (30kg) as the currently-used insert. Also, the equipment should be easy to use and considerably cheaper than the parboiling insert presently employed. As well, there should be less latent heat loss due to steam escaping and less sensible heat loss due to convection. Thus, the overall thermal performance of this equipment should be considerably higher than the currently-used equipment, and less fuel should be needed per kg of rice parboiled. It should be noted that the time required for parboiling will probably not be affected very much. This equipment will be acquired/made/assembled and then tested under field conditions. The equipment should be robust, long lasting, and easy to repair by the end user. Ideally, it would be possible to use the same equipment with several different sizes of cauldron.

9.4 Objectives and Scope - Alternative fuel

For this third improvement, the first objective is to develop a method to process the husk/bran material into a form which can be burned easily in the stoves presently in use and, especially, in the modified stove which is to be developed. The second objective is to characterize this fuel (in terms of energy content, moisture content, ash, and further qualitative characteristics), and to test it under realistic field conditions. In order to compress this material a machine should be constructed and is to be powered by human strength only leading to relatively low capital costs as well as low operating costs. Also, only a very moderate skill level is required to operate such a machine. The best size/shape combination of briquettes is also to be determined. Different binders will also be investigated. Of course, any binder used must be cheap and of local origin. When burning, the briquettes must give off sufficient heat without flaring too much, and they must not give off bad smells while burning, nor emit any obviously noxious fumes. The briquette fuel must be acceptable to local users in terms of shape, size, and appearance (similar to the fuel available right now). It may not be possible to utilize the briquettes alone; instead it may be necessary to use them as a co-fuel with wood. Thus, in this case, the wood consumption would be reduced, but not eliminated altogether. Overall, as a fuel, the briquettes should be cheaper than wood, and perform at least as well.

10. Literature Review

10.1 Stoves in Developing Countries

The traditional stove consists of three clay supports which are arranged in a triangle (Figures 10a and 10b). The thermal efficiency of such design has been reported to range between five and fifteen percent by the FAO (2006). Many variations exist, in which various modifications to the basic pattern are incorporated. Many researches in other region of the world often incorporate material such as cement or metal to their stove design. They have sophisticated designs such as rocket stove (Witt, Weyer and Manning, 2006) or two pot stove in metal or ceramic (Ballard-Tremeer and Jawurek, 1996) which do not apply to the need of the end-users for this project. The constraint on cost and availability of the material reduces considerably the possible complexity of the stove. Acceptance among the community suggests that the design must be kept simple and cheap. In that case, it was very important to look at the current situation in the village of interest.

10.1.1 Stove in Gobé, Benin

Like in most part of the developing world, the women of Gobé use a traditional based stove. However, in this village, the three supports are linked with more clay on two sides of the triangle to protect the fire from the wind. The wood fuel is then fed in through the front opening (Figure 10c). Adding to the low efficiency, the open fires produce a considerable amount of smoke which can have a negative influence on the health of the villagers, especially the women and children who work very close to the fires. Thus, the CO, NO_x, and formaldehyde in the smoke can cause cardiovascular and respiratory diseases, various eye ailments, birth defects, as well as many types of cancer (FAO, 2006).

Figure 10a
Traditional Stove

Figure 10b
Modified Stove

Figure 10c
Modified Stove

Generally, a stove is used with one size of cauldron only and a woman or group of women will have access to stoves of various sizes, depending upon need. They will, however, use one specific stove to do their parboiling. That stove is located in a central place in the group's work area so that up to fifteen women of a coop can share access. As well, each household has its own stove for cooking which is generally based on the same design as the one used for parboiling, but smaller.

10.1.2 Material of Construction

The clay from which the stoves are made can be obtained almost anywhere from the village's soil by digging. It is mixed with water. Sometimes pebbles are included as well. In Gbaffo, the villagers mentioned that they use material taken from termite nests, if available, to obtain a better quality clay. Overall, it takes about two days to build a stove due to the time required for the drying of the material. To obtain a reliable stove, the clay should dry slowly. Subsequent to construction a stove can be damaged by rain and fast drying in the sun. However, because of the readily availability of clay, the stoves are easily repairable. The villagers have also indicated that, to obtain a more solid stove, it can be made of concrete. This is not commonly done because cement is expensive and often not locally available.

10.1.3 Example of an Improved Stove

In the village of Gbaffo, the NGO *Un Monde,* has helped the women build an "improved stove" which essentially consists of the normal three supports, but surrounded by an annulus, also made of clay (Figures 11a and 11b). In this case, the supports are made of

Figure 11a
An Improved Stove

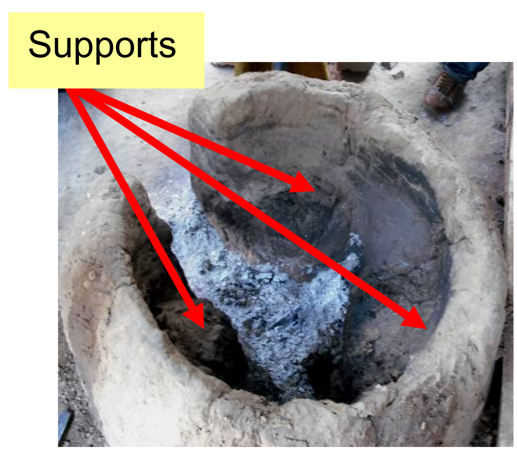


Figure 11b
The Supports Inside the Stove

rocks, covered with clay to make them the same height. A straw thatched roof was also constructed over this stove to protect it from degradation by rain and solar radiation.

The women who use this improved stove have said to observe a considerable reduction in the amount of fuel used. This is probably due to the wind being blocked and the heat therefore being transferred to the bottom of the cauldron more efficiently. However, during preliminary work, it was observed that the improved stove in Gbaffo produced more smoke and took longer to start up than the more usual one used in Gobé. In Gbaffo each of six women's groups has built their own improved stove but the forty-five women involved in those groups are still all sharing one parboiling insert.

10.1.4 Fuel in Use

The most commonly used fuel is wood in the form of branches and logs. When available, this is mostly obtained in the forest by women. Otherwise, it is bought from a local supplier, especially during the rainy season. The price of wood differs from one village to the next, depending on the location. The fire is made in the stove with the whole branches and logs (with other words, the fuel is not reduced in size before it is fed into the fire), with the unburned parts sticking out of the fireplace (Figure 12) and the burning wood practically touching the cauldron's bottom. The unburned fuel is then fed into the stove as required to keep the fire going. However, a fraction of it will burn before being fed in, leading to fuel consumption without any benefit. Although there may be substantial differences between stove designs, the thermal efficiency of the fuel/ stove/cauldron/water_in_cauldron system is very low for all stove arrangements in use, including the usual three-support stove (Figure 10a), the modified stove (Figure 10b and 10c), and the improved stove (Figure 11a). Thus, the fraction of the chemical energy available in the fuel which is actually transferred to the water in the cauldron is quite small for all designs. That is the specific issue which is addressed in this project. Of course, a further fraction of the energy which is transferred to the water in the cauldron is lost both as sensible and as latent heat, further lowering the overall thermal performance of the equipment.

Figure 12
A Wood Fire in a Stove

10.1.5 Experiments (on the Stoves)

The test conducted on the prototypes are based on the *Water Boiling test* which mainly consists of calculating the energy required to boil 10 L of water compare to the energy output. The manipulations of the test are as follow: (from Hedon)

- Take the temperature of the ambient air.
- Make sure the stove is at ambient temperature and that it has not been used in the last hours.
- Take wood samples for analysis (weigh the samples if possible). Take different sample for every variety of wood and label them properly.
- Weigh the empty cauldron.
- Determine the volume of water added to the cauldron. (10 L)
- Weigh the cauldron with the water in it.
- Weigh the un-burnt wood.
- Start the fire and the chronometer.
- Take the time at which the fire is running good.
- Take temperature of the water every minute.
- When the temperature is 100oC, stop the fire and the chronometer.
- Knock off char from un-burnt wood as best as you can. Estimate the amount of char left on the wood (between 2 and 5%).
- Weigh char and un-burnt wood separately.
- Take char samples. (Weigh it if possible)
- Weigh remaining water in cauldron. Take water temperature.
- Do the same this time with a warm stove.
- Calculate the efficiency of the stove following

Energy in

Mass of wood used = Mass of wood before – Mass of wood after

Mass of char used and wood transformed in char = Mass of char before – Mass of char after

Total energy consumed = Mass of wood used * energy content of wood + Mass of char used* energy content of char

Energy out

Q (energy of vaporization) = (Mass of water before – Mass of water after)* energy requires for vaporization of water (2260 kJ/kg)

Q (energy to bring water to a boil) = Mass of water at the beginning* specific heat of water (4.186 kJ/kg °C) * (Start temperature – Final temperature)

Total energy out = Q (energy of vaporization) + Q (energy to bring water to a boil)

Efficiency = Total energy out/ Total energy in * 100

Heat and mass concepts (section 10.2) will also be applied to the design of the improved stove.

10. 2 Parboiling and its Equipment

10.2.1 Parboiling in Benin

Essentially, "parboiling" of rice means that the rice is slightly cooked before it is dried and stored. With reference to the two villages mentioned two main parboiling methods are of interest: the "traditional method" and the "currently-used method". The currently-used method is the one mainly used in the two villages of interest, but the traditional method is still employed extensively in other areas of Benin. Both methods are explained in details in the Background of the present report (section 7).

10.2.2 General Heat Transfer Principles

All the section 10.2 comes from Incropera et al. (2007) unless stated otherwise.

An approximate distribution of heat transfer has to be made in order to improve and assess the efficiency of the stoves. Those calculations can be long and mathematically challenging, but fair assumptions can simplify the model and make calculations much easier while still fairly accurate. The basic principles underlying heat and mass transfer are explained in the next section.

General heat transfer follows the subsequent formulae:

$$Q_{in} + Q_{generated} = \Delta Q_{storage} + Q_{out}$$

All energy input to the system, from external source (Q_{in}) or from internal generation ($Q_{generated}$), has to balance the energy output of the system (Q_{out}) as well as the energy accumulated in the system ($\Delta Q_{storage}$). To improve efficiency of the system, the energy losses (part of the energy output which does not serve the purpose of the system) have to be minimized. For example, energy taken for the evaporation of the moisture in the wood is diverted from the cooking pot and therefore ''lost''. Figure 13 from Sharma et al. (1990) illustrates other examples of heat being diverted from the cooking purpose.

Figure 13 : analysis of different wood burning rates. a—Radiation losses; b—heat lost in evaporation of water originating as hydrogen in fuel; c—heat lost as carbon monoxide in flue gases; d—unknown losses; e—heat lost in evaporation of moisture in fuel; f—heat lost as charcoal and ash; g—flue gas losses; h—convection losses; i—sensible heat gained by the stove; j—sensible heat gained by the pots; k—useful heat.

Moreover, the different types of heat transfer presented in the next sections can be anticipated in the case like a fire/stove/cauldron system.

10.2.3 Conduction

Conduction is a mode of heat transfer through which particles at higher level of energy (higher temperature) transfer energy by interacting with less energetic particles of the same medium.

Differential heat transfer rate for this kind of transfer is:

$$dq_{cond} = -k \, dA \, dT/dn$$

Where: dq is the differential heat transfer by conduction in W

k is the thermal conductivity in W/m*K

dA is the differential surface area perpendicular to the heat transfer rate and over which this later acts in m^2

dT/dn is the differential thermal change on the differential length dn in K/m

Heat transfer rate is perpendicular to the surface area and from high temperatures to cold temperatures.

In our case, conduction can be experience through the heating of the clay stove, the cauldron, the insert, the paddy rice.

10.2.4 Convection

Convection is a mode of heat transfer through which heat is transferred from a surface to a moving fluid or vice-versa.

Newton's law of cooling:

$$dq_{conv} = h\ dA_s\ (T - T_\infty)$$

Where: dq_{conv} is the differential heat transfer by convection in W

h is the convection heat transferred coefficient in W/m^2*K

dA_s is the area over which the heat transfer happens (perpendicular to the heat transfer) in m^2

T is the temperature of the surface where convection occurs in K

T_∞ is the temperature of the fluid in K

In our case, convection can be experience through the heating of the water by the cauldron and of the air by the fire or by the hot stove and insert.

10.2.5 Radiation

''Thermal radiation is the energy emitted by matter that is at a nonzero temperature.'' (Incropera and al, 2007)

From the Stefan-Boltzmann law ($E = \varepsilon\ \sigma\ T_s^4$), radiation heat transfer can be calculated:

$$dq_{rad} = \varepsilon\ \sigma\ dA\ (T_s^4 - T_{sur}^4)$$

Where: dq_{rad} is the radiation heat transfer (emission – absorption) in W

ε is the emissivity of the surface (relative to a blackbody for which $\varepsilon = 1$)

σ is the Stefan-Boltzmann constant which is equal to $5.67 \times 10^{-8}\ W/m^2*K^4$

dA is the surface area of the body which emits energy in m^2

T_s is the temperature of the surface in K

T_{sur} is the temperature of the surroundings in K

In our case radiation can be experience from the clay stove, the cauldron, the insert and the paddy rice.

10.2.6 Storage

Accumulation of energy in a body can be seen only when the body is not at steady-state. (e.g. When a fire is started inside a cold stove, part of the energy from the fire is accumulated by the stove material which increases temperature until steady-state is reached.)

$$dq_{st} = m\ c_p\ dT/dt$$

Where: dq_{st} is the heat stored by the differential volume material in W

m is the mass of the differential volume in kg

c_p is the specific heat of the material in J/kg*K

dT/dt is the rate of temperature change in K/s

10.2.7 Energy Generation

It is to note that in the case of clay, metal, water and rice, no generation of energy is expected. The only generation of energy will occur from the burning of wood (one could rightly argue that it is only a transfer of chemical energy to thermal energy), but in our case we will consider it like a generation. Generation of energy by a wood fire is usually expressed as a function of time and it can be measured from the energy content of wood and the average wood burning rate.

10.2.8 Phase Change

There is some energy associated with a phase change. When water from the cauldron evaporates, it takes energy with it. The latent heat of vaporization is a function of the pressure and temperature and is expressed in kJ per kg of liquid vaporized. At 100^{o}C and 1 atm, the latent heat of vaporization of pure water is 2257 kJ/kg (Çengel et al., 2006).

10.3 Biomass Briquettes

Several previous studies have been conducted on the use of rice husks as an alternative fuel. Most past researches were mostly focused on use of husks only and less on bran. Husks are mostly regarded as a potential fuel regardless of the bran. Bran is sometimes used as animal feed since it has some higher nutritional value. In other parts of the world, different methods seem to exist and were developed to process the husks such as the combustion in a fluidised bed combustor, the transformation into chars by pyrolysis, the production of biomass briquettes, the energy generation by means of a power plant, the co-combustion of rice husk with coal in a cyclonic fluidized-bed combustor or the fabrications of rice pellets. However, most of these methods are technology intensive and are hardly applicable in a village context of a developing country. Therefore, the literature review was oriented towards characterisation of rice husks and bran, and its processing into biomass briquettes.

10.3.1 Characterization of Rice Husks and Bran

In the production of white rice, the husks and the bran are considered as agricultural residues. Out of the 582 million tons of paddy rice harvested each year in the world, 145 million tons of rice husk are produced. (FAO, 2006) Paddy rice is composed of about 72% of rice kernels, 5-8% of bran and 20-22% of husk (Prasad, 2001). Whereas in other locations these two materials might be produced as separate streams, because of the way the rice is milled in the area of study, they come out as a single, mixed stream. Different challenges, such has the high moisture content and the low bulk density, are related to the use of biomass in its original form. Normally the rice husk contains about 8 to 9% moisture (Guerrero, 2008) and depending on the rice variety, 13 to 29% of its weight is ash (Prasad, 2001) with most of the rest being combustible. The bran also has fair oil content. The rice husks would contain about 40% cellulose, 20% silica and 30% lignin. (Chindaprasirt, 2009). Rice husk has also a fair amount of ash content, within 13 to 24%, which is the usual range suggested by the literature for ash content. (Prasad, 2001) This ash mostly contains silica (SiO_2) in proportion of 87 to 97 %, depending on the variety of the paddy. (Prasad, 2001) Further elemental analysis of rice husks and its ash can be characterise as follow:

Table 1 – Elemental Analysis of Rice Husk and Ash (Skrifvars, 2005)

	Composition (wt %)									
Fuel	C		H	N		Cl	S		O	
Rice Husk	40.1		4.7	0.5		0.06	0.05		54.5	
	Ash Composition (wt % Oxide in Ash)									
	SiO_2	MgO	Al_2O_3	Fe_2O_3	TiO_2	K_2O	MnO	P_2O_5	CaO	Na_2O
Rice Husk	95.9	0.3	0.1	0.1	0.005	1.9	0.1	0.6	0.6	0.01

The processing of rice husks and bran into briquettes requires compression of these materials into a denser form, since there are quite loose in their natural form. Initially, the raw husk alone has a bulk density varying from 0.04 to 0.2 g/cm^3. (Kaliyan, 2009) For rice bran the bulk density is slightly higher varying from 0.29 to 0.4 g/cm^3. (Sreenarayana, 1985) The relaxed density is the density of a material after its relaxation time is over. Most of the relaxation usually occurs during the first 10 minutes after the end of the compression and it can continue for the next 2 hours, this time is also called the recovery time. (Chin Chin, 2000) The relaxation time usually increases with the moisture content. (Faborode, 1989) The relaxed density is related to the applied pressure. A formula was developed by Dr. Chin Chin (2009) and uses empirical values to relate these two concepts:

$$D = a * \ln (P) + b$$

Where D = Relaxed density (kg/m^3)

P = Applied pressure (bar)

a & b = Empirical values for rice husk (20.5 & 344.1 respectively)

The theoretical energy content of rice husks alone slightly varies from an author to the other. No heating value was available for rice bran alone of for a mixture of rice husks and bran together.

Table 2 – Energy Content of Rice Husks

	Genieva, 2008	Bergqvist, 2008	Skrifvars, 2009
Energy Content	358.5 kcal/g	352.77 kcal/g	370.2 kcal/g (dry basis)

10.3.2 Processing of Biomass Briquettes

To compress the husks and bran material into briquette, a certain form of force amplification mechanism is required. A greater pressure application increases the formation of attraction forces between the molecules. These bonds forms when solid particles are bring close enough to each other during compression. (Kaliyan, 2009) Different systems such as gears, pulleys or screws exists but are considered inappropriate for the present's project context and situation. A more interesting option consists of a lever principle. The equation for a simple lever is as follows:

$F_1 \times D_1 = F_2 \times D_2.$

Where F_1 = force produced by the piston (N)

F_2 = force applied by the operator (N)

D_1 = distance between fulcrum and force application point (m)

D_2 = distance between fulcrum and piston (m)

Therefore, if a required compression force is about 5 times the force of a manual power stroke, the distance between the fulcrum and the free end of the lever must be 5 times the distance between the fulcrum and the piston joint (Figure 14).

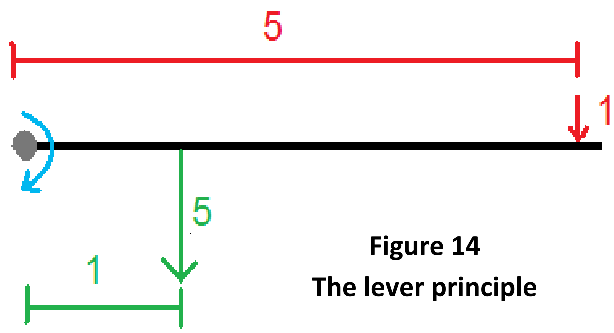


Figure 14
The lever principle

Different sizes and shapes of briquettes such as rectangular of circular are possible for biomass densification. It is suggested that a die thickness over diameter (or length) ratio higher than 10% increases the durability of the briquette (Kaliyan, 2009):

$$t / d * 100\% \geq 10\%$$

Where t = thickness of the material compressed (m)

d = diameter (for circular briquette) or length (for rectangular briquette) (m)

According to Dr. Kaliyan (2009), increasing this thickness to length ratio increases the shear force applied on the briquette. This force would be responsible for the greater durability of briquette. Such ratio of 10% or less would indicate at the limit when a briquette becomes too thin and presents insufficient structural strength.

The physical forces that bond the material together also contribute to the strength and durability of a densified product. (Kaliyan, 2009) Such binding forces are 1) solid bridges, 2) attraction forces between solid particles, 3) mechanical interlocking bonds, 4) adhesion and cohesive forces, and 5) interfacial and capillary pressure. It is evaluated that a dwell time is considered essential for better densification and creation of binding forces rather than a simple impact of the piston. (Kaliyan, 2009) The dwell time can be defined as the time period during which the pressure applied is hold on the material to be compress. A longer dwell time will increase the shear strength of briquettes and decrease the relaxation time. Most of the advantages of a dwelling time occur within the first 10 seconds of pressure application. (Chin Chin, 2000) A simple impact load or a rapidly applied load doesn't give enough time for permanent creep deformation within the particles. (Faborode, 1989) Heat would also increase further more permanent deformation.

Water also plays a major role in the creation of intermolecular attractions (Faborode, 1989). Up to a certain level, moisture is a binding agent by developing Van der Waal forces and a lubricant by decreasing the friction inter-particle friction and the pore spaces. (Kaliyan, 2009) However, beyond the saturation point, which is about 30% for rice husks, water occupies volume that would normally be taken by the biomass and it increases the resistance to compression. (Faborode, 1989) The saturation point is defined as the moisture content at which the cell walls of the biomass are completely saturated but without having any free water in the cells. (Faborode, 1989)

Along with water, addition of a binder increased the durability and the shear strength of the briquettes to be produced. (Chin Chin, 2000) The literature recommends some binder addition in the order of 0.5% to 5% to create enough bridges and strong bonds between the particles. (Kaliyan, 2009) Viscosity of a binder will increase adsorption which is the surface adhesion of particles that generates stronger molecular bonds. (Kaliyan, 2009)

11. Prototypes Development and Initial Designs

Innovation in the villages is often a big challenge because the women have been using traditional methods and equipment for many generations and their revenue depends directly upon it. However, the lack of efficiency of the parboiling process has forced the women to allocate more time and effort to this activity than needed. The stress on the environment generated is also considered and should be reduced. For that purpose, various prototypes have been built to reduce the amount of energy input. Thus, three main streams were evaluated: improving the stove and the insert efficiency as well as looking for an alternative source of energy

11.1 Stoves

11.1.1 Approach to be followed

The idea is to improve the stove that the women are using instead of producing a completely new design in order to make it more readily acceptable. To solve the problem of low stove efficiency, a first visit in the village will be made to test the efficiency of the actual stove. The new stove has to be easy to build so that it can be reproduced and used widely. The main intent is to reduce the consumption of fuel and therefore reduce the cost and time spent for the collecting of the wood. Consequently, the impact on the environment should be positive. The use of wood as fuel will be made more sustainable and greenhouse gas output will be reduced. Compared to the traditional three stone stove, a 35% saving in fuel efficiency seems to be a realistic aim for a better stove design. (Hedon, 2008) The stove should reduce the quantity of smoke by controlling the air flow and therefore producing a more efficient and complete combustion. The heat transfer from the fire to the cauldron will ideally be improved by reducing the convective heat loss to the surroundings. In order to build a better stove, several designs with different features will be chosen and build. The water boiling test (see literature review) is to be use to compare their different characteristics such as material, shape and quantity of clay used. The optimum stove will be chosen. The technology should be passed on to the local NGO's who will implement the design, and to the village women who are involved in parboiling. User responses will also be collected. Several aspects of stove design are discussed below, together with some possible approaches.

11.1.2 Brainstorming

Materials

Clay is the main material used in the villages to build stoves because it is easily available, at the cost of labour. Although clay is fairly strong in compression, because of its nature and the way it is worked, a fairly large amount is usually employed in the construction of a traditional stove. This results in the stove itself absorbing a lot of the heat produced by the fire. As well, clay is not a good insulator so that heat will escape from the stove by conduction, even when it is formed into an annulus to reduce convective losses. To improve stove performance it has been suggested that insulating material be mixed in with the clay to reduce its conductivity as well as both the mass and the heat capacity of the material. Accordingly, vermiculite, pumice, sawdust, charcoal, perlite, and even dung and other organic materials have been suggested and tried as fillers (Hedon, 2008). Little pieces of herbs (about 2 cm) will be mixed with clay for that purpose.

Other problems with clay are its relative lack of resistance to impact and its property of cracking after repeated wetting/drying cycles. Thus, stoves left outside to open sky tend to crack because they will be thoroughly wetted by rain, and then dry too fast under the direct sunshine. The incorporation of some of the insulating materials mentioned above will be tested to see its impact on reduce cracking. The possibility to strengthen the stove and reduce its mass at the same time by incorporating chicken wire in the structure will be investigated. In the end, the viability of the various approaches to stove construction will depend on the cost and availability of the materials as well as the amount of labour that must be invested. One interesting possibility is to attempt to incorporate some objects or materials which are normally regarded as waste. For instance, empty cans might be used to construct a chimney.

Shape

Under most circumstances, improved stoves are either cylindrical or rectangular (Figure 15), with the cylindrical shape being preferred for the one-pot arrangement and the rectangular one for a two-pot arrangement.

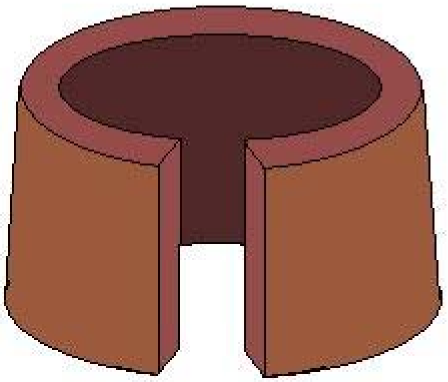


Figure 15a
A cylindrical improved stove

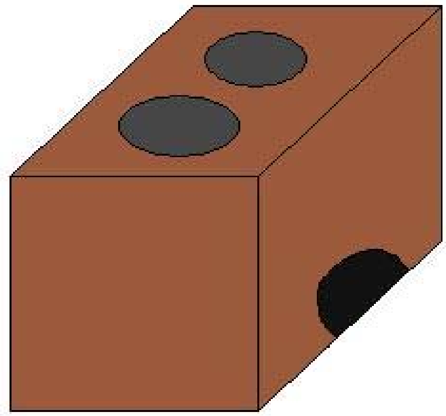


Figure 15b
A rectangular improved stove

The two-pot option could be eventually investigated in further work but, since in the villages of interest some of the women have already been introduced to the cylindrical, improved stove made for one pot, it will probably be best to retain that shape for this study. The tow-pot also requires more building skills and clay material do not seems to be a suitable material for that type of construction.

Depending on the materials of construction, stoves can be made in several different ways. Thus, they can be formed from soft material like clay, or clay with filler mixed with it, they can be dried to open air to hardness or sometimes baked. One advantage of this approach is that various design features such as channels can be easily incorporated in the design by carving during the soft stage. Stoves can also be built up from hard, pre-formed components such as bricks or blocks which may be cemented together and covered with a facing which may then be baked on. Due to the minimal facilities available in the villages, the baking of bricks would probably be difficult to achieve at a reasonable cost. Thus, the traditional formed-clay approach will probably be the most appropriate under the given circumstances.

In the village of Gbaffo an improved stove was seen in which the cauldron was still held up by three supports (Figures 11a and b) but the fire was protected from the wind by a wall. In that instance, the wall was quite thick, and integrated with the supports. The wall could, however, be made much thinner since it is not load-bearing. Thus, the protective wall could be moved away slightly from the supports, made a little higher and much thinner to reduce the amount of material (Figure 16a). Although enclosing the fire has some advantages, an adequate air supply should always be available to keep smoke formation at a low level. In this regard, it may be desirable to carve air holes in the bottom of the surrounding wall (Figure 16b).

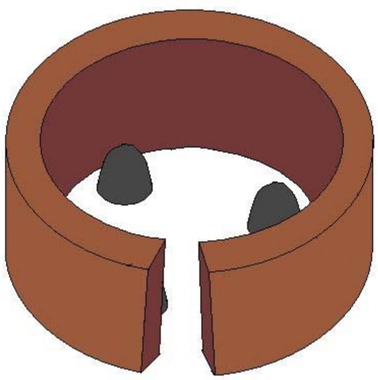


Figure 16a
Cylindrical wall moved away from supports

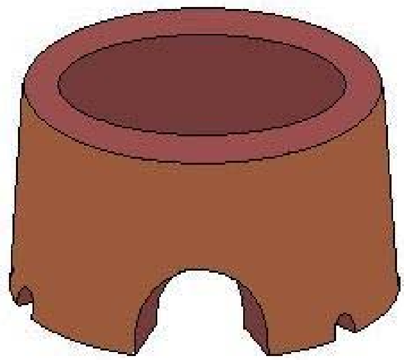


Figure 16b
Air holes made in the wall

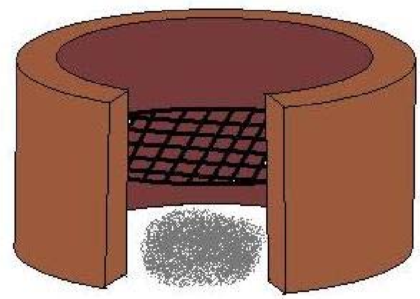


Figure 16c
Stove with a grate

Grate

Another improvement that can be made to the village stove is the addition of a grate whose main purpose is to support the fire at a certain distance above the ground (Figure 16c). This facilitates air entering the fire through the grate’s holes and thus aids clean and complete combustion of the fuel. Moreover, it makes it easier to remove the ash which falls to the ground through the holes. Use of a grate does create the requirement that the fuel be cut to pieces which will fit entirely inside the stove.

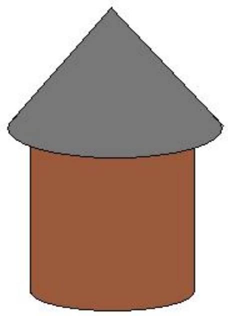


Figure 17a
Umbrella-shaped cover

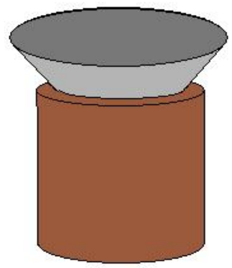


Figure 17b
Cone-shaped cover

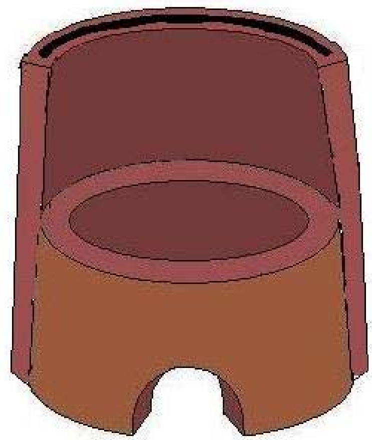


Figure 18
A double-walled chimney

<u>Chimney</u>

A stove chimney serves several purposes. First, by virtue of the difference in gas density between its inlet and outlet, it causes a draft and thereby directed air flow through the fire. Secondly, it directs the smoke away from the person attending the fire. The latter factor may be more important for stoves which are located indoors, rather than outdoors. In chimney design the height, shape (bends and horizontal sections reduce its draft), and insulation must all be considered, as well as the desired temperature of the exhaust. The pipe diameter should be sufficient, but not too large, so as to avoid excessive heat loss. For the type of stove under consideration, a diameter of about 7.5 cm has been reported to work well (UN, 2002). To prevent rain from falling in, an umbrella-shaped or funnel-shaped cover can be added (Figure 17). This will also act as a damper.

One aspect of adding a chimney to a stove is the requirement for weekly maintenance. This can be either an advantage or a disadvantage; it could create work for a specialist in the village, or it could cause unwelcome, extra work for the women. A chimney-related concept is to build a semi-circular double stove wall as high as the top of the cauldron and to use that wall as chimney at the same time (Figure 18). The heat loss from such as arrangement would need to be examined closely to assess its advantages and disadvantages.

Front opening

The fact that women are using uncut wood restrains the type of front opening that a stove can have, since the opening has to be big enough to allow fuel to be added, often as a batch. Accordingly, in Gbaffo, the improved stove had a large front opening (see Figure 11a) which, in principle, might be made a lot smaller (see Figure 16b) if only the fuel were reduced in size. In fact, it will be difficult to have a smaller front opening in the stove unless much smaller pieces of fuel are used.

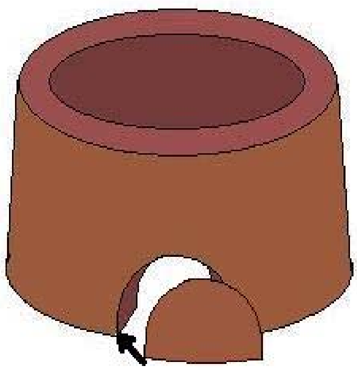


Figure 19a
Addition of a door

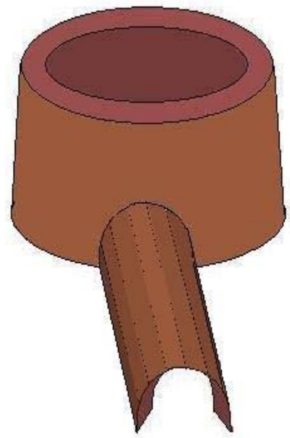


Figure 19b
Addition of a tunnel

A door or blockage of the opening could then also be added to further control the fire and conserve heat (Figure 19a). Fastening such a door to the stove might be advantageous in terms of its utility as a damper, but would also increase the difficulty of constructing the stove. If it were not too expensive, steel strips could also be added to the structure, at the door, to reinforce it (UN, 2002). To assess the effect of these various changes, the difference in thermal efficiency between the cut and the uncut wood would need to be evaluated. The briquette type fuel being developed in Project 3 has the advantage of being small enough so it will easily fit through a damper door.

A tunnel-type front opening was also considered (Figure 19b). This would reduce convective heat loss, but would be quite inconvenient for tending the fire, as well as for ash removal. Also, the wood might start to burn in the tunnel, without that being very useful for the cooking. Small openings at the bottom of the stove would be essential to assure a sufficient supply of oxygen. These would allow control of the fire.

Top opening of the stove

In the villages it was observed that the stoves used for parboiling were used with specific cauldrons. Thus the stoves are sized for a particular cauldron diameter. If a wall is added to a stove (as in Figure 16a), the stove's top opening should be sized so that a minimum amount of heat will escape through the space between the cauldron and the wall. To accomplish this, the wall could be built just slightly larger than the maximum diameter of the cauldron, and as high as the top of the cauldron. Of course, the arrangement should not be inconvenient to the women who will use it and who have to lift the cauldron onto and off the stove. At the same time the distance between the fire and the cauldron bottom should be kept to a minimum.

11.1.3 Prototype Development of the Improved Stove

In order to test new stove features, some stoves had to be built. For the construction of the stove, an incomplete circle was first dung on the ground (about 5cm deep) to allow a good foundation of the stove. Clay was use as base material for all the stove because it is readily available, at cost of labour. The clay, found almost anywhere in the village, was mixed with water and kneads using mainly the feet. Some balls of 15-20 cm of diameter were form and then it was shaped in the desired stove design and at the desired location. The stoves were, like it is commonly practiced in the villages, dried only with the wind and not fired. This natural method of drying was said by the villagers to help a drying in depth to reduce the deep cracking. All the stoves had two holes at their base to allow sufficient air flow for a more efficient complete combustion, therefore also reducing the unhealthy smoke. It was observed that it was easier to dig holes or arch in the stove's wall after the structure was build. All the stoves were smaller in height then the stove observed in the village to reduce the space between the fire and the cauldron allowing a better heat transfer.

Even though the soil properties were tried to be keep constant throughout the experimentation, the clay that the Africa Rice Research center provided for the project was different from the one in the villages. It was gray clay probably from a river bed and not red clay soil found in the village. The day after the construction of the four first stoves using that grey clay (Stove 1, 2, 3, 4), major cracks in the material were observed (Stove 2, 3, 4). That could be explained by the high concentration in clay of that soil and the properties of the clay (expanding when mixed with water and contracting after drying.) Red soil was then taken on the Africa Rice campus. This soil had a higher content in sand than in clay therefore the stoves were difficult to build. To solve this problem, the red soil was mixed with 25-30 volumetric % of grey clay. This mix was then used as the base material for the tested stoves.

Three stoves of the same shape were built (Stove 5, 6, 7), one with clay only and the two others mixed with a small fraction of different organic materials (5-10 volumetric % of rice husk or herbs). The first goal was to test if the addition of organic matter helped the cohesion of the clay particles, therefore reducing the cracking of the clay after the drying of the stove.

Thereafter, three other stoves (Stove 8, 9, 10), made out of clay soil only, were constructed and tested to monitor the influence of their shape. The first stove (Stove 8) had three aeration holes instead of two because of its tight top opening eliminating the feeding of air by the top gap between the stove and the cauldron. It also had some holes in the upper part of the wall to allow the smoke to escape. These holes created a small chimney helping the air circulation and the smoke control for the health of the user. The adjusted top opening reduces the heat losses by convection and by dissipation consequently directing the heat to the cauldron. Once the cauldron was sitting on top of the stove, about 15 cm from the bottom of the cauldron was covered by the clay. No real chimney was built because of the nature of the material used. The use of other material like old oil can was investigated but the availability in the villages was nil.

The purpose of testing the second shape (Stove 9) was to observe the impact of different quantities of clay on the efficiency of the stove. This stove was built using the least amount of clay possible. The shape was changed (no bumps on the top part) and there was also an insertion of chicken wire to solidify the wall and further reduce the clay quantity. It is known that the clay absorbs a considerable amount of heat, therefore reducing the quantity of clay is wished to reduce the energy storage in the stove and allocate more energy to the cauldron in a reduce time period.

The third shape (Stove 10) was designed to allow the fire to be made on top of a grate positioned in the middle of the stove structure. The ash was allowed to fall on the ground and the air circulation was maximized by increasing the surface area of the fire in contact with air. However, the wood needed to be cut which is opposite to the current practice.

The *Water Boiling Test*, (refer to section 10.1.5) which consists of calculating the energy required to boil 10 L of water compare to the amount of energy produced by this task, was used to compare the stoves. The stove in the village of Gobé was first tested and the prototypes were tested at *The Africa Rice* research facility, in Cotonou. On each stove, the test was conducted with a cold start as well as a warm start.

Table 3: Tested Stoves

Name	Picture	Descriptions	Observations
Stove 1		Material(s): gray clay Volume: N/D Features: - representation of traditional stove - three supports in clay	Cracked a lot Destroyed it to use the clay for mix No test on that stove
Stove 2		Material(s): gray clay Volume: N/D Features: - three supports in clay - wall surrounding without touching to the cauldron - two holes at the base - arch door	- use lots of clay - cracked a lot - one trial, but abandoned after 8 minutes because the fire didn't wanted to light up properly; not enough space between the cauldron and the fire and not enough air

Stove 3		Material(s): gray clay Features: - representation of the Gobé stove - three supports link on two side with little wall on clay	Cracked a lot Destroyed it to use the clay for mix No test on that stove
Stove 4		Material(s): gray clay Features: - representation of the Gbaffo stove -semi-circle with three bumps towards the inside on the upper part to support the cauldron	Cracked a lot Destroyed it to use the clay for mix No test on that stove
Stove 5		Material(s): mix* Volume: 0.04275 m^3 Features: -semi-circle with three bumps towards the inside on the upper part to support the cauldron (the cauldron only sit on top of the supports) - two holes at the bottom	Cracked more than stove 6 and 7 - opening of the stove in opposite direction of the wind
Stove 6		Material(s): mix + herbs Volume: 0.04078 m^3 Features: -semi-circle with three bumps towards the inside on the upper part to support the cauldron (the cauldron only sit on top of the supports) - two holes at the bottom	- Only surface cracks - The herbs was not dry when mixed (about 15-20% volumetric) - wind coming on the left side of the stove

Stove 7		Material(s): mix + rice husk Volume: 0.05856 m^3 Features: -semi-circle with three bumps towards the inside on the upper part to support the cauldron (the cauldron only sit on top of the supports) - two holes at the base for air flow	- More cracks than the stove 6 but only surface cracks - use of husk only, pieces of about 1cm long (about 15-20% volumetric) - wind coming on the left side of the stove
Stove 8		Material(s): mix Volume: 0.03809 m^3 Features: - adjusted top opening (for a cauldron 25) - arch door -2 holes at top (chimneys) -3 holes at the base for air flow	- smoke coming out from the chimneys - cracked because mix only - wind coming on the left side of the opening
Stove 9		Material(s): mix Volume: 0.04098 m^3 Features: - semi oval for the cauldron to sit on top - built with 1m^2 of chicken wire - 2 holes at the base for air flow	- a lot faster to dry - hard to built, risk on injuries - cracked a lot - wind toward the opening

Stove 10		Material(s): mix Volume: 0.05184 m^3 Features: -semi-circle with three bumps towards the inside on the upper part to support the cauldron (the cauldron only sit on top of the supports) - two holes at the base for air flow - Grate of 30 cm of diameter - higher to allow ash removal under the grate and fire on the grate	- grate is not of good quality - need to cut wood - fire harder to light up - fire very close to cauldron - wind coming toward the opening
Stove Gobé		Material(s): Gobé clay Volume: 0.05009 m^3 Features: - three supports link on two side with little wall on clay	- many stove of different sizes - built few months ago, damaged by rain and sun -wind coming toward the opening
Stove Gbaffo		Material(s): Gbaffo clay Volume: 0.2051 m^3 Features: -semi-circle not adjusted to the cauldron - cauldron sitting on the 3 inside bumps	- fire hard to light up - lots of smoke - protected by a straw roof and two walls - not a lot of wind that reach the stove

- mix is red sandy clay soil and 25-30 volumetric % of gray clay

11.2 Insert

11.2.1 Approach to be followed

The initial considerations for the development of the improved insert was the reduction of the material used, as well as a reduction of both latent and sensible heat loss. Therefore, it was decided that the new insert should fit entirely inside the cauldron, thus reducing the surface area exposed to air. This reduced the amount of metal used to fabricate the insert (and therefore also the price of the insert) and also the loss of heat through convection. Steam loss is potentially decreased because there is only one joint through which it can escape: between the cauldron's rim and the lid.

11.2.2 Brainstorming

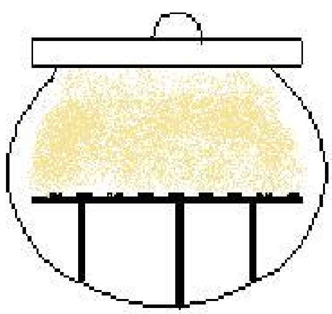


Figure 20
False bottom in cauldron

The first approach that was considered to achieve the afore-mentioned goals was to put a false bottom in the cauldron, as per some of the women's innovated methods. In this, the principle is to use the cauldron both as boiler and as vessel in which the rice is steamed, with the rice mass sitting on the false bottom, well above the water level (Figure 20). Since the diameter of the cauldron's mouth is smaller than the diameter at the height at which the false bottom would be installed, the device would need to be foldable in some way so that it could be easily inserted and removed from the cauldron. Moreover, it was observed that the cauldrons are not perfectly circular in cross-section so that it would be difficult to achieve a tight fit between the cauldron wall and the foldable insert. To prevent rice from falling into the water below, a porous jute or raffia cloth could be used to cover the insert. Various designs were examined for robustness, simplicity and convenience.

Figure 21
A vegetable steamer
(from: www.mayaskitchen.co.za)

First, ordinary vegetable steamer could be adapted for rice parboiling (Figure 21). It would simply be placed at the bottom of the cauldron on its legs, and its sides would be unfolded. Rice would then be placed on top of a cloth covering it. This design did not seem nearly robust and stable enough for use in the villages since it would have to support a fairly large mass of rice (25 kg) and it probably wouldn't be handled delicately in the village environment. Also, it would be very difficult to fabricate locally.

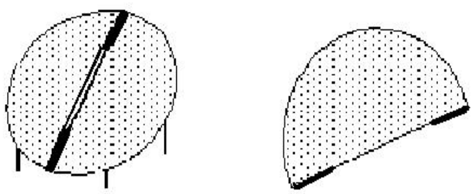


Figure 22
Two hinged half-circles

Secondly, the false bottom might consist of two perforated half-circles joined together with hinges, supported on legs (Figure 22). The hinges are necessary to ensure that the insert can be folded up and will fit through the cauldron's top opening. A main disadvantage of this design is that the hinges may be subject to breakage if not handled gently enough. Since the village women are very strong and are used to work with robust equipment, this type of insert might be subject to frequent breakage, and therefore a rather short life.

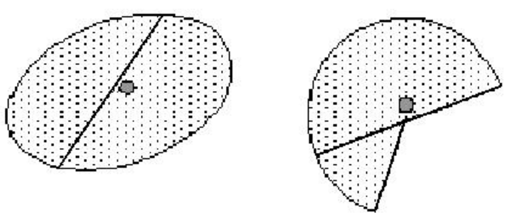


Figure 23
Two pinned half-circles

To improve the robustness of this type of insert, a pinned construction could be used. Thus, two pieces, each slightly larger than a half-circle, could be pinned together (Figure 23). In this design, use of a hinge is avoided, but legs can only be put on the bottom of one of the pieces. To support the side without legs, the rim could be made to touch the side of the cauldron. Overall, because most cauldrons are not truly circular in circumference, this would probably not be very stable.

The fourth design option that was considered is a construction made up of two independent pieces which can be easily assembled into a full circle. Both pieces would have legs, and they would be fastened together by having two of the legs of one piece fitting through holes in the other piece (Figure 24). This arrangement seems to fit the needs and social situation of the village environment reasonably well.

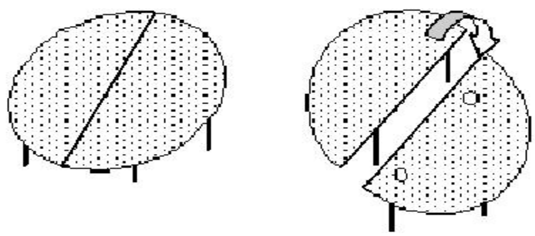


Figure 24
Two assembled halves

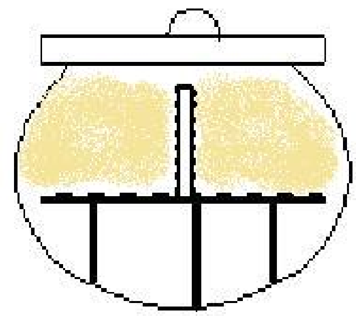


Figure 25
Added perforated cylinder

Although the false bottom approach would leave sufficient volume free inside the cauldron to parboil the required quantity of rice (batch size about 25 kg), the steam distribution would probably not be very good since the rice bed would be quite thick. Consequently, the rice would probably not cook very evenly throughout, unless it were stirred frequently, a requirement we are attempting to eliminate. One modification which was considered is the addition of one or two small, perforated cylinders mounted on top of the false bottom insert to improve steam distribution (see Figure 25). Evidently, these cylinders would need to be closed off at the top, which might also be perforated. This equipment would, however, be difficult to fabricate and would be quite fragile. Also, the cylinders would probably interfere with the removal of the rice from the cauldron.

Overall, the false-bottom approach allows some problems to be resolved, but it tends to lead to others (like breakage, instability in the cauldron and hard to fabricate locally). As result of the various considerations outlined above, a second approach was then investigated, based on the use of an insert which is slightly larger and more complicated than the false bottoms, but still smaller and simpler than the currently-used insert. In this approach, the insert fits entirely within the cauldron, thus eliminating the cauldron-insert sealing problem as well as substantially reducing the total heated surface area. The entire bottom and side wall of this proposed insert are perforated so that steam can penetrate easily into the rice mass. This assures even cooking while avoiding the requirement to stir the rice during steaming. The functional capacity is the same as, or

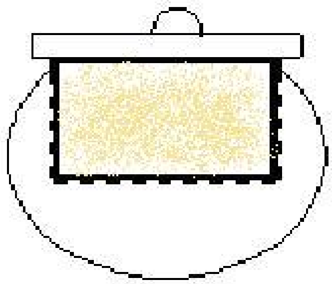


Figure 26a
Insert suspended from rim

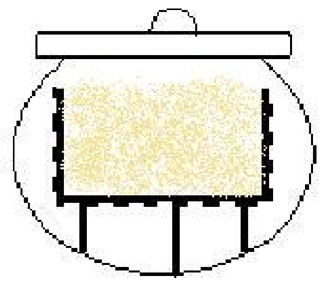


Figure 26b
Insert standing on legs

very close to that of, the currently-used insert. Because the proposed insert fits entirely within the cauldron it is possible to achieve a reasonable seal between the lid and the rim of the cauldron. The proposed insert is much smaller and lighter than the currently-used one, but is fabricated in much the same way and from the same material: galvanized steel that is bent, rolled and soldered, then perforated.

Two major design options presented themselves in this case: a) suspend the insert from the cauldron's rim and, b) support the insert on legs (Figure 26). Although the suspended insert would be somewhat easier to fabricate, there may be a problem with effectively sealing the insert against the cauldron's rim, and then the lid against the insert's top. Moreover, the unevenness of the cauldron's circumference would cause problems with the design of such equipment. The second option has the advantage that it is the simplest arrangement, and that steam can also enter the rice mass through the top since the insert and contents are entirely contained within the cauldron.

The idea of making the insert adaptable to different cauldron's size was eliminated. This kind of design would have required delicate equipment and probably much less energy-efficient design at all cauldron's diameter. However, the proposed insert can be adapted to different cauldron's size depending on the situation and the need of the village coop.

Additional practical features to this medium-sized insert approach would be to add handles. This would make it easier to lift the equipment into and out of the cauldron. To prevent loss, the handles might be fastened to the insert although this involves the disadvantage of them becoming hot. If fastened, the handles should be located on the inside of the insert, and fold down so as to not interfere with filling and emptying. There should probably be two handles to distribute the weight and to facilitate lifting the insert with contents, if necessary.

For the scope of this project, in the social context of Gobé, the insert on legs seemed to be the most appropriate and fit equipment. Thus, it is the latter design (Figure 26b) which was kept for further analysis and testing.

11.2.3 Prototype Development

A prototype was developed from the earlier design selected (insert on legs, refer to figure 26b). The model cauldron used as a guide for the dimensions was bought in Cotonou. It has the same size (#25) than the cauldrons the women in Gbaffo and Gobé are using for parboiling with the currently used equipment.

The design was then brought to a local artisan and it was asked that the carton model was reproduced in galvanized metal sheet. The design specifications are mentioned in Figure 27. The price asked by the artisan was 50 000 CFA and the design could be done in 5 days. The work was well done and on time. The insert was soldered and the soldering joints were filled. The holes were done one by one with an electric drill on all sides with a 1 mm drill bit.

For manipulation purposes, handles have been installed on the insert. Many kinds of handles were evaluated before the final design was chosen and accomplished by WARDA artisans. The best option is handles that can be manipulated by two people

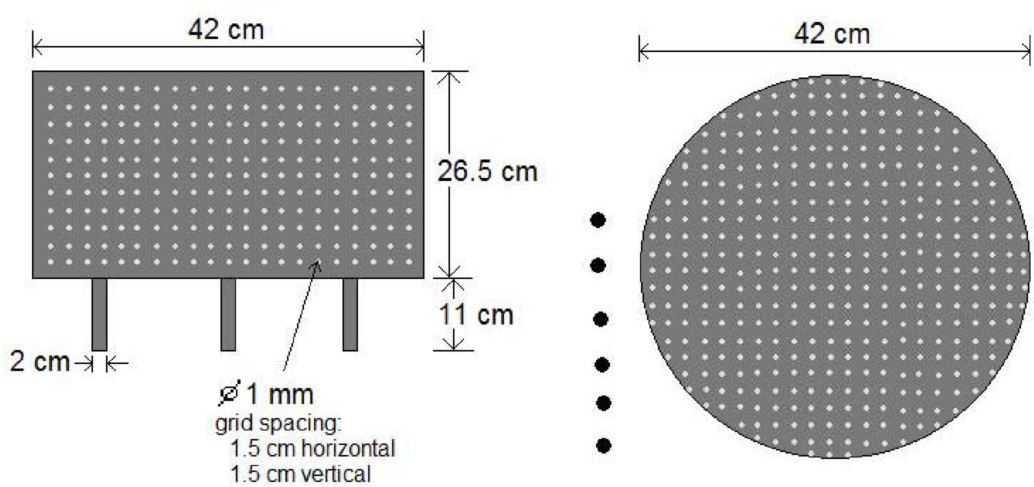


Figure 27
Insert design specification

Figure 28
Retractable handles on the insert

(one on each side, so that no one gets burnt by hot steam coming out of the insert) and steady enough to withstand the wetted paddy rice. Stay-on handles were chosen to eliminate the possibility of losing one part. Manipulation of the insert would then be done with a piece of cloth because of the handles would get hot after the parboiling step. Two handles made out of simple metal wire were an option, but were disregarded because they would have been easier to use them alone then with someone. Foldable or retractable side handles seemed to be the most fitted choice. The handles would not be in the way to close the cauldron and could be built steady enough for the weight to be lifted. The retractable outside handles were chosen which would not interfere with rice removal and could be easily made with pieces available locally (see Figure 28).

11.3 Biomass Briquettes

11.3.1 Approach to be followed

To solve the problems of wood over-consumption and of by-products accumulation, the approach is based on forming an alternative fuel in the form of compressed aggregates from the husk/bran material, the intent being that the aggregate particle density be considerably higher than the bulk density of the husk/bran material. The husk/bran material as such has a relatively low bulk density and would be difficult to handle and to combust in a controlled manner in the stoves found in the villages. The husk alone has a bulk density varying from 0.04 to 0.2 g/cm^3. (Kaliyan, 2009) For rice bran the bulk density is slightly higher varying from 0.29 to 0.4 g/cm^3. (Sreenarayana, 1985) In fact, the women in the Gbaffo coop have already tried to burn the material in its unprocessed and loose form, but the results were so poor that they abandoned the practice.

The main concept is to manufacture the compressed aggregates from the loose material with a manually operated machine. This approach was chosen to ensure the equipment is simple and easy to manoeuvre, and the technology accessible to the villagers. This is important since motors and fuel material would probably be expensive and difficult to acquire. Advantages of using a low-pressure briquetting method include relatively low capital costs as well as low operating costs. Also, only very moderate skill level is required to operate such a machine.

Thus, the machine will be a human powered press which will be used to compress the loose husk/bran material into briquettes which will be both convenient to handle and to burn. In this work, briquetting is favoured over pelletizing. Briquettes are easy to handle, fast to produce, and easy to manufacture in small quantities. The manufacture of pellets usually requires higher pressures and more sophisticated equipment such as an extruder. Pellets would be more difficult to burn than briquettes in the clay stoves in the villages and, because of their small volume, the fire would probably need to be fed quite frequently. These various considerations led to the decision of making briquettes with a manually-operated press. Advantages and disadvantages of various sizes and shapes of aggregates, both in terms of their manufacture, storage, combustion and handling will be considered.

Different binders were also investigated. Any binder used has to be cheap and of local origin. When burning, the briquettes must give off sufficient heat without flaring too much, and they must not give off bad smells while burning, nor emit any obviously noxious fumes. It may not be possible to utilize the briquettes alone; instead it may be necessary to use them as a co-fuel with wood. Thus, in this case, the wood consumption would be reduced, but not eliminated altogether. The briquette fuel must be acceptable to local users in terms of shape, size, and appearance (similar to the fuel available right now) and it must be easy to teach people how to use it in their stoves (e.g., stacking of briquettes). Since rice husk is very high in ash the use of briquettes may result in ash accumulation which could possibly cause handling problems and constitute an inhalation hazard during cleaning. Thus, ash production in the stoves should be monitored and, if possible, minimized.

11.3.2 Brainstorming

Briquette compression

A number of ways of pressing the briquettes were investigated, all involving a piston and a type of mold (not necessarily circular in cross-section) in which the piston compacts the material. The first option considered was longitudinal compression of the material, along the longer axis of the briquette (Figure 29a). However, this was seen as problematic for the production of the size of briquettes that are foreseen since, as is the case in extrusion, the friction on the walls of the cylinder would need to be overcome. To obtain a uniform density throughout such briquettes, a very large force would be required. This implies that the piston would need to be powered by means of a hydraulic activator or a very robust screw mechanism rather than direct human effort.

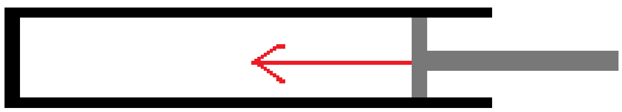


Figure 29a
Longitudinal compression

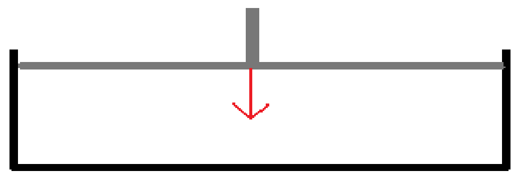


Figure 29b
Lateral compression

The second option considered was lateral compression of the material, along the shorter axe (Figure 29b). This implies a slender rod shape. In this, the problem of excessive wall friction is overcome and the force required on the piston is a simple multiple of the area of the briquette's surface facing the piston. Accordingly, this was found to be the preferred approach to briquette forming. A number of mechanical arrangements are then possible to generate the compressive force required through human effort. Any such arrangement should be cheap, simple, fast in operation, and easy to repair.

Compression mechanisms

The maximum force that can be easily applied by a human, equal to his or her own weight (about 0.5 to 1.0 kN), was judged insufficient for the compression of a briquette of reasonable size. Thus, to make briquettes through direct human effort it will be necessary to use some force amplification mechanism. Various possibilities considered were: pulleys, levers, gears, and screws. In a village context of a developing country, the use of pulleys and gears would not be applicable since the components are not readily available, such technology is too expensive, and the villagers don't have the technical skills to deal with it. As well, the mechanisms probably wouldn't be sufficiently robust while dirt, sand, etc. would interfere with their operation. Screw mechanisms are simple, reasonably robust and can produce large forces. They are also already used, for example, in village contexts for pressing grapes and olives. However, they are rather slow to operate and a certain rate of briquette production will need to be maintained in order to be less time consuming than collecting wood.

Thus, to assure a reasonable briquette production rate at a reasonable cost, a lever-based approach to force amplification seemed most appropriate. Lever-based mechanisms are simple, easy to understand and they can be made from locally-available materials.

<u>Briquette shape and size</u>

The briquettes could be made in various shapes. A slender, circular cylinder (Figure 30a) would be easily acceptable since it resembles a branch, and it would burn quite readily since it has a fairly high surface-to-volume ratio. It has an advantage over a cylinder of rectangular cross-section (Figure 30b) in that it has fewer corners and therefore is less subject to abrasion during handling (fining). On the other hand, the rectangular cylinder has a higher surface-to-volume ratio and can be volumetrically packed more efficiently. Other shapes, such as a squat, large-diameter circular or elliptical cylinder are also possible (Figure 30c).

Figure 30a

cylinder briquette

Figure 30b

Rectangular cylinder briquette

Figure 30c

cylinder briquette

A large number of combinations of length or diameter, width, and height will be possible for the briquette and together these will determine the briquette's volume. Overall, the briquettes should be large enough so that they don't burn too fast, in order that the fire not need be tended continually. At the same time, they should be small enough so they don't burn too slowly. They should have a shape and a surface-to-volume ratio that allows them to light easily and burn well. And, it should be possible to put a number of them in a stove at the same time without impeding good air circulation.

Binders

To hold the husk/bran material together in a briquette form after compression, a binder will be needed. A binder is a substance that promotes cohesion and mechanical strength of the briquette, added in small proportion to the base material. A binder also contributes to the energy content of the briquette (Kussel, 2007). A potential binder has to be evaluated in terms of its functionality, its cost, whether it might inhibit combustion, produce too much ash or smoke, and whether it is edible or not. The amount of binder to be added will influence the briquettes physical and chemical properties. In the present report, the amount of binder will always be stated as a fraction of the bulk husk/bran material's volume before compression. Various substances were identified as potential binders due to their known adhesive properties. Gum Arabic, any other tree saps, palm oil and/or other cooking oil, gumbo, akassa, cassava or yam flour, jathropha oil, and clay have been mentioned in this regard.

Gum Arabic would be much too expensive for this application, and was therefore eliminated immediately. The availability of other tree saps is limited. Palm oil, other cooking oils, akassa, cassava, yam and gumbo are edible substances so that their use would influence the food supply. Jathropha oil is an interesting option, but it was investigated that this tree does not grow in southern Benin. Clay has several undesirable attributes: it affects combustion process and it lead to excessive ash production. Besides the materials mentioned above, it has been suggested that water is a suitable binder for husks and bran (Chin, 2000). Of course, if water is used, it will be necessary to dry the briquettes after forming them. Water will also be required in order to use any type of flour as a binder. Another interesting point is that bran naturally contains some oily substances which, at the microscopic level, may be released when pressure is applied (Kaliyan, 2009). Such substances could potentially contribute to binding of the briquette material. Also, palm oil is cheap and readily available. The availability of any binder selected must be evaluated. The effectiveness and overall value of various binders will be determined experimentally.

Lever press mechanism

The manual lever press mechanism discussed would consist of an arm which is pressed down so that a magnified force is applied at one end on a piston (Figure 31a). During the stroke, the piston would then compact vertically the husk/bran mixture in a mould. The distance through which the end of the lever moves will be larger than the distance through which the piston moves. It could also be possible to amplify the force even more by adding a second lever (Figure 31b).

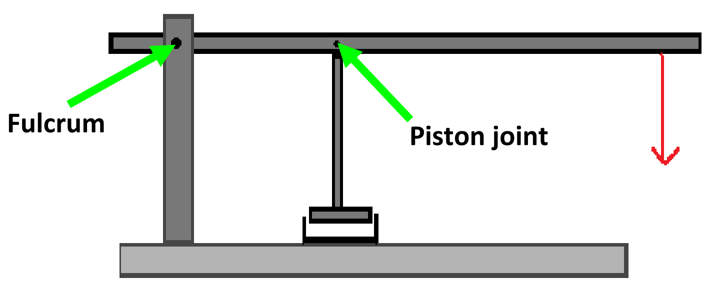


Figure 31a
Single-lever press

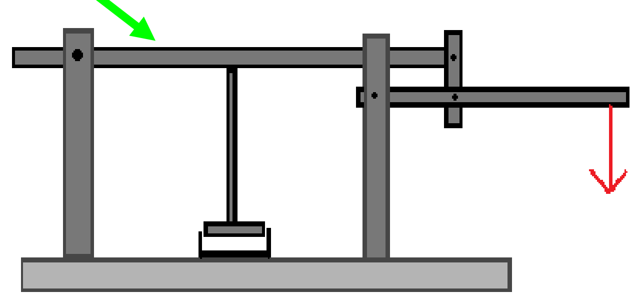


Figure 31b
Double-lever press

For both arrangements, the design implies that the main operator lowering the lever stands up behind the press which would be sized so that, when horizontal, the main lever will be at hand level of a “standard” person's straight arm, about 80 cm from the ground level. In this way, maximum compaction in the mould will occur while the lever is horizontal in order to obtain the maximum downward force from the operator. In this position, the piston will also be vertical so as to avoid any horizontal force component and to maximize the force applied. To remove the briquette from the mould and to refill it again, the piston will need to be moved upward a certain distance. This can be easily obtained with the single-lever mechanism. However, for the double-lever press the operator will have to move the end of the lever through a larger distance to obtain the same amplitude of piston movement. Thus, there is a trade-off between convenience and force obtained at the piston.

In order to achieve a good production rate, the press will be operated by two people: an operator who supplies the motive power by moving the lever up and down, and a second person to fill the mold and to remove the briquettes after they are formed. Production should be fairly fast. It is anticipated that, on the average, two men could produce 8 briquettes per minute. This will be equivalent to about 500 briquettes per hour. In other projects there has been mention of a dwell time (Chin Chin, 2000). This period of time refers to how long the pressure should be applied for the briquette to attain its final density and retain its form. Overall, this dwell time could influence the production rate.

During the brainstorming sessions, several aspects of the press mechanism were the subject of more attention. The first was the levers' proportion. The equation for a simple lever is as mentioned earlier:

$$F_1 \times D_1 = F_2 \times D_2.$$

Also, the vertical distances through which these forces travel will have an inverse ratio in a frictionless system.

$$F_2 / D_2 = F_1 / D_1 \text{ and } L_2 / D_2 = L_1 / D_1$$

Where L_1 = length of vertical displacement of F_1

L_2 = length of vertical displacement of F_2

If the power stroke at the end of the lever is 30 cm then, in the arrangement shown in Figure 32b, the piston will travel through a distance of 6 cm. The position of the piston joint on the lever will be largely determined by the force required at the piston to compress the briquettes.

The fulcrum was also discussed, with two arrangements being examined for the joint linking the lever arm and the vertical support. In the first, a hollow tube or similar device is fastened to the lever and rotates around a rod fixed between the vertical supports (Figure 32a). In the second, the rod between the vertical supports passes through a hole

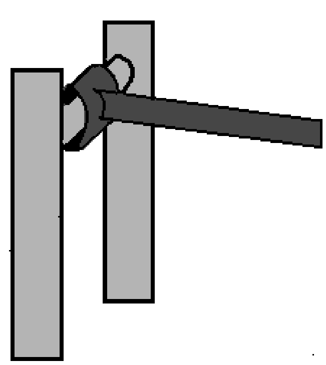


Figure 32a
Fulcrum arrangement #1

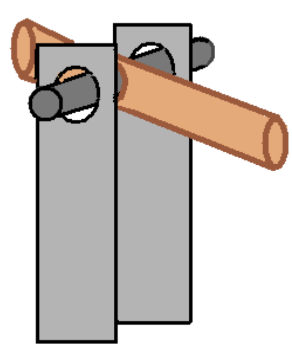


Figure 32b
Fulcrum arrangement #2

made in the lever arm. Because it would probably be easier to fabricate, the second arrangement was chosen for the fulcrum. It was suggested that the hole be lubricated but the movement around the fulcrum will be minimal so this will not be necessary. In fact, lubricant would probably cause dirt to accumulate in that part of the press.

The piston was also examined in some detail. In order to keep the piston from swinging back and forth during operation and to keep it vertical at all times, a link was added to the system, parallel to the main lever (Figure 33), thus forming a parallelogram. This link is not load-bearing, but serves only to keep the piston aligned. It would be fixed to the vertical supports in the same way as the main lever, with a rod passing through holes.

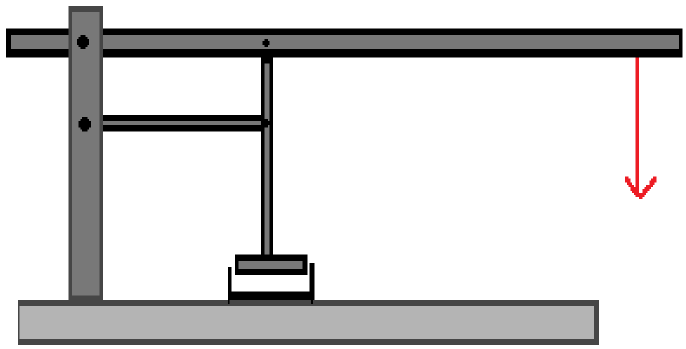


Figure 33
Parallelogram linkage

Although the parallelogram linkage will reduce the swinging motion of the piston about its joint with the main lever, it may still be subject to transverse disturbances due to lateral movement of the main lever arm. In order to minimize such motion, various other additions to the press were also considered (see Figures 34a, b, and c). These will

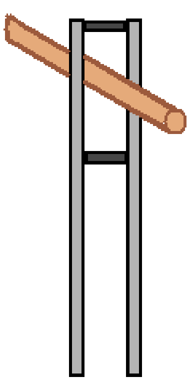


Figure 34a
Guide 1 for the main lever to reduce lateral movement

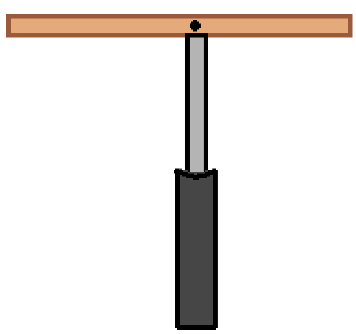


Figure 34b
Guide 2 for the main lever to reduce lateral movement

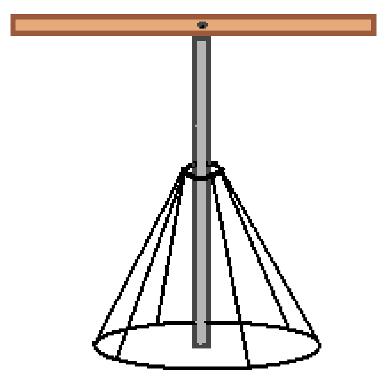


Figure 34c
Guide 3 for the main lever to reduce lateral movement

reduce lateral motion of the main lever arm, and thereby lateral movement of the piston. They would be installed very near the point where the downward force is applied to the lever.

The last feature discussed was the removal of the briquettes from the mould once the compression cycle is finished and the piston has been returned to the upper end of its stroke. To achieve this, a pedal mechanism could be installed underneath the press (Figure 35). This does mean the press would have to be raised above the ground, with some support underneath it. As well, the mould would have to have a push plate connected to the pedal so that, when the pedal is pushed down, the push plate will move up and eject the briquette from the mould. To avoid shearing the briquettes, the push plate will have to be the same size as the briquette, thus covering the entire bottom of the mould. Two arrangements for this were considered (Figure 36). To prevent husk/bran from caking between the push plate and the bottom plate shown in the first arrangement, the second will be adopted. This arrangement will also take less wood or metal to fabricate it than the first one. The dimensions of the mould and the push plate will depend on the size and shape of the briquettes being formed. Depending on the size of the briquettes being made, if sufficient force is available at the piston, it may be possible to make more than one briquette at a time.

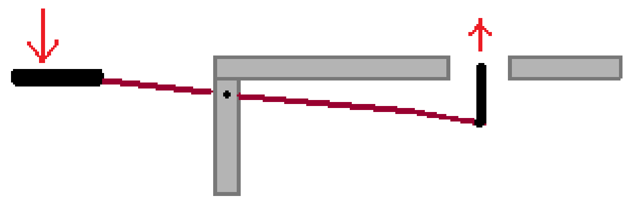


Figure 35
Pedal system for removal

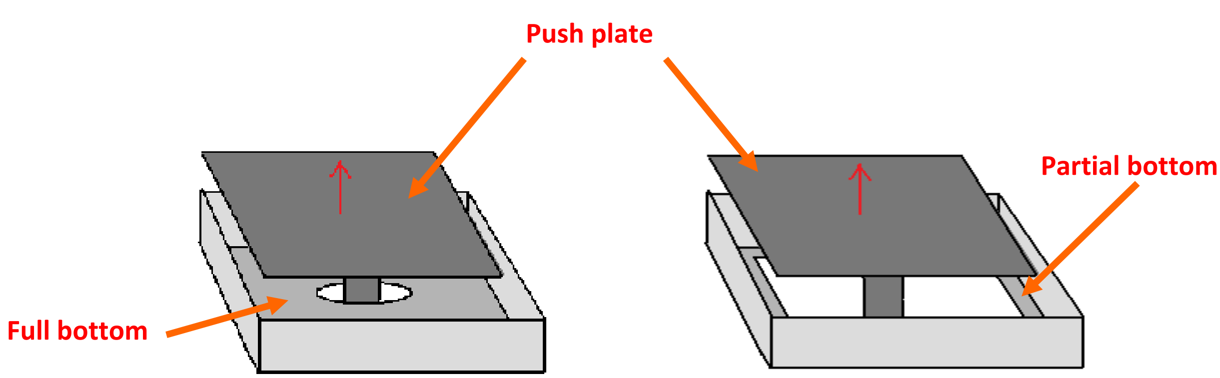


Figure 36a
Full bottom plate

Figure 36b
Partial bottom plate

Materials

The lever-based press machine and its components could be built from different materials. To ensure solidity, it should be made of steel or hardwood. The mould and the piston will be subjected to fairly large compressive forces and should certainly be built strongly. A rectangular mould could be welded out of angle iron with the push plate made of flat steel. The mould should be smooth on the inside, so the welding fillets should be on the outside. A circular section of pipe could be also used as a mould for round briquettes.

A major inconvenience of steel is that it rusts. Similarly, wood has the disadvantage of rotting when subjected to moist conditions. Wood is easy to work with, reasonably cheap, and simple to acquire. Many people know how to shape it, and wooden pieces are easy to replace if broken. Thus, most of the frame and main parts of the press will probably be built of hardwood, with some components made from steel.

11.3.3 Prototype Development of the Press

A first mock up of the design, following the single-lever press model, was constructed out of soft wood (Figure 37). First, the lever presented major lateral instability. Also, it was calculated that the force produced by the piston was about 2.2kN (See detailed calculations in Appendix 1) This was considered insufficient for rice husk/bran densification assuming an application force of 0.5kN. The instability and insufficient compression lead to the decision of designing a double-lever press and building a second mock-up (Figure 37b). With the addition of a second fulcrum, the two levers were more stable and together, they were offering greater force amplification.

Figure 37a : Single-lever prototype

Figure 37b : Double-lever prototype

With equivalent length of lever, the force in the double-lever press was about 3.5 times greater than in the single-lever. The double system was then adopted. The lever equation mentioned earlier still holds ($F_1 \times D_1 = F_2 \times D_2$). Setting F_1 as the force applied by the piston, F_2 then represents the force exerted on the vertical link joining the two levers (Figure 38). The equation is applied again for the second lever ($F_2 \times D_4 = F_3 \times D_3$). The overall multiplication factor of the force will be proportional to the ratios of the distances D_4/D_3 and D_1/D_2. During mock-up construction, a problematic was raised from choosing a double-lever design. It consisted of the limited movement amplitude of the main lever while space is required for briquette removal and dye refilling. Using two levers reduced the ratio of the piston amplitude over the power stroke amplitude by the factor of 3.5. To overcome this concern, different options were available. First, it was possible to move the piston closer to the second fulcrum. However, this would reduce the distance ratio D_2/D_1 therefore decreasing F_1. In this case, the design of a double-lever would not be as relevant. The second option was to use a removable dye which would be easily refilled without being constrained by a lack of space. The third option (which could be combined or not to the removable dye) consisted of a removable piston, i.e. a press block that would not be linked to the main lever. This possibility would not only overcome the lever's small amplitude, but also the piston's non-vertical trajectory. Since the main lever follows a circular path around the first fulcrum, some difficulties were observed with the vertical movement of the piston in the mould. Even with the use of a parallelogram linkage, the piston needed to be guided manually during

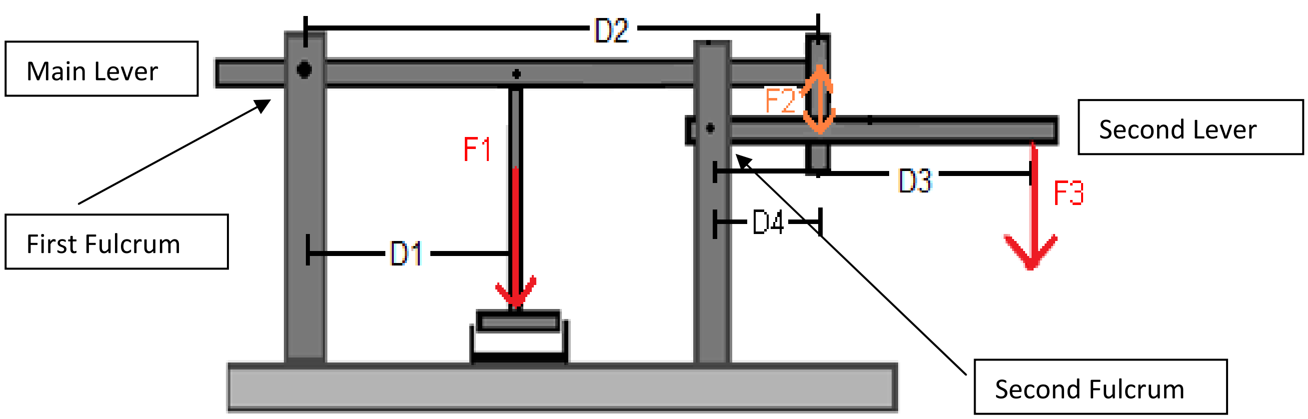


Figure 38
Sketch of the double-lever press

compression.

Other problems concerning the pedal arrangement also became evident. It was obvious that using a pedal system for the briquette's removal was inconvenient. The pedal was difficult to align properly underneath the mould. Friction between the push up plate and the side walls of the dye also lead to an uneasy removal since the push up plate didn't remain horizontal. Therefore, it was suggested to eliminate the pedal system and to replace it with the concept of the removable mould.

Second Prototype - Double-lever press design

The second prototype design of the double-lever press was constructed out of hard wood. Two pieces of 2 m x 28 cm x 30 cm block of Cachou wood were purchased at a price of 20 000 CFAs each (about $50.00 CAN) and cut in beams by carpenters from a local wood shop. Overall, the press consists of a bolted assembly where all beams are hold together in compression. The second prototype consists of the final press design and its different features will be presented in the final design section.

12. Experiments and Results

12.1 Stoves

With the help of some Africa Rice workers, the stove's prototype were built and tested. On each stove, the *Water Boiling Test* was conducted with a cold start as well as a warm start. The warm start is more representative of the situation in the villages, because of the repetitive used of the stove by the women (about 6 parboiling/day). It was observed that the cold start on each stove of the Water Boiling Test took more time to bring the water to a boil. That could be explained by the clay absorbing heat to warm up (energy losses through q storage). Three complete tests with a cold and a warm start were performed on each stove except for the final one built in the village by lack of time.

The following results are an average of the cold and warm start experiments on the different tested stoves based on the *water boiling test*. It is to note that the energy contents of the wood were tested by the laboratory of the University of Abomey-Calavi. (Refer to table 11) For more details on the construction of the stoves see the *Prototype Development* section.

Table 4: Results of the Stove's Prototypes tested with the *Water Boiling Test*

Stove	***Average efficiency (%)***
Gobé	9
Gbaffo	*15*
Stove 5 (mix)	*11*
Stove 6 (mix + herb)	*9.2*
Stove 7 (Rice husk)	8.6
Stove 8 (Fitting)	11
Stove 9 (Chicken wire)	9.2
Stove 10 (Grate)	9.2
New in Gobé	11

See Appendix 2 for calculation example and more detailed results on each test.

<u>Errors Sources</u>

It is to note that the experiments were done outside in a non-controlled environment. Thus, the heat losses by convection (from the fire, the stove and the insert to the surrounding air) were not equal among all the tests. The wood logs used for the test were of different sizes and varieties. This implies that the energy content and the surface area of the burning wood were not constant. Thus the energy generated (q gen) was not constant but was calculated with the weight of the wood burned and an average energy content. Moreover, some tests had to be conducted on stoves that were not completely dry due to the lack of time. In fact, the tests on the prototypes were started three to five days after the construction time. The rainy season may have played a role in extended drying period. It is to note that the stoves were not all constructed the same day and they were made of different quantities of clay which also influences the drying period. However, in the village the stoves had many month of usage and were then completely dry. This impacts the energy losses to dry the stoves. The heat gained by the stove was then not only sensible but heat was lost to evaporate the water in the stove. Furthermore, the moisture content of the wood was not taken into consideration because of lack of infrastructure but it was observed that the logs used in the village were drier than the one used at the Africa Rice station. Other losses like radiation losses, heat losses as charcoal and ash were not considered either. In sum, the results of the experiments are only preliminary and more precise ones should be done in order to be able to base the choice strictly on numerical data.

<u>Observation</u>

Based on visual observation, the addition of organic matter in the clay mix has positive results, both stove (mix with herbs of 2.5 cm long and rice husk) experienced less cracking than the stove made out of clay soil only.

While doing the water boiling test, it was observed that the smoke was better control when using the stove with the fitting top opening and the chimney holes.

The stove with the least amount of clay seemed to have better performance than the others. That could be explained by the less clay absorbing heat (lower q conduction to the stove) and smaller required time period to dry. However, the stove 9 was also very difficult to build because of the many cutting wire sticking out of the stove (chicken wire). More sophisticated tools were needed like metal cutters for the construction and there was risk of injuries.

Less smoke was coming out of the stove with the grate once started probably due to a more complete combustion but it was harder to light up. It had the disadvantage of needing cut wood logs but at the same time the advantage in reducing wood burning out of the fire place resulting from the uncut wood logs practice (current one).

The first stove tested on each testing day shown a longer required period to bring to a boil because of the way that the fire was started. In fact, the first fire was started using mashes and some palm residues as the following were started using the hot char and the wood of the previous fire.

12.2 Insert

The prototype of the insert on legs with retractable handles was tested while parboiling rice. It consists to parboil rice and make sure that the whole batch is well parboiled. The assessment of the rice parboiled was done visually and thermally with the help of a woman familiar to rice parboiling. One can easily see that the rice which is well parboiled is partially opened and that it is a little bit paler then its unparboiled counterpart. All the recorded observations are included in the Appendix 3.

From the first experimental test, where the rice was mostly not parboiled after a long time on the fire, the insert perforations were made bigger with an electric drill. The final diameter of the holes was 2.5 mm. This size proved to allow better steam penetration as well as to retain all the rice in the equipment.

The prototype tested has improved characteristics over the currently-used insert, but some drawback would have to be reduced with further work. The main snag with the prototype developed is that rice is parboiled mostly from the top towards the bottom. Thus, steam follows an easy path on the side of the insert and up to the lid. The steam then escapes in greater quantities and the rice is parboiled first on top. This un-uniform cooking distribution leads to problems to assess whether rice is parboiled all the way to the bottom. A spoon was used to assess steaming, but this solution can only be temporary. The insert was meant to be less work-intensive than the traditional method. With the spoon, the women have to verify the rice once or twice before parboiling is uniform while the currently-used insert would only require to open the lid and to look at the top layer. Hence, there would be a need to make this prototype more applicable to field conditions and more easily operable.

12.3 Biomass Briquettes

A first set of experiments was conducted using a block experiment design with three repetitions. A number of variables were identified as to impact the briquetting process. Some of them were fixed and were considered as constant parameters: the compressive force, the briquette's depth and the pressure dwell time. The compressive force applied by the operator was approximated as 0.5 kN (75% weight of a 70 kg person). The dye was filled using a fixed amount of husk/bran/binder mixture (200 ml or 500 ml according to the different size of dye) leading in both cases to an average final briquette thickness of 2.5 cm after compression. It was evaluated that a dwell time of a few seconds is considered essential for better densification rather than a simple impact of the piston. (Kaliyan, 2009) In the present experiment, the dwell time was set at 3 seconds for reasonably fast briquette production.

Figure 39 Shape of briquettes

Other variables were unfixed. These were defined as primary independent variables and consisted of the shape (length and width or diameter), the position of the piston and the binder (type and concentration). Three different shapes of briquettes were considered: one cylindrical and two different sizes of rectangle (Figure 39). The circular dye was cut from an old metal pipe 0.8 cm thick and 8.0 cm inside diameter. The rectangular dyes were made out of bolted pieces of wood (Figure 41). The two piston positions were used in order to assess the influence of the compressive force. The first position was established 26 cm from the first fulcrum while the second position was 22 cm further apart, i.e. 48 cm from the first fulcrum. The surface area and the pressure applied were considered as secondary independent variables. Also, four binders were tested: water, palm oil (Figure 40a) clay, and cassava flour. The use of water was essential with each binder. Water served as a solvent for clay and for cassava flour in order to disperse the binder uniformly through

Figure 40a
Palm Oil

Figure 40b
Cassava flour in hot water

Figure 41
Circular and rectangular dyes

the husk/bran mixture. It is important to mention that cassava flour was solved in hot water from which the desired glue texture is obtained (Figure 40b). In general, water plays a major role in the creation of intermolecular attractions (Faborode, 1989). 600 ml of water was added for each 2.0 L of husk/bran. This is equivalent to a water content of 30% of the dry basis volume of husk/bran. In the present report, all binder and water concentrations are express in terms of percentage of the bulk husk/bran volume before water addition. Water was found to be essential even with oil as binder since oil itself was not sufficient to allow good cohesion of the husk/bran particles together. The two binder concentrations experienced were 1.5% and 5% of husk/bran volume. The literature recommends some binder addition in the order of 0.5% to 5% (Kaliyan, 2009). In the case of water alone as a binder, water contents of 20% and 40% were used.

12.3.1 Briquette Results and Discussion

The following table presents the dimensions of the briquettes produced during the block experiment (size, volume, surface area) and the subsequent pressure applied in function of the compressive force.

Table 5 – Briquette Measurements

Shape	**Diameter (m)**	**Size w x l (m)**	**t / d Ratio (%)**	**Surface Area (10^{-3} m^2)**	**Volume (10^{-6} m^3)**	**Pressure (kN/m^2)**	
						Pos 1 10 kN	**Pos 2 5.5 kN**
Circular	0.08	-	31	5.03	125.8	1 988.1	1 093.4
Smaller Rectangle	-	0.05 x 0.1	25	5.0	125.0	2000.0	1 100.0
Bigger Rectangle	-	0.08 x 0.16	17	12.8	320.0	781.3	429.7

Observations

Different qualitative observations were collected during the first experiment. These preliminary results were helpful to determine the best briquette size, shape and compressive force. First, the briquettes were found to be much more fragile than expected. Their manipulation required delicate handling to reduce shearing of the un-dried compressed husk/bran (Figure 42). The briquettes were then lifted from the press and deposited on the ground with a masonry plate. Rapidly, the surface on which the briquettes were places for drying became an issue since shearing was easily occurring. The briquettes were thereby placed on straight smooth surfaces found at hand such as wood planks, cardboard or metal sheet. Also, environmental factors such as high humidity level (i.e. during rainy season) and surrounding animals (gecko, birds, etc) complicated the drying process. The drying is an essential step to decreases the moisture content down for appropriate combustion. An optimal final moisture content of 8-9% is suggested. (Kaliyan, 2009) For even drying, briquettes also need to be turned upside down. However, the vast majority of the briquettes were still too fragile for this after 24 hours. After 4 days, the briquettes were finally dry but many presented evident signs of rotting on their bottom face. Ideally, the briquettes should be at least strong enough to be rotated during the drying process to prevent them from rotting. It could also be possible to dry the briquettes on a grate that would allow simultaneous drying of both faces. It was also decided that the water content of the mixture should be later lowered below 30% to reduce the drying time.

Figure 42

Shearing of briquettes

<u>Piston Position</u>

All briquettes produced at piston position 2 (i.e. furthest from the first fulcrum and smallest compressive force) were very fragile. The briquettes were easily broken and permitted very low manoeuvrability. This eliminated any possibilities of transportation or stacking. Evident cracks were also present and the corners of the rectangular briquettes collapsed during drying as a sign of insufficient densification (Figure 43). The briquettes fabricated at piston position 1 (i.e. closest to the first fulcrum and highest compressive

Figure 43: Collapsing of sides and corners

force) presented better structural characteristics and were much easier to handle. It became obvious that the piston's position and the resulting compression force had a major impact on binding the husk/bran together. A greater pressure application increases the formation of attraction forces between the molecules. These bonds forms when solid particles are bring close enough to each other during compression. (Kaliyan, 2009)

Table 6 – Compressive Force Applied

Position of stand	Distance from first fulcrum (cm)	Multiplication ratio	Compressive force (kN)
Position 1	26	20	10
Position 2	48	11	5.5
Final Position	18	28.6	14.2

Shape of Briquettes

The shape influenced the convenience of manipulation of the briquette. The large rectangles were difficult to handle, easy to shear and much harder to remove from the dye without apparent damage. Looking at Table 11 their t / d ratio is the smallest one. The smaller this ratio is, the lowest is the durability. These rectangular briquettes were also subjected to the lowest pressure (Table 5) which can also explain this low structural solidity. The first open flame combustion test revealed that this shape was choking the fire more than feeding it. The large surface area was preventing good aeration which produced too much smoke.

Table 7 – Pressure in Function of the Shape

Shape	Surface Area (m^2)	Pressure at Final Position with 14kN (kN/m^2)
Circular	5.03×10^{-3}	2 843
Small Rectangle	5.0×10^{-3}	2 860
Big Rectangle	12.8×10^{-3}	1 117

The two other shapes were much easier to handle, and over time, the circular briquettes were presenting more advantages. This shape can be easily moved by hand since the fingers are surrounding the whole circumference and decreasing the risk of cracking. The smaller rectangular briquettes need to be moved using the masonry plate most of the time. If taken by hand, they often brake in their middle. The same problem was present for the rotation during drying. The rectangle briquettes were braking while the round ones were remaining in a good condition. Moreover, the main lever didn't compress the top of the rectangular press block evenly (Figure 44). More pressure was applied on one side which leaded to an uneven pressure distribution on the husk/bran material. This problem was not as significant with the cylindrical press block since the diameter is shorter that the length of the rectangular press block. However, in the future, the top end should be slightly rounded to ensure good compression and equal pressure distribution. In the end, the circular briquette was adopted to answer the project's objective to find the best shape of briquette in terms of manufacture, storage, combustion and handling.

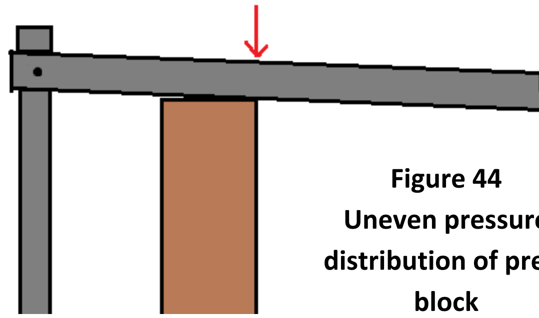


Figure 44
Uneven pressure distribution of press block

Type and Concentration of Binder

At low pressure densification, the binder is a key factor in the briquettes' structural characteristics. At higher pressures, lower binder concentration could probably be used since better bonds would be created between the molecules. A 1.5% binder concentration revealed to be insufficient with any of the four types of binder. With 5% binder content the briquettes had generally a better constitution. The 1.5% was then rejected. In terms of binder type, water was the first one to be eliminated. The pressure generated seemed to be insufficient to extract enough of the oil substances naturally present in the bran to use water alone. Also, another cohesive substance is needed since at such low pressure water doesn't create enough bonds in the material to be used alone. At 20% and 40% water content, the compressed material didn't hold together. At 40%, this could be explained by the fact that too high water content prevents good compression since the husk/bran material is saturated. The fibre saturation point (i.e.

moisture content at which the cell wall are saturated) for agricultural residues such as rice husk is considered to be about 30%. (Kaliyanm 2009) Beyond the fibre saturation point, water occupies volume that would normally be taken by husk/bran (Faborode, 1989) and this high water content increases the resistance to compression. However, minimal moisture is essential to reduce inter-particle friction (Faborode, 1989) and to act as a binding agent by creating Van Der Waal forces within the material. (Kaliyan, 2009)

Figure 45
Mix of husk/bran, binder and water

The binders were generally hard to spread evenly through the husk/bran material, especially oil and clay. The husk/bran had to be rubbed vigorously between the hands for uniform binder distribution (Figure 45). The thick paste made of cassava flour and hot water was the easiest one to mix with the husk/bran. Also, the more viscous the binder, the more adhesion it produced. This was the case for cassava flour. This can be explained by the fact that viscosity increases adsorption. (Kaliyan, 2009) Adsorption is the surface adhesion of particles that generates stronger molecular bonds. (Kaliyan, 2009) Oil was also considered a weak binder in terms of cohesion. The oil briquettes were very friable. The clay ones gained structural strength with drying though they were very weak initially. Cassava flour was by far the binder that offered the best immediate adhesive properties. Just after compression, the briquettes (especially the cylindrical ones) made with cassava flour were the only ones that could be easily removed from the press by hand. These briquettes also presented a strong relaxation after immediate removal of the piston, having a spongy appearance while still humid. The relaxation can be defined as the slight increase in volume of a compressed material once the pressure is removed. The relaxation is not known to have any impact on the briquette performance. It is mostly considered as a physical characteristic that influences density.

The briquetting rate was evaluated at approximately 200 briquettes per hour with two operators. This was slower than the rate predicted of 500 briquettes per hour. The press was also operated by a single person but at a slower operating rate (70 – 100 briquettes per hour). It appeared that the husk/bran/binder mix preparation was time consuming for the binder needed to be well spread and accounted for the slower fabrication rate. 10 L of dry bulk husk/bran material produced approximately 60 cassava flour briquettes. The same volume of initial mixture leaded to about 45 clay or oil briquettes. This difference can be explained by the swelling property of cassava flour and hot water into the husk/bran. Therefore, from a productivity point of view, cassava flour can be advantageous as for the higher number of briquettes generated.

Table 8 – Qualitative Structural Conclusions

		Water		**Oil**		**Clay**		**Cassava Flour**	
		20%	**40%**	**1.5%**	**5%**	**1.5%**	**5%**	**1.5%**	**1.5%**
Circular	**Position 1**	-	-	-	±	-	+	±	+
	Position 2	-	-	-	-	-	-	-	±
Small Rectangle	**Position 1**	-	-	-	±	-	±	±	+
	Position 2	-	-	-	-	-	-	-	±
Big Rectangle	**Position 1**	-	-	-	-	-	±	±	+
	Position 2	-	-	-	-	-	-	-	±

Legend: - Bad results, does not stick together, will not be further investigated ± More experiments will be conducted to draw conclusions + Good results, hold well and will be taken into consideration

At the end of the block experiment, as a preliminary conclusion (i.e. before the first combustion test), the best briquettes produced in terms of structural characteristics were the cylindrical one with a 5% of cassava flour concentration.

Open Flame Test Observations

Figure 46a
Combustion of an oil briquette

Figure 46b
Combustion of clay briquettes

The first combustion tests didn't lead to the same conclusion than the block experiment concerning the best binder. The burning behaviours of the briquettes were observed during an open flame combustion test which consisted of a qualitative test during which briquettes were feed in a fire. The briquettes containing oil were by far the ones that burned better (Figure 46a). As expected, the clay ones were the worst in terms of flame generation (Figure 46b). They produced a fair amount of smoke, didn't catch into fire and often just got black on the outside while remaining intact in the middle. The cassava flour briquettes took longer to generate flame than the oil ones but overall, they burned better than the clay ones. No particular smell or noxious fumes were noticed during the combustion of any of the briquettes.

All briquettes generated important amount of ash. Because of incomplete combustion, clay briquettes were the ones producing the highest amount of ash. Oil and cassava briquettes had less unburned residues but were still leaving more ash in the stove than wood. In all cases, the flames didn't spread easily to the center of the briquettes and tend to stay on the edges. This is also why the bigger rectangular briquettes didn't perform well. This may suggest that thicker briquettes would probably be more difficult to burn. While thinner briquettes were too fragile to handle the 2.5 cm thickness was considered ideal. Finally, it may be interesting to note that briquette manipulation in the fire is not as convenient as wood, especially in terms of injuries. They are shorter and their deposit is made closer to the fire than wood. Then, some hand burns could be more easily experienced by the users. Also, briquettes usually needed to be placed directly on an existing flame otherwise they didn't easily catch fire. However, the existing flame does not have to be generated by wood. A flame can be initiated from palm oil residues which is the material presently used to start wood fires.

Rice husk ash is mostly contains silica (SiO_2) in proportion of 87 to 97 %. (Prasad, 2001) This high silica content would not allow spreading the briquettes ash as an agricultural amendment since it would not add any nutrient value to the soil and probably just increase it acidity. The ash could be used as a bulk material for construction. Researchers have looked into using rice husk ash in gypsum boards or as a replacement to quarts in the vitrification process. (Prasad, 2001) Less technology intensive uses of ash could include adding it as a bulk material to clay for construction or transforming into biochar for soil conditioning.

12.3.2 Laboratory Analysis - Energy Content, Ash Content and Moisture Content

Raw Husk and Bran Analysis

Before drawing further conclusions on the binder that performed best, analytical investigations of other properties were needed. The briquettes were brought to the University of Abomey-Calavi (UAC) where they were suggested to water content, energy content and ash content analysis.

Table 9 – Characteristic of the Unprocessed Rice Husk and Bran

Material	Dry Matter (g/100g)	Energy Content (kcal/100g)	Ash Content (g/100g)	Energy Content Dry Basis (kcal/100g)
Rice Husk	89.47	357.53	20.59 ± 0.03	399.59
Rice Bran	87.23	408.27	12.91 ± 0.03	467.83
Husk and Bran Mix	91.36	389.61	19.04 ± 0.11	426.47

The moisture content of the husk/bran material (8.64%) concurs with the recommended value (8-9% Guerrero, 2008). Rice husk alone has greater dry matter and ash content, and has lower energy content than bran. This was expected because of the oily substance naturally contained in the bran. Bran has slightly lower dry matter content because of the moist from the oil it contains. Its ash content is also quite lower than husk. Therefore, the high ash content in the briquettes can be attributed more to the rice husk than to the bran. Overall, the ash content of rice husk is within 13 to 24%, which is the usual range suggested by the literature for ash content. (Prasad, 2001) Previous researches on rice husk have determined its theoretical energy content value at 358.5 kcal/g (Genieva, 2008) or at 352.77 kcal/g (Bergqvist, 2008). This can be used to attest the significance of the present project results. Even if no high accuracy was expected with the apparatus used at the UAC, the results are in accordance with the literature values. Therefore, the laboratory analyses performed were precise enough for the subsequent results presented in this report to be reliable.

Briquette Analysis

Table 10 – Characteristics of Briquettes

Binder	Binder Content (%)	Dry Mather (g/100g)	Energy Content (kcal/100g)	Ash Content (g/100g)	Energy Content Dry Basis (kcal/100g)
Oil	1.5	83.73	337.14	17.60 ± 0.02	402.65
Oil	5	85.33	380.72	16.17 ± 0.01	446.17
Clay	1.5	85.67	317.88	22.03 ± 0.01	371.05
Clay	5	87.99	317.77	23.53 ± 0.03	361.14
Cassava Flour	1.5	83.27	324.14	17.44 ± 0.03	389.22
Cassava Flour	5	87.21	360.38	17.36 ± 0.04	413.24

Table 10 presents the laboratory analysis of the briquettes from the block experiment. As expected, the binder effectively influenced the energy content, but not necessarily in appositive manner. When comparing to the raw husk and bran dry basis energy content value (426.47 kcal/100g) all the different binders are lowering the energy content of the briquette except for oil at 5% concentration (446.17 kcal/100g). The energy content of the clay briquettes confirms the observations made during combustion test and their low energy content explains why they burned less well. The clay briquettes also have the highest ash content (23%). In this case, clay increases the ash content of since it is higher than the raw husk/bran alone (19%). However, it appears that the addition of oil (16%) and of cassava flour (17%) to the husk/bran increased the combustion capacity of the material since the ash contents of these briquettes are lower than the one of the raw husk/bran material. All ash contents are contained between the literature range of 13 to 24 %. (Prasad, 2001) It appears that in general, the binders will decrease the energy provided by the husk/bran material by lowering the energy content while it will increase its burning properties by reducing the ash content. Also, all briquettes have moisture contents between 12% and 17%, higher than the raw husk/bran (8.64%). For better efficiency, the moisture content should be brought down at least to the recommended humidity level of 8 - 9%. (Guerrero, 2008) This could be achieved by drying the briquettes under the sun for a longer period of time.

Wood Analysis

To further assess the briquettes' performance, the values from Table 10 can be compared with the results from the same analysis that were performed on some local wood samples. The wood samples consist of a random sampling on the wood branches burned by the women. The samples were taken from different tree species and prepared with a weighted mean of the different wood varieties. Then, it was irrelevant to compare any of the wood results to literature values since the analysis were not performed on pure variety wood samples. The char consists of the wood parts that undergone incomplete combustion.

Table 11 – Characteristic of Wood

Location and Time of Wood Sample	**Dry Matter (g/100g)**	**Energy Content (kcal/100g)**	**Ash Content (g/100g)**	**Energy Content Dry Basis (kcal/100g)**
ADRAO	88.70	429.24	2.43	483.92
Gobé (29-30 July)	80.42	385.48	2.46	479.34
Gobé (1st July)	87.99	456.15	3.25	518.38
Gbaffo (2nd July)	89.34	444.51	3.44	497.53
Mean	86.61	428.85	2.90	494.79
Char Gobé	55.79	489.63	5.61	877.68
Char Gbaffo	95.63	645.53	10.33	675.00

It can be noticed that the various wood ash contents are considerably low compared to the briquettes' ash contents. All the briquettes' energy contents are also lower. However, it is interesting to point out that the wood's moisture content is sometimes higher than the briquettes' moisture content. This can illustrate that wood is not always well dried before to be used in the stoves. The moisture content may also vary during the year depending on the season. These wood samples were all taken during the rainy season. Also, char presents higher energy content values although it has higher ash content.

12.3.3 Further Experiments

Water Content

More briquettes experimentations were done after the first block experiment. These subsequent trials had the purpose to further determine the optimal initial water content. As mentioned previously, even if they were holding well, briquettes made with 30% water content were assessed to be difficult to dry, to rot easily and then present bad smells. A trade off exists between the drying time and the bonding properties. Different trials were conducted using 5% binder concentration (oil, clay and cassava flour) and varying the water content (25%, 20% and 15%, 10%). The importance of water in the formation of adhesive bonds was easily illustrated. Briquettes with 10%, 15% and 20% water content were very friable and collapsed while drying. Some trial briquettes consisted of 15% water and 10% binder. These were as not solid as 15% water and 5% binder briquettes. This confirmed the necessity of adding water to the mixture and that a higher binder percentage alone was inefficient. The optimal water content was then identified as 25%, slightly below the fibre saturation point of 30%. Once the moisture level was set at 25%, it was used for all subsequent experiments.

Binder Concentration

Further experiments were performed on binder concentrations. Some combinations of more than one binder were then investigated to address the challenge of simultaneously obtaining a good adhesive and flammable binder. This was also to produce stronger briquettes that would be more convenient to handle and to burn. Then, the overall binder content was increased over 5%. However, smaller concentrations could probably be used under higher pressure densification procedures. All combinations were produced in multiple repetitions of 10 to 15 briquettes with a volume of 2 L of bulk husk/bran material.

A first combination of 2% cassava flour and 5% oil was tried. The idea was to add some structural strength to the briquette that was performing best during combustion. No significant ameliorations were noticed in terms of the briquette's solidity and the combination was rejected. Afterwards, the idea was to add some oil to 5% cassava flour to increase the combustion property. Combinations such as 5% cassava - 3% oil and 5% cassava - 5% oil were tested. Both were burning better than a briquette with cassava flour alone. No significant differences in combustion were observed between the 5% oil content over 3% oil content. A last trial of 7% cassava flour – 3% oil was also conducted. This option presented the best structural solidity. The combustion was similar than the 5% cassava - 3% oil but with additional strength.

Also, clay was still not completely eliminated since it was the most interesting in terms of social aspects such as cost, availability and acceptability. These properties are important to consider when producing briquettes in the context of a developing country such as Benin. Oil and cassava flour are not as readily acceptable since they are edible substances. To try to address this problem, combinations of oil and clay were tested: 5% clay – 3% oil, 5% clay – 5% oil and 3% clay – 5% oil, but without satisfying results. All these different trials presented higher levels of cracks than their equivalent cassava flour and oil combinations. After drying, they were also holding relatively well but were still too friable for to handle conveniently and to consider stacking and transportation. The concentration was then further increase and 7% clay – 3% oil and 7% oil – 3% clay briquettes were fabricated. The idea of using an overall 10% binder content was not very interesting in terms of low briquetting cost but it became relevant in the project when thinking about solidity for briquette transportation to the villages.

In the end, three binder combinations have been retained for the purpose of village experiment and demonstration: 7% cassava flour – 3% oil, 7% clay – 3% oil and 7% oil – 3% clay. Their distinct calorific content analyses from the UAC are presented in the following table. They can also be compared to 8% oil briquettes. Even if the strength of these high oil content briquettes was expected to be very low, it was relevant to evaluate the influence of oil on the briquettes characteristics. The results are also compared with the 5% cassava flour briquettes that were the best alternative of the first block experiment.

Table 12 – Characteristics of Combined Binders Briquettes

Binders	Energy Content (kcal/100g)	Dry Matter (g/100g)	Ash Content (g/100g)	Energy Content Dry Basis (kcal/100g)
Clay 7% Oil 3%	389.13	88.36	35.23	440.40
Oil 7% Clay 3%	354.91	87.91	21.68	403.72
Cassava 7% Oil 3%	395.95	86.59	15.18	457.27
Oil 8%	461.12	86.4	10.27	533.71
Cassava Flour 5%	360.38	87.21	17.36	413.24

Some interesting observations can be made from these values. First, they can be compared to the literature. The theoretical energy content of rice husk was mentioned to be 358.5 kcal/g (Genieva, 2008) or 352.77 kcal/g (Bergqvist, 2008). The experimental data of energy content are about all higher and this could be attributed to the fact that the briquettes were made of a mixture of rice and bran. As seen in Table 14, bran has a higher energy content than husk alone, increase the energy content of the husk/bran material. Palm oil binder also increases significantly the energy content of the rice/husk material. The 8% oil briquette presents even higher energy content than any of the wood samples. Even if the ash content of the 8% oil briquette is not as low as wood, it is lower than any other briquette. Once again, clay briquettes reveal themselves to be definitively not interesting especially in terms of ash content. Mixing clay with oil increases its energy content which is higher than the raw rice/bran mixture energy content. Surprisingly, the 7% oil – 3% clay briquette has lower energy content than the 7% clay – 3% oil one.

A comparison can be made between the 5% cassava flour briquette and the 7% cassava - 3% oil one. It was not a surprise to notice that oil added to the energy content. This briquette has also lower ash content even if the concentration of cassava is slightly bigger. On a qualitative perspective, the 7% cassava – 3% oil briquettes were also stronger, more convenient to transport because of higher cassava content. They also burned better because of the oil addition with energy content a bit closer to the wood mean energy content.

12.3.4 Relaxed Density

The relaxed density is the density of a material after its relaxation time is over. Most of the relaxation usually occurs during the first 10 minutes after the end of the compression and it can continue for the next 2 hours. (Chin Chin, 2000) The relaxation time usually increases with the moisture content. (Faborode, 1989) The theoretical value of bulk rice husk density ranges between 0.04 and 0.2 g/cm^3. (Kaliyan, 2009) Bran, which is heavier, has a bulk density of 0.3 to 0.4 g/cm^3. (Sreenarayanan, 1985) The proportions of husk and bran respectively in the mixture of husk/bran material were calculated to be 60.6% and 39.4%. From these values, the range values of bulk density for the husk/bran material used are 0.14 to 0.28 g/cm^3. Some theoretical data were also found for the compressed density of rice husk, but they were considered irrelevant since density strongly depends on the binder and the compression force used.

Table 13 – Density of Briquettes

Binder	Mean Mass (g)	Thickness (cm)	Volume (cm^3)	Relaxed Compressed Density (g/cm^3)
Clay 7% Oil 3%	70.282	2.8	140.74	0.50
Oil 7% Clay 3%	73.852	2.5	125.66	0.59
Cassava 7% Oil 3%	67.820	2.8	140.74	0.48

The objective of increasing the particles density was met. The manually operated press was successful to densify the bulk husk/bran material. Effectively, the compressed density of each briquette is higher than the upper bulk density value of the husk/bran material (0.28 g/cm^3). However, a higher density is not necessarily related to higher energy content. Greater density would not be an indication of better strength either. (Kaliyan 2009) Density is more relevant to assess the amplitude of the compression achieved. In the case of the 7% oil – 3% clay briquette, the mix is at its minimum 2.1 times denser than before compression and 4.2 times at its maximum. The presence of binder also accounts for the higher compressed density. Surprisingly, considering the weight of clay, the compressed density value is higher with 3% clay than with 7% clay. In the end, density could also be an indicator of the combustion rate. A denser fuel would burn slower than a less dense one. (Chin Chin, 2000)

13. Final Designs

13.1 Stoves

The choice of improved stove was made mainly by observation. It is very hard to explain the different efficiency calculated because of the too large quantity on unknowns. The moisture content of the wood, the variety and the size of log, the volume, humidity content and properties of the soil used, the number of previous usage on the stove and the ambient air condition are the major characteristic that haven't been taken into consideration and could really influence the efficiency. However, positive observations have helped choosing a design.

The Stove 8 with chicken wire and least amount of clay wasn't chosen because of the cost and non- availability of the chicken wire in the villages. That stove was also hard to built, it needed some specific instruments like metal cutter and there was high risk of injuries cause by the sharp metal wires. Rusting metal could therefore not only injured but also ill villagers with tetanise.

The design with the grate wasn't chosen because of the extra material needed. It was observed that the grate bought was made of metal that wouldn't have last for a long time under the usage conditions. The weight and the heat of the fire would deteriorate the cheap metal rapidly. In that case, a special grate would have to be made by an artisan with a considerable cost increase, unreasonably for villagers to reproduce the technology.

Figure 47 Stove build in Gobé

The chosen design was the stove with fitting top opening (stove 8). This model seems to control and reduce the amount of unhealthy smoke better than the other stoves. The holes in the middle of the stove structure created a small chimney helping the circulation of air coming from the bottom holes and directing the smoke away from the users. The adjusted top opening served to reduce the heat losses by convection and by dissipation consequently directing the heat to the cauldron. The cauldron, once sitting on the top of the stove, was also covered with clay up to 15cm from the bottom. It would be interesting to analyse if that covered part of the cauldron reduces the heat loss by convection and by radiation of the cauldron's wall. The disadvantage of this stove is that it is built to fit one size of cauldron only and the front opening has to be big enough to provide the sufficient quantity of wood needed. It was also easy to build and the material need was simple, available and cheap.

The material use was the clay available in the village and some herbs bought from a local supplier (for 200 Francs CFA). The herbs were cut in pieces of about 5-8 cm and the quantity represented about 15-20 volumetric %. The women in the village notice that the organic matter helped to reduce the cracking of the stove compare to the use of clay only (the usual practice). For a better analysis of the situation, the mass, the conductivity and the specific heat capacity of the clay/organic matter would have to be tested to evaluate their efficiency compare to the use of the clay material only.

It was observed that the soil composition influence substantially the shape of the built stove. The higher the concentration in clay the soil was, the easier it was to build but the most cracking was also observe after the drying period. This could be explained by the properties of the clay (expanding when mixed with water and contracting after drying). In fact, the stove built in the village was harder to shape. The clay had a high sand concentration; therefore, a larger volume of clay was needed to build the stove. The construction of an arch door was then more difficult and abandoned.

Only one clod start and two warm start boiling test were performed on the new design. The stove was built on the first day of the visit (Monday, July 27th) and was tested 3 days later (Thursday, July 30th). It is to note that the stove was not completely dry due to the lack of time and the rainy weather. During the testing, marks on the outside wall were clearly indicating the incomplete drying; only about 10 cm from the top showed the appropriate color. Therefore, the efficiency of the new design is probably higher than the one calculated. Here are the major differences between the new and traditional stoves.

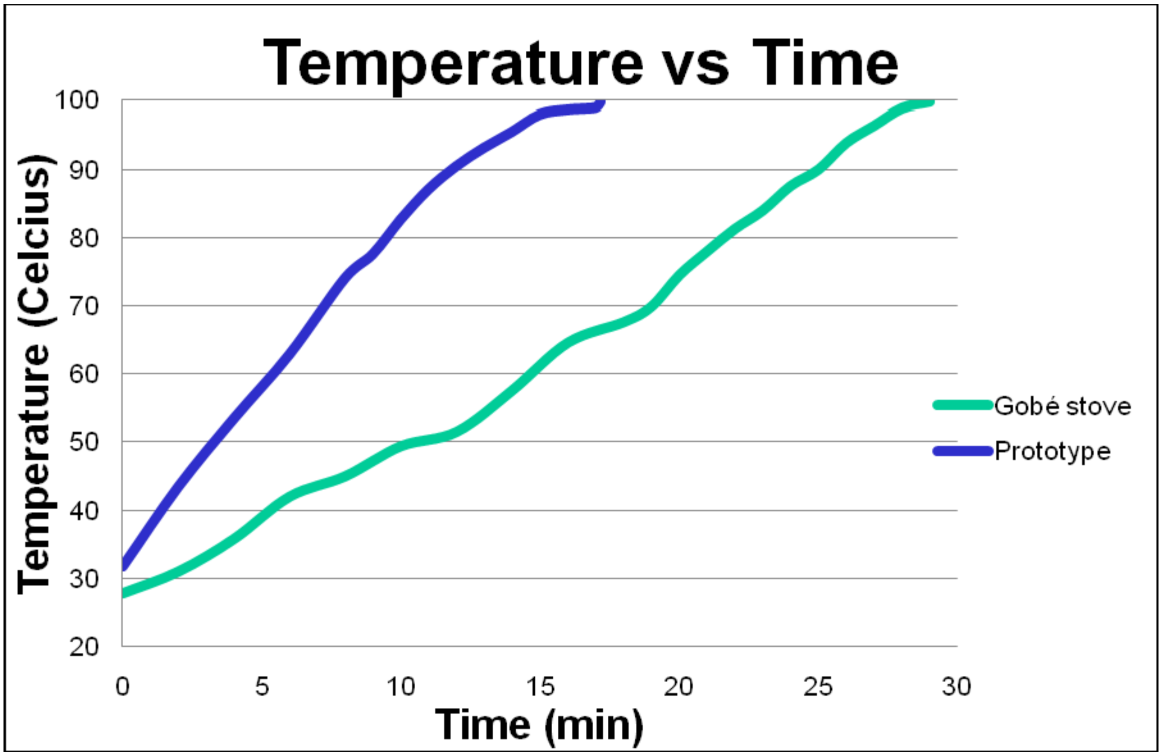
Table 14: Difference between the Traditional and the New Stove built in the Village of Gobé

	Traditional	**Improved**
Energy in (kJ)	47 934	45 074
Energy out (kJ)	3 384	4 924
Energy loss (kJ)	44 550	40 150
Efficiency	7 %	11 %

It was calculated that the improved stove had a clay volume reduction of 20% which impact the energy loss by the sensible heat gained by the stove. This reduces the energy transfer to the stove and maximizes the energy gained by the cauldron. It was also observed that the time required to bring the water to a boil was reduce by about 45% assuming the same heat generation rate. Therefore, time and wood consumption are to be reduced. The following graph shows the temperature of the water (10L) in the cauldron in function of the time.

For this project, it was easy to reproduce the design in the village of Gobé because of its low cost of materials and its low technicality. In fact, the reproduction of that stove will help to determine the durability of the stove, and its effect on the stove damage. The women feedback on the functionality of the stove is also highly important as they are the daily users.

Figure 48: Temperature as a Function of Time for two stoves



Recommendations and possible improvements

In order to obtain reliable results, test in control area would be needed to allow assessing better the different effects of the materials, shapes and amount of clay on the efficiency of the system. The results of the water boiling test could be used to compare the stoves but more laboratory tests would be needed to be able to assume better values of the energy generation. The humidity content of the wood could be taken into consideration.

Because of lack of time, the stoves were not testing with wood that was cut in small logs instead of being use at their full length (current use in village). This would be a study of interest regarding the fuel saving because of the elimination of the fraction of wood sticking out of the stove and burning non-efficiently. It would also be interesting to try to quantify the amount of energy loss and their origins.

13.2 Insert

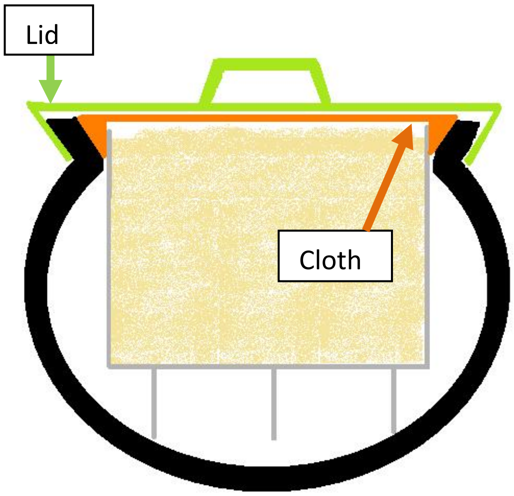


Figure 49
Ameliorations for the new insert

As seen in the testing phase, the prototype was not optimal and required increased time to assure equal steam distribution through the paddy rice. The proposed solution to this setback is illustrated in figure 49. It will be further referred to as the MRT design. The monitoring problem could be ruled out if an insert that fit tightly to the cauldron can be constructed (no gap between the insert and the cauldron at the smallest opening). The steam easy path out of the cauldron would then be closed and the steam would be forced into the paddy rice form the bottom and lateral holes. The use of a piece of cloth at that intersection would be preferable to reduce further more steam losses. Thus, the monitoring of the rice parboiling will be easier given that with the amelioration the bottom layers of rice will parboil first and the middle top layer last. The manipulator would only need to take the lid off and to lift the cloth covering the rice and monitor the rice in the middle of the insert. When the middle top rice is parboiled, all the rice would be parboiled.

<u>Table 15 - Comparison of Numeric Parameters of the Parboiling Equipments</u>

		Currently-Used Insert	MRT Design	Deviation (%)
Areas (m^2)	Total Surface Area	0.866	0.565	+ 74 %
	Perforated Surface Area	0.326	0.565	+ 25 %
	Area subjected to air	0.414	0	- 100 %
Capacity	Capacity (total) (m^2)	35.0	18.4	- 47 %
	Average Mass of Rice (useful) (kg)	(60% of 50) 30	30.76	+3 %
Other Properties	Time to parboil (min)	30	Approx. 30	-
	Price (CFA)	35 000	15 000	- 57 %

The characteristics of this new MRT insert (which are quite similar to the prototype except for the diameter parameter) are compared to the current insert characteristics in the table 15.

The insert used for the experimentation showed some weakness as far as manoeuvrability and real-life utilization goes. First of all, the prototype is quite heavy (4.9 kg) for regular use by the women. It was built very strong, but could eventually be built out of thinner metal sheets. The material used for the final MRT design would therefore be two times thinner then the prototype. Thus, this action could possibly bring the cost of production to 15 000 CFA, a more reasonable price for wide distribution and adoption amongst rural processors. Also, the price would be more than two times lower than the actual price of the currently-used insert. Secondly, some difficulties were experienced to lift the retracted handle. The handle would get stuck midway when not lifted straight. An easy solution would be to make the handle holding rings a little bigger and to add small metal pieces on each side of the insert where the handles are as to guide the handles straight up.

The capacity of the insert was an important criterion when design it. A diminution in total capacity of the insert of 47% in volume was measured. However, from what the women said, the currently-used insert is usually only used at approximately 60% of the full capacity because of un-uniform steam distribution. Thus, the same mass-based capacity is observed for both equipments at useful capacity (capacity at which the women usually use it). This characteristic makes the MRT design better because no space is lost. The equipment is small, but still parboils the same quantity of rice.

Moreover, by decreasing the unused volume, the area that undergoes convection heat losses has been reduced to minimum (reduction of 0.41 m^2 of surface in contact with air). Convective heat losses are proportional to the area in contact with a medium of different temperature (in this case; air). As a result, the energy used to produce 1kg of parboiled rice is reduced. Further quantitative or model analysis would be needed to assess the relative importance of convection to heat losses and the actual reduction in energy required for parboiling. However, form the basic heat transfer theory, the reduction of the convective heat losses from the insert and the lid can be estimated at

318,7 W. The details of those calculations with the different assumptions made figure in appendix 4.

Along with the convective heat loss reduction, a reduction in the latent heat loss from steam escapes is anticipated. The considerable reduction in opening's perimeter reduces the steam escape. The main responsible for this diminution are the reduction of the diameter of the lid and the elimination of the second opening since the MRT design fits totally inside the cauldron. Consequently, the circumferences have been reduced by 53,9% over the currently-used insert which would indicate a reduction of the steam (and latent heat) losses of 53,9% all other variables assumed to be equal (see appendix 4 for more details). Besides, the steam getting through the paddy rice will be increased because of the 74% increase in perforated surface area. Also, no change in the quality of rice parboiled is expected with the MRT design (as there was no change with the prototype).

Overall, the general concept of the first prototype works. It has improved characteristics over the currently-used insert, but the proposed modifications of the MRT design will make the new design easier to implement.

13.3 Manual Press

The final design of the manual press consists of the second prototype developed for the experimentation phase (Figure 50). It was decided to use wood over metal as building material since it is more convenient to work and it offers better manoeuvrability. The structure is a bolted assembly where all the beams are hold together in compression. The fulcrums are made out of steel pipe which are inserted through the levers and the lateral posts (Figure 51a). For robustness of the design and resistance to shear forces, the main base beam has a cross-section are of 9 x 20 cm. The main and second levers have cross-sections of 7 x 10 cm and 7 x 7 cm respectively while the other beams are 9 x 9 cm in cross-sections (see appendix 5 for detailed measures and SolidWork sketch)

Figure 50 Final Press Design

Since the press could eventually stand on uneven surfaces, it was decided that the base beam would not lie directly on the ground. For stability, two short beams were installed perpendicularly underneath each base end. The base beam is also longer than the distance between the two sets of posts (i.e. the distance between the two fulcrums) in the direction of the second lever in order to overcome the moment of force produced by the application of a downward force. The posts supporting the levers are fixed on each sides of the base beam with bolts that are not aligned with each other to ensure better stability against the moment of force. Blocks have been added between the set of vertical posts to keep them well aligned together (Figure 51b). The posts of the second fulcrum also serve as guides for the main lever during its vertical displacement. Therefore, no guiding system described in the brainstorming session was necessary. Referring to the objective of keeping a mechanical arrangement that is simple, fast to operate, cheap and easy to build, a press block and a removable dye are aspects of the design that were adopted. Therefore, a simple press block is used and no parallelogram linkage was required. This offers good manoeuvrability even if the lever's amplitude is small (a few centimetres

Figure 51a
Fulcrum Arrangement

Figure 51b
Block between posts

Figure52
Wood plank on stand supporting dye in filling and briquetting positions

only). The piston is placed at a position near the first fulcrum as to maximize the force. On the base beam, a stand was installed on which the dye is placed manually at the beginning of each compression cycle. A wood plank was placed horizontally on this stand for better convenience. This wood plank allows the dye to be slide back and forth into briquetting and refilling position (Figure 52). The piston is then inserted in the dye at refilling position (closer to second fulcrum) where the lever amplitude is higher. After sliding the dye/piston in its briquetting position (closer to first fulcrum) the pressure can be applied. The mould is emptied in briquetting position by leaving the piston in place and by moving the dye slightly upwards, releasing the briquette on the horizontal wood plank. The piston positioned at a position of 18cm from the fulcrum when compressed generating a force multiplication ratio of 28.6. It is evaluated that the maximum force produced by the press is about 20kn from an initial compressive force of 0.7kN.

13.4 Biomass Briquettes

Among the different briquettes tested, the circular one was retained as for the final briquette design. As mentioned earlier, this shape is more convenient since it offers better strength and is easier to manipulate. This briquette is also more solid since it has been subjected to a higher pressure. With its surface area of 5.03×10^{-3} m² and a compressive force of 20kN, a pressure of 3 976.14kN/m² is applied.

As mentioned in the literature review, it is suggested that a die thickness over diameter ratio higher than 10% increases the durability of the briquette (Kaliyan, 2009):

$t / d * 100\% \geq 10\%$

Where t = thickness of the material compressed (m)

d = diameter (m)

This ratio was the highest with the circular briquettes, with a value of 31.25%.

$$t / d = 2.5 \text{ cm} / 8.0 \text{ cm} * 100\% = 31.25\%$$

For the binder, the briquette that was identified as the most promising one was prepared with a binder combination of 5% cassava flour and 3% palm oil concentration (with 25% dry basis water content). They presented the best combination of cohesive, combustion and strength characteristics. Their energy content was evaluated at 19 KJ/g (on a dry basis). Considering the stove's low energy efficiency, about 2 kg of wood are needed to bring 10 L of water to a boil. From the 35 000KJ of energy required to boil 10 L of water, it was possible to compute the energy required to boil water. The different characteristics of these final briquettes can be compared to the characteristics of wood used in the Département des Collines in Benin.

Table 16: Characteristics of Wood and Biomass Briquettes

Characteristics	Briquette	Wood
Humidity Level (%)	13.41	13.39
Ash Content (%)	15.18	2.90
Energy (KJ/g)	16.6	18.0
Energy Dry Basis (kJ/g)	19.0	20.7

With 19.0 KJ/g of briquette energy content, and also taking into account the moisture and ash content, about 2.5 kg of alternative fuel would be needed to boil the same amount of water in the same conditions.

Dry mass of briquette = Energy to boil water / Dry energy content of briquette
= 35 000 KJ / 19.0 kJ/g = 1 842 g (dry basis)

Wet mass of briquette = Dry mass * 100 % / (100 – % humidity)
= 1 842 g * 100 / (100 – 13.41) = 2 127.3 g (wet basis)

Total mass of briquette = Wet mass * 100 % / (100 - % Ash content)
= 2 127.3 g * 100 / (100 – 15.18)
= 2 508 g = 2.5 kg of biomass briquettes

Thus, for 5% cassava flour and 3% palm oil content binder content, the amount of briquettes needed to bring to a boil 10 L of water can be estimated to 40 briquettes with an average mass of 60.0g per briquette.

Combustion rate of briquettes

An empirical burning rate law is suggested for biomass briquettes. (Chin Chin, 2000) This law is of the following form:

$\dot{m} = a * p^n$

Where $\dot{m}$ is the mass burning rate (g/min)

P is the compaction pressure (bar)

a and n are empirical constants

Values for a and n for various briquettes can be found in Table 17.

Table 17: Empirical values of burning rate law (Chin Chin, 2000)

Biomass briquette	a	n
Sawdust	2.007	-0.357
Rice husk	**1.270**	**-0.315**
Peanut shell	1.045	-0.267
Coconut fibre	1.095	-0.270

According to this burning rate law, the rice husk biomass briquette would be burning at a rate of 0.4 g/min.

$P = 3\,976\,140 \text{ Pa} * 10^{-5} \text{ bar} / 1 \text{ Pa} = 39.7916 \text{ bar}$

$\dot{m} = 1.270 * 39.7916$ ^ $(-0.315) = 0.4$ g/min

$\dot{m} = 0.4$ g/min * 60 min/hr = 24 g/hour

The average mass of a briquette is 60.0g. Taking into account the moisture content and the ash content, the combustible dry mass of a briquette is about 44.0g. Therefore, even if this seems quite unlikely, in theory, one briquette would be completely burned after 110 minutes.

$Mass_{dry}$ = 60.0 g * dry content / 100 % = 51.95 g

$Mass_{dry\ and\ combustible}$ = 51.95 g * combustible content / 100% = 44.0g

$\dot{m}$ = 44.0g/briquette / 0.4g/min = 110 minutes

<u>Density</u>

Under a pressure of 3 976.14kN/m² and with a mass of 60.0g, the final briquettes have after compression, a density of 0.43 g/cm$^{3.}$ The initial bulk density of rice husk/bran material is in the range of 0.14 to 0.28 g/cm^3. (Sreenarayanan, 1985) This represents an increase in density of 1.5 to 3 times.

An empirical formula for the relationship between pressure and density can be expressed in the following form (Chin chin, 2000):

$$D = a \ln P + b$$

Where D = density (kg/m³)

P = the die pressure (bar)

a & b = empirical constants found in Table 18

Table 18: Empirical values for the computation of the density (Chin Chin 2000)

Biomass Briquettes	**a**	**b**
Sawdust	78.3	185.6
Rice Husk	**20.5**	**344.1**
Peanut Shell	36.5	415.4
Coconut Fibre	60.6	54.1

According to this empirical formula, the briquettes have a density of 420 kg/m³.

D = 20.5 * ln (39.7916 bar) + 344.1 = 419.6 kg/m³

This is similar to the experimental density of 0.43 g/cm³ or of 430 kg/m³ when expressed in the same units:

D = 0.43 g/cm³ / 1000 g/kg * 100³ cm³/m³ = 430 kg/cm³

Recommendations and possible improvements

Recommendations are to be made for design improvement and before further village implementation. Primarily, the overall strength and robustness of the press has to be increased. To increase the solidity of the press, a different wood type than cachou should be used. Ideally, a locally available hardwood should be favoured. Some parts of the mechanism could also be reinforced with metal, mostly the lever compressing the press block. The use of hardwood and metal would also decrease the elasticity in the lever and decrease possible force dissipation. Overall, the friction didn't seem to be a major source of force dissipation.

To increase more the compressive force using the actual design, the vertical linkage could also be closer to the second fulcrum reducing the distance D_4. The piston position is already being exploited at its maximum potential and it is not recommended to increase the length of the lever furthermore since this would reduce its resistance to shear force when compressing the press block. Reducing the distance D_4 from 27 cm to 15 cm would result in a multiplication ratio of 43.

The press block should be made slightly smaller in diameter to allow an easier removal of the dye. Its upper end edge could also be rounded for even pressure distribution by the lever (Figure 53). A cylindrical plate could also be held on top of the dye to facilitate its upward movement to release the briquette (Figure 53). Holes could be made through the dye's circumference to allow excessive water to be evacuated during compression and to decrease the water resistance that builds can inside the dye.

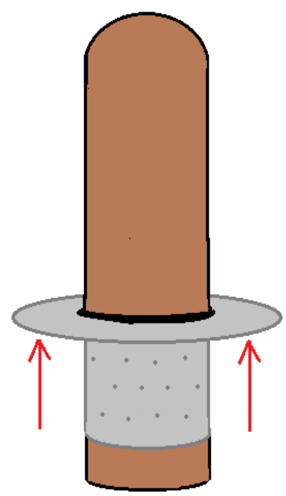


Figure 53 Mould improvement

It would be recommended to further decrease the moisture content of the briquettes to increase their efficiency. This could be achieved by increasing the drying time. All the drying should also take place under the sun. Adding holes to the dye may also help to decrease water content of the briquettes. Decreasing the percentage of water added to the mixture is not recommended because water is essential to create inter-molecular bonds and to produce briquettes that are not too fragile.

During mixture preparation, cassava flour should be left in the hot water for at least 20 minutes before adding it to the husk/bran material. During this period of time, the flour absorbs the water and it becomes stickier.

It is strongly suggested to look into non edible plant oils such as jatropha oil as potential binder. Such oil is non edible and has high energy content since it is presently used in the fabrication of bio-diesel in the sub-Saharan region. The cohesive property of jatropha oil under low pressure densification process would need to be further assessed.

It was mentioned by some local people that the production of palm oil produces a liquid waste that would have interesting sticking properties. Palm residues would get washed with water and this water would collect the sticky substance from the residues. This water is presently not known to have any used and it is thrown away. However, this waste water would be available only in some region were palm oil is produced such as in southern Benin. Palm oil is not produced in the Département des Collines. Then, maybe there is no one size fit all binder. Maybe this one should be different from one region to the other depending of the available resources. The potential of this sticky waste water should be investigated in the regions where produced.

The rate of briquette production should be increased to make the process more viable. Two moulds could be used to increase the process of briquette production. While one is in use on the press, the other one could get emptied from the previous cycle and refilled before the end of the next cycle. The compression stroke over, the two moulds could be simply interchanged and the cycle repeated again. The speed could also be increased if a third person was responsible for the preparation of the husk/bran/binder mixture.

14. Cost Analysis

The successful implementation of the developed design will mostly rely on the economic gains it proposes compared to the currently-used design. However, the cost analysis for the whole system is intrinsically linked with the implementation method and the role of the women in the briquetting process. As outsiders, it is very difficult to prescribe or evaluate what will be the distribution of roles or the pricing on new items. Therefore, for this cost analysis, different scenarios were observed without any prioritization of the scenarios. The different outcomes of the new system should not be compared one to another, but compared to the old parboiling method. Since all the outcomes were more positive economically then the old system, there is much more chance that this technology will make its way into different villages (with different hierarchic structures).

14.1 Variable costs

Variable costs are similar for paddy rice and milling in both systems.

The cooperatives of women who own one insert and cauldron are not of the same size in all regions and they don't operate the same amount of rice per period. Thus, the amount needed for subsistence can vary widely. Subsistence money was assumed to be 500 FCFA per day of work. In two days of work, including buying the rice, washing it, parboiling, drying, milling and selling, 15 women of Gobé would produce 100 kg of parboiled rice. The subsistence money per kg of rice parboiled is 150 FCFA [500FCFA/women/day*2 days*15 women/100 kg of parboiled rice].

Table 19: Breakdown of the price of briquettes

Price of Material (FCFA/kg rice)	(Included in milling price)
+ Price of Binders (FCFA/kg rice)	12,68
+ Repair on Press (FCFA/kg rice)	0,97
= Cost of making Briquettes (FCFA/kg rice)	13,65
+ Labour Cost (FCFA/kg rice)	2,6
= Price on market (FCFA/kg rice)	16,25

During one parboiling, 8kg of wood will be used with a capacity of 30 kg per parboiling. For the new system, 10kg of briquettes will produce the same energy as wood for a capacity of 30,76 kg per parboiling. The price of wood was for the village of interest 500 FCFA used to parboil approximately 19 to 50 kg of rice (depending on the season).

Details on the price of briquettes are shown in table 19. In this table, one can see that most of the price for briquettes is the binder. Binders were determined as been 3% of palm oil and 5% of cassava flour. The prices of those binders on the market are approximately: 300FCFA/L for palm oil and 100FCFA/L for cassava flour. Moreover, it was assumed that the material (husk and bran) was returned to the women free of charge after the milling. Hence, the miller could get rid of an accumulating waste rapidly.

Labour cost for briquettes was determined from the minimal subsistence money (500 FCFA). It was assumed that workers would work 10 hours a day and that 100 briquettes per hour is made. The labour would then be 8 FCFA/kg of briquettes which translates into 2,6 FCFA/kg of rice parboiled (10kg of briquettes to parboil 30,76 kg of rice).

14.2 Maintenance and Repair

Maintenance and repair are minimal for this kind of system. The stove can be repaired free of cost with readily available clay. The insert needs very low maintenance or repair. The briquetting press will need reparation every once in a while (cost included in the price of briquettes). It was assumed that approximately 1200 FCFA would be needed to repair the press after 1000 kg of rice was parboiled (5418 briquettes made). Also, the user of the press will need to make sure regularly that the screws are tighten. Therefore, a screwdriver and a wrench were included in the investments under Press Maintenance.

14.3 Variable Income

Variable income from rice per kg is also equivalent whatever the material used. Parboiling activities are most important after the main rice harvest period in January and February. Very little to no parboiling is done the rest of the year. On the market, after harvest time, white parboiled rice is sold for approximately 350 FCFA per tongodo (0,7kg) [500 FCFA/kg] (ZOSSOU). To comply with this, it was assumed that all the parboiled rice can be sold on the market at the aforementioned price. It was also assumed that the quality of the rice parboiled with the new system was not higher significantly enough to cause a variable income increase.

14.4 Fixed Costs (Investment)

The briquetting press could be reproduced for 20 000 CFA. The press and the insert were designed so that local artisan can reproduce them with the available tools they have. The cost for the women can then be lower than investment-intensive reproduction of the material. The price of the cauldron is the same as it has not been modified for the new system.

14.5 Payback Period of Different Scenarios

The payback period was calculated on a non-discounted basis and per kilogram of rice parboiled. Depending on the size of the cooperative which owns the equipment and the diversification of their economic activities, the payback period will be reached on different period of time, but always at a certain amount of rice produced.

Table 20 presents the payback period for different scenarios. OLD refers to the method currently used for parboiling (traditional stove and current insert with wood as a fuel). It is our base point to compare any other scenarios. The four scenarios analysed are the most likely scenarios from what we have observed. The scenario 2 (NEW BUY) is if a local buys the press and makes the briquettes for the women to use. The NEW (MAKE) refers to the cooperative of women buying one briquetting press and making their own briquettes for parboiling only. The fourth scenario is similar to the previous but the women would also sell some of their briquettes at the market. The final scenario analysed was one were the briquettes would be more advantageous for half of the year and the wood would be more advantageous the other half. Hence, the women would use briquettes half of the time and wood the other half.

The system as a whole is advantageous economically for the women. The scenario 3 has very similar payback period compared to the old system (only 1,2% difference). For scenario 2, 4 and 5, the payback period are significantly lower than the one from the old parboiling system. The details show that on average the briquettes are the same price to buy compared to buying the wood. However, when made by the women, the cost of the briquettes is lower than the average cost of wood. Also, in the scenarios observed, the new insert and the new stove contribute to the reduction of the investments.

Table 20: Economic Analysis of the New Parboiling System in Comparison with the Old One

	1. OLD	2. NEW (BUY)	3. NEW (MAKE)	4. NEW (MAKE and SELL)	5. NEW (BUY, half/ half)
Variable Costs (FCFA/kg of rice)					
Wood	16,7	-	-	-	8,3
Briquette	-	16,25	13,65	13,65	8,13
Rice	150	150	150	150	150
Milling	20	20	20	20	20
Subsistence	150	150	150	150	150
Variable Income (FCFA/kg of rice)					
Parboiled Rice	500	500	500	500	500
Sold Briquettes	-	-	-	19,8	-
Investments (FCFA)					
Briquetting Press	-	-	20 000	20 000	-
Press Maintenance	-	-	1500	1500	-
Insert	35 000	15 000	15 000	15 000	15 000
Material Stove	-	200	200	200	200
Cauldron	20 000	20 000	20 000	20 000	20 000
Payback Period (kg)	337	215	341	305	215

15. Social and Environmental Impacts

- Reducing the stress on the forest

The increasing parboiling rice activity related to higher rice production highly impacts the demand for wood fuel. This increasing fuel demand directly affects the surrounding forests. The new designs would allow reducing the overall wood consumption used during parboiling by increasing the efficiency of the process and by reusing the residues.

- Valuing milling residues as energy

Between 1990 and 2000 a number of initiatives by government agencies and NGO's led to an increase in Benin's rice production from 10 940 tonnes per year to 53 441 tonnes per year (Zossou, 2008). Since September 2009, FAO has started a project to increase the rice production of Benin to 300 000 tons per years. (FAO, 2009) Therefore, this important increase in rice production results in an increasing production of waste residues. However, these by-products readily available represent a great potential for an alternative fuel. Moreover, presently the villagers are disposing of the residues by burning them in open air piles. The present innovation reuses this free energy that is being wasted, which implies that it also becomes the new energy source for the steaming step in the rice parboiling process. Some local workers have proved the feasibility of using only 7 or 8 briquettes to cook a sauce for a meal.

- Other environmental concerns

Valuing the rice milling by-products and improving the heat transfer to the cauldron is also a solution to other environmental concerns of a developing country already being affected by climate change. Reducing the deforestation would help conserving better quality soil and air. Such new alternative fuel will help to decrease the greenhouse gases emissions with a carbon neutral energy source as well as to solve the waste management problem and the pollution challenge created by the accumulation of the husks and the bran. The improved stove would allow a complete combustion reducing the harmful gases related to inadequate combustion (NO_x, CH4, etc).

- Decreasing the cost related to wood consumption

When wood cannot be gathered directly from the surrounding forest, especially during the rainy season, the women will go and buy it at the local market. Increasing demand relative to supply is now causing the price of wood to increase. In the village of Gobé, women spend about 500 CFA (approximately $1.30) on wood to parboil approximately 75 kg of un-milled rice. In response to this situation the women will sometimes use palm nuts and various wastes, such as old sandals, to augment their fuel supply. This has not only an impact on the environment but also on the personal health of the users. The improved technologies could decrease the need of spending on wood by reducing its needs. (see Cost Analysis)

- Expending the market

Improving the rice quality by improving the parboiling equipment could allow the women to stay competitive with the importing rice from the Asian countries. The women claimed that the uneven parboiling of the rice implies that they spend lots of time on sorting to get good quality rice (good color and unbroken). Moreover, it is whished that the women could be able to produce more rice in one parboiling.

- Women Empowerment

Empower women is one of the millennium development goals to eradicate poverty around the world. By increasing the efficiency of the process it has been seen that they could produce at lower cost. By creating briquettes with the rice residues, women will have the opportunity to raise extra money by selling them to the market. Advantages of using a low-pressure briquetting method include relatively low capital costs as well as low operating costs. Such project within the women can reinforce their organisational skills, encourage stronger management aptitudes, promote cooperative spirit and lead to overall the women emancipate.

- Increasing available time

During our visit to the village the women clearly expressed that it was more and more difficult to get wood and that an important fraction of their time was spend to gather wood. They also said that they had to walk further and further to find wood. However, the milling facility is located in the village. Therefore, the by-product is available close to their working place and this represents some available time that could be dedicated to briquette fabrication. The briquette production rate is evaluated at about 250 briquettes an hour. It is also suitable that the stove be durable and easy to repair to reduce the rebuilding needs. The improved parboiling equipment would also be designs to be easy to manoeuvrable so only one or two women are needed for that step. In the end, the women would probably be saving some time that could be potentially used for sending more girls to school.

- Developing the expertise of local artisans

One of the main objectives of that project was to build new technologies that were simple, fast to operate, cheap and easy to build. The materials use to build the press, the stove and parboiling equipment were chosen because of their availability and were build in collaboration with local artisans to ensure that they would be able to reproduce them. This is an occasion to develop their present ability and to earn additional money.

16. Design Implementation

Preliminary introduction of the technology in one village has been conducted for the three main designs that make up the solution to their everyday problems. In the village of Gobé, a cooperative of fifteen women in charge of the parboiling activities were present for the test on the new system and had a chance to give their comments on this one.

A new stove was built on the middle of the village with the clay from this village and with herbs found nearby. The women observed that the stove had fewer cracks after the drying due to the organic matter. They have also notice a reduction in smoke and better control of it. That design was easy to implement since the women were used to work with the clay material. The technicality was low and the cost was nil. The time required for the construction of the stove was not substantially higher than for the traditional method.

For the new parboiling equipment, the maneuverability did not cause any problem for the women. However, women perceived the insert as quite small. They thought that a bigger capacity would be more time-efficient. Thus, it was hard to let the women understand the advantage of this new insert; time reduction seems to be the single most important criteria for them (the one they understood and could monitor the best). Since there was no time reduction in the parboiling process and there was a capacity reduction, the prototype was seen as less efficient then the currently-used one. The observed reactions seemed to tell they did not understand how an insert that is totally in the cauldron could work better than theirs. For example, the women were trying to find a smaller cauldron so that the new insert could stick out of the cauldron like the currently-used one. Those reactions did not seem strong or resistant and they were just trying to help out as much as they could. More education about efficiency of wood use (why wood consumption is more important to consider than time to parboil) and utilization of the prototype would help ameliorate the perception the women have of this prototype.

As for the alternative fuel, the press was completely dismantled and rebuilt in the village. Overall, the use of husk/bran material as an alternative fuel was a new idea that was readily accepted by the women since they are use as fuel in a similar way than wood. Also, one of their first impressions when seeing the briquettes was that this could potentially be an additional source of income by selling them to the market. After about 5 or 6 compression cycle, the women showed remarkable interest in learning how to operate the press. It was a very encouraging sign to see they easily understood the principle and were able to produce good briquettes in a short period of time. This is a good authentication of the simplicity of design and ease of operation of the press which is promising for future village implementation. Applying a downward force on a lever was also instinctive since the water pumps in the village are working operated with the same principle. Altogether, the women presented an optimistic attitude toward briquette fabrication.

The village demonstration of the press and its use by the women served to identify different issues still to be overcome regarding the press's design for future implementation. Those ameliorations were discussed in section 13.4.

In the end, the local NGOs should be put in charge of assessing who will be the future of the projects and its different users. The potential briquette producer and press owner in the village can be diverse social groups or individuals within the villages. The stove could be used for cooking and for parboiling. All of this needs to be decided upon by someone that knows very well the social context and the hierarchy of individuals in the village of implementation. This is why the technology is to be distributed and explained to local NGOs before any implementation can happen.

17. Conclusion

In conclusion, this design project is part of larger international development project conducted between McGill University and the Africa Rice Center. It is an opportunity for engineers to help the population in developing countries by sharing their knowledge with the communities in need. This is a chance for concrete action towards international cooperation. The present project targets more specifically food security issues in West Africa. In this mind set, it is wanted that the designs answer to some of the challenges the women are presently facing in their every day work related to post-harvesting activities, more precisely during parboiling activities. This rice processing method presents important gaps that could be improve to become more adequate and efficient. A more efficient parboiling system would require 1) an improved stove which increase the heat transfer to the cauldron and decreases the heat dissipation 2) a better insert that would be cheaper, smaller and that would decrease the steam losses and convective heat losses and 3) an alternative energy source to decrease the wood consumption and transform the rice husks and bran into a new resource.

This pilot project had as main objective to increase the efficiency of the post harvesting activities in West Africa. By improving the insert, the steam loss was reduced and the cost was minimized. Moreover, the new modified stove has shown good results as controlling the unhealthy smoke away from the user. Together with the alternative fuel development, the new stove has shown the potential to reduce the stress on the environment due to the activity of rice parboiling. Furthermore, these designs have shown positive impact on reducing the financial pressure on the women by reducing the overall cost of that practice over a reasonable period. The work conducted with the Africa Rice and with the generous help of the women's coop of Gobé seems to be promising for further development and implementation. It is desired that the in the end, the designs will be well documented enough to be passed on to local NGO in Benin in order to implement the technical solutions at a village scale.

18. References

1) ADRAO. 2005. *Test de performance de nouveux dispositifs d'étuvage de riz dans les zones de Glazoué, de Dassa et de Ouèssè.* http://www.warda.org/workshop/aw2005/contents.htm.

2) Africa Rice Center. 2009. *Strategic Plan*. from: http://www.warda.org/warda/splan.asp [Accessed November 15th, 2009]

3) Ahiduzzaman, M. 2007. *Rice Husk Energy Technologies in Bangladesh.* Agricultural Engineering International. Vol 9. 10 pp.

4) Ballard-Termeer G., Jawurek H. H., 1996. Comparison of Five Rural, Wood-Burning Cooking Devices: Efficiencies and Emissions. Biomass and Energy, Vol. 11, No 5, pp.419-430. Johannesburg, South Africa.

5) Bergqvist, M., Wardh s., Das, A. & Ahlgren, E. 2008. *A techno-economic assessment of rive husk-based power generation in the Mekong River Delta of Vietnam.* International Journal of Energy Research. Vol. 32. 1136 – 1150 pp.

6) Çengel, Y.A., Boles, M.A. 2006. *Thermodynamic: An Engineering Approach, Fifth Edition*. McGraw-Hill. 988p.

7) Chin Chin, O. & Siddiqui, K. 2000. *Characteristics of some biomass briquettes prepared under modest die pressures.* Biomass and Bioenergy. Vol. 18. 223 - 228 pp.

8) Chindaprasirt, P., Jaturapitakkul, C. & Rattanasak, U. 2009. *Influence of finesse of rice husk ash and additives on the properties of lightweight aggregate.* Fuel. Vol. 88. 158 -162 pp.

9) Consultant Journal. 2006. *Consulting fee rates | Consultant fees*. from http://www.consultantjournal.com/blog/setting-consulting-fee-rates [Accessed November 15th 2009]

10) Dagan. A. 2006. *Analyse des déterminants socio organisationnels et institutionnels de l'adoption du dispositif amélioré d'étuvage de riz dans la commune de Djougou*. Thèse d'Ingénieur Agronome. 78 pp.

11) DAT - Délégation à l'Aménagement du Territoire. 2007. *Les disparités spatiales au Bénin: États des lieux et analyses.* Benin. 1 – 47 pp.

12) Faborode, M. 1989. *Moisture Effects in the Compaction of Fibrous Agricultural Residues.* Biological Wastes. Vol 28. 61-71 pp.

13) Faborode, M. & O'Callaghan. 1987. *Optimizing the Compression/Briquetting of Fibrous Agricultural Materials.* Agricultural Engineering. Vol 38. 245 – 262 pp.

14) FAO Food Outlook. 2006. *Global Market Analysis No.2. FAO Corporate Document.* http://www.fao.org/docrep/009/j8126e/j8126e00.htm. [Accessed on May 25th 2009]

15) Genieva, S.D., Turmanova, S. Ch., Dimitrova A.S. & L.T. Vlaev. 2008. *Characterization of Rice Husks and The Products of Its Thermal Degradation in Air or Nitrogen Atmosphere.* Journal of Thermal Analysis and Calorimetry. Vol. 93. 387-396 pp.

16) Ghani, W., Alias, A.B., Savory, R.M. & Cliffe K.R. 2009. *Co-combustion of agricultural residues with coal in a fluidised bed combustor.* Waste Management. Vol 29. 767-773 pp.

17) Guerrero, M., Pilar Ruiz, M., Millera, A., Alzueta, M. & Bilbao, R. 2008. *Characterization of Biomass Chars Formed under Different Devolatilization Conditions: Differences between Rice Husk and Eucalyptus*. Energy and Fuels. Vol 22. 1275-1284 pp.

18) Hedon. 2008. *The improved cooking stove*. http://www.hedon.info/improvedcookstove. [Accessed June 15th 2009]. Last edited on 11th September 2008. Version 18

19) Houssou, P. 2005. *Development and test of improved parboiling equipment for paddy rice in Benin*, INRAB/PTAA, Porto-Novo, Benin, 5p.

20) Houssou, P. & Amonsou, E. 2004. *Development on improved parboiling equipment for paddy rice in Benin* (INRAB/PTAA), Uganda Journal of Agricultural Sciences. Vol 6. 617-620 pp.

21) Houssou. P. 2003. *Développement de l'étuvage du riz au Bénin. Savanes africaines : des espaces en mutation, des acteurs face à de nouveaux défis.* Actes du colloque, mai 2002, Garoua, Cameroun. Prasac, N'Djamena, Tchad - Cirad, Montpellier, France.

22) Incropera, F.P., DeWitt, D.P., Bergman, T.L. and Lavine, A.S. 2007. F*undamentals of Heat and Mass Transfer Sixth Edition*. John Wiley & Sons. 995 p.

23) Kaliyan, N. & Morey, V. 2009. *Factors Affecting Strength and Durability of Densified Biomass Products. Biomass and Bioenergy.* Vol 33. 337-359 pp.

24) Kossou, G. 2008. *Impact de l'apprentissage par video de la technique améliorée d'étuvage du riz sur les connaissances et les pratiques des femmes dans le Département des Collines,* Bénin. Faculté des Sciences Agronomiques. Université d'Abomey-Calavi. Benin.

25) Lawin, K. G. 2006. *Analyse des déterminants de l'adoption du matériel amélioré d'étuvage du riz dans la commune de Glazoué (département des Collines)*. Thèse d'Ingénieur agronome, Faculté des Sciences Agronomiques, Université d'Abomey- Calavi, Bénin.

26) Madhiyanon, T., Sathitruangsak, P. & Soponronnarit, S. 2009. *Co-combustion of rice husk with coal in a cyclonin fluidized-bed combustor.* Fuel. Vol 88. 132-138 pp.

27) Mahe Nau Haider, 2002 *Success without Subsidy: A Case Study of the Fuel-Efficient Smokeless Stoves Project of the Escorts,* Foundation in Changa Manga, Found on http://un.org.pk/undp/publications [Accessed May 23th 2009]

28) Météo Média. 2010. *Statistiques: Cotonou, Bénin* [Online]. Available: http://www.meteomedia.com/statistics/C01573/bnxx0002 [Last Accessed April 1st 2010]

29) MMEE & MDEF. 2006. *Stratégies pour la fourniture d'énergie nécessaire pour l'atteinte des OMD au Bénin.* Final version. Benin.

30) Prasad, C. S., Maiti, K. & Venugopal, R. 2001. *Effect of Rice Husk Ash in Whiteware composition*. Ceramics International. Vol 27. 629-639 pp.

31) Réseau des Ingénieurs du Québec. 2009. *Enquête sur la rémunération 2009*. from http://www.reseauiq.qc.ca/fr/carriere/remuneration/enquete_remuneration2009.html [Accessed November 15th, 2009]

32) Russell, A. 1997. *Briquetting agricultural residues*. Boiling Point. Vol 39.

33) Sharma, S. K., Sethi B. P. S. and Chopra, S. 1990. *Thermal Performance of the "Rohini"—an Improved Wood Cookstove.* Energy Convers. Mgmt Vol. 30, No. 4, pp. 409-419.

34) Singh, D. 1985. *Mechanical and Combustion Characteristics of Paddy Husk Briquettes.* Agricultural Wastes. Vol 13. 189-196 pp.

35) Skrifvars, B., Yrjas, P., Kinni, J., Siefen, P. & Hupa, M. 2005. *The Fouling Behavior of Rice Husk Ash in a Fluidized-Bed Combustion. 1. Fuel Characteristics.* Vol. 19. 1503-1511 pp.

36) Sreenarayanan, V., Chattopadhyay, K., & Rao, K. 1985. *Dielectric Propertires pf Rice Bran.* Journal of Food Processing Enginnering. Vol. 8. Issue 4. 231-242 pp.

37) *The Engineering Toolbox. 2005. Overall Heat Transfer Coefficients for some common Fluids and Heat Exchanger Surfaces [Online]. Available: http://www.engineeringtoolbox.com/overall-heat-transfer-coefficients-d_284.html [Accessed January 12th 2010].*

38) Witt M., Weyer K., Manning D., 2006. Designing a Clean-Burning, High-Efficiency, Dung-Burning Stove: Lessons in cooking with cow patties. Aprovecho Research Center, Creswell, Oregon

39) WARDA. 2005. *Cashing in with parboiled rice.* Video. Benin.

40) Weisstein, Eric W. "Conical Frustum." From *MathWorld*--A Wolfram Web Resource. http://mathworld.wolfram.com/ConicalFrustum.html [Accessed November 14th, 2009]

41) Zossou, E. 2008. *Innovations organisationelles, méthodologiques et technologiques déclenchées par la vidéo éducative: cas du processus amélioré d'étuvage du riz au centre du Bénin.* Maitrise de DEA. Faculté des Sciences Agronomiques, Université d'Abomey-Calavi. Benin.

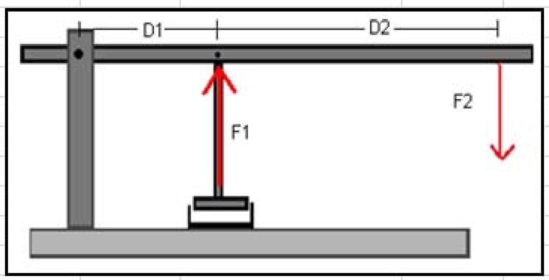
Appendix 1: Calculations for the Briquetting Press Experimental Design

Comparison of the two Mock-ups Compressive Forces:

<u>1) Single-lever Design:</u>

$$F_1 = F_2 * (D_1 + D_2) / D_1 = 0.5 \text{ kN} * 1.3 \text{ m} / 0.3 \text{ m} = 2.16 \text{ kN}$$

	A	B	C	D	E	F	G	H	I	J	K
1	**ONE SUPPORT**										
2	**Force calculations**						**Arc displacements**				
3											
4	D1 = Distance from fulcrum to piston (m) :			0,3			L2 = height of arc lenght at application point =				1,00
5	D2 = Distance from piston to force application (m) :				1		L1 = height of arc lenght of piston joint =				0,23
6											
7	F2 = Downard application force (N) :			500							
8											
9	Lever's law: F1*D1 = F2*(D1 + D2)										
10											
11	F1 = Piston compressive force (N) :			2166,67							



<u>2) Double-lever Design:</u>

Using same effective lever length as single-lever design:

Second lever:

$$F_2 = F_3 * (D_4 + D_5) / D_4 = 0.5 \text{ kN} *.5 \text{ m} / 0.1 \text{ m} = 2.5 \text{ kN}$$

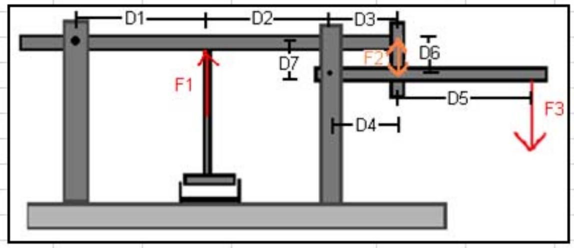
Main lever:

$$F_1 = F_2 * (D_2 + D_3 + D_1) / D_1 = 2.5 \text{ kN} * (0.5 + 0.1 + 0.3) / 0.30 \text{ m} = 7.5 \text{ kN}$$

Double-lever mock-up produces a force 3.5 times bigger than the single-lever Design:

$$7.5 \text{ kN} / 2.2 \text{ kN} = 3.5$$

	A–C	D	E	F	H–L
25	**TWO SUPPORTS**	**Force calculations – two arms horizontal**			
26					
27	*FIRST LEVER:*				
28	D1 = Distance from fulcrum to piston (m):			0,30	
29	D2 = Distance from piston to 2nd fulcrum (m):			0,50	
30	D3 = Distance from 2nd fulcrum to end of first lever (m):			0,10	
31					
32	*SECOND LEVER:*				
33	D4 = Distance from 2nd fulcrum to joint (m):		0,10		
34	D5 = Distance from joint to application force (m):		0,4		
35					
36	D7 = Vertical distance between two horizontal levers (m):			0,55	
37					Lever's Law on second arm: D4 * F2y = (D4 + D5) * F3
38	F2y = vertical component of joint lever force (N) =		2500,00		
39	F2x = horizontal component of joint lever force (N) =		0,00		
40					
41	cos (a) = (D4 - D3) / D6 (Degrees) =	0,0			
42	a = invcos((D4 - D3)/D6) (Degrees) =	90,0			
43					
44	F3y = Vertical force of application at end of second lever (N):			500,00	Lever's law on first arm: D1*F1 = (D1 + D2 + D3) * F2y
45					
46	F1 = Piston compressive force (N) =	7500,00			
47					
48	**Arc displacements**				
49					
50	L3 = height of arc lenght at application point =		1,00		
51	L2 = height of arc lenght at joint point on 2nd arm =		0,2		
52					
53	L1 = height of arc at piston joint =	0,06667			



Length of the piston's vertical displacement:

<u>1) Single-lever Design:</u>

$L_1 = L_2 * D_1 / (D_2 + D_1)$

$= 1.0\ m * 0.3\ m / 1.3\ m = 0.23\ m$

<u>2) Double-lever Design:</u>

$L_2 = L_3 * D_4 / (D_4 + D_5)$

$= 1.0\ m * 0.1\ m / 0.5\ m = 0.2\ m$

$L_1 = L_2 * D_1 / (D_1 + D_2 + D_3)$

$= 0.2\ m * 0.3\ m / 0.9\ m = 0.067\ m$

Ratio of the piston amplitude over the power stroke amplitude decrease by a factor of 3.5:

0.23 m / 0.067 m = 3.5

Surface area of briquette:

Circular:

$A = \pi * r^2 = \pi * (0.04\ m)^2 = 5.0 \times 10^{-3}\ m^2$

Rectangular:

$A = W \times L = 0.05\ m \times 0.10\ m = 5.0 \times 10^{-3}\ m^2$

Volume of briquette:

With h = 2.5 cm = 0.025 m

$V = A \times h = 5.0 \times 10^{-3}\ m^2 \times 0.025\ m = 125.0 \times 10^{-3}\ m^3$

Pressure applied on briquette:

With force in position 1 = 10 kN and force in position 2 = 5.5 kN

$P_1 = F / A = 10\ kN / 5.0 \times 10^{-3} = 2\ 000.0\ kN/m^2$

$P_2 = F / A = 5.5\ kN / 5.0 \times 10^{-3} = 1\ 100.0\ kN/m^2$

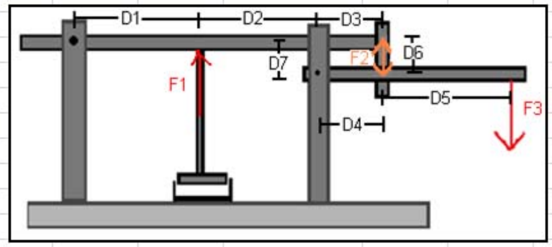
Force multiplication ratio:

Ratio = Piston compressive force / Applied force

= 5.5 kN / 0.5 kN = 11

Compressive force in final position:

	A–C	D	E	F	H–L
25	**TWO SUPPORTS**	**Force calculations – two arms horizontal**			
26					
27	*FIRST LEVER:*				
28	D1 = Distance from fulcrum to piston (m):			0,18	
29	D2 = Distance from piston to 2nd fulcrum (m):			0,74	
30	D3 = Distance from 2nd fulcrum to end of first lever (m):			0,27	
31					
32	*SECOND LEVER:*				
33	D4 = Distance from 2nd fulcrum to joint (m):		0,27		
34	D5 = Distance from joint to application force (m):		0,89		
35					
36	D7 = Vertical distance between two horizontal levers (m):			0,55	
37					Lever's Law on second arm: D4 * F2y = (D4 + D5) * F3
38	F2y = vertical component of joint lever force (N) =		2148,15		
39	F2x = horizontal component of joint lever force (N) =		0,00		
40					
41	cos (a) = (D4 - D3) / D6 (Degrees) =	0,0			
42	a = invcos((D4 - D3)/D6) (Degrees) =	90,0			
43					
44	F3y = Vertical force of application at end of second lever (N):			500,00	Lever's law on first arm: D1*F1 = (D1 + D2 + D3) * F2y
45					
46	F1 = Piston compressive force (N) =	14201,65			
47					
48	**Arc displacements**				
49					
50	L2 = height of arc lenght at application point =		1,00		
51	L1 = height of arc lenght at joint point on 2nd arm =		0,23276		
52					
53	A3 = height of arc at piston joint =	0,04554			
54					



Dry basis energy content :

Dry Basis Energy Content = Energy Content * 100% / % Dry Matter

= 381.97 kcal/100g * 100% / 80.42%

= 479.97 kcal/100g

Briquette density :

Density = Mass / Volume

= 70.282 g / 140.74 cm^3 = 0.5 g/cm^3

Husk and bran proportions in husk/bran mixture:

Using two equations and two unknowns

1) Rice husk % + Rice bran % = 100%

   X + Y= 100%

Using respective dry basis energy content of rice husk, rice bran and husk/bran mix

2) 399.59 kcal/100g * X + 467.83 kcal/100g * Y = 426.47 kcal/100g * 100%

   399.59 kcal/100g * (100 – Y) + 467.83 kcal/100g * Y = 42 647 kcal/100g

   Rice bran : Y = 39.4%

   Rice husk : X = 100 – Y = 60.6

Husk/Bran mixture density :

Lower range density:

$0.04\ g/cm^3 * 60.6\% + 0.3\ g/cm^3 * 39.4\% = Density * 100\%$

Upper range density:

$0.2\ g/cm^3 * 60.6\% + 0.4\ g/cm^3 * 39.4\% = Density * 100\%$

Density Range = 0.14 g to 0.28 g/cm^3

Amplitude of compression:

Amplitude = Relaxed density of briquette / bulk density of husk/bran

$= 0.59\ g/cm^3 / 0.28\ g/cm^3$

= 2.1 (at the lowest)

$= 0.59\ g/cm^3 / 0.14\ g/cm^3$

= 4.2 (at the highest)

Effective length of second lever and compressive force with a 45 degree angle:

Cos Θ = effective length / real length

Opp = cos (45˚) * 1.16 m

= 0.82 m

Compressive force in second lever = 0.82 m * 0.7 kN / 0.27 m = 2.12 kN

Force in first lever = 2.12 kN * 1.19 m / 0.18 m =14.0 kN

Appendix 2: Test on Stove Prototypes

Name	Test	Start	Time required (min)	Efficiency (%)	Observations
Gobé	Test 1 (July 1st 2009) Not windy (26.3 C)	Cold (1)	30	7	Stove dry, Wood dry Fire started with hot coal
		Warm (3)	11	2	Stove dry, Wood dry Fire started with hot coal
	Test 2 (July 29th 2009) Not windy (26.2 C)	Cold (43)	22	15	Stove dry, Wood dry Big logs, big fire 1st fire of the day, started with hot coal (mass negligible)
		Warm (44)	23	13	Stove dry, Wood dry Big logs, big fire Started with hot coal (mass negligible)
Gbaffo	Test 1 (July 2nd 2009) Not windy (27.2 C)	Cold (4)	39	13	Stove dry wood wet Fire started with palm leftover* 1st fire of the day, very hard to start
		Warm (5)	17	17	Stove dry wood dry Fire started with hot coal
Stove 5 Mix	Test 2 (July 20th 2009) very windy (27.5 C)	Cold (10)	37	9	Stove wet wood not too dry, small logs 1st use of the stove ever started with hot coal
		Warm (11)	19	7	Stove wet wood not too dry, small logs started with hot coal

Stove 5 mix	Test 2 (July 22h 2009) windy-rainy (27.6 C)	Cold (25)	23	10	Stove humid wood dry, small logs started with hot char (mass negligible)
		Warm (26)	14.2	7	Stove humid wood dry, small logs started with hot char
	Test (July 24th 2009) very windy (28.8 C)	Cold (39)	16	11	Stove more dry wood dry, small logs started with hot char
		Warm (40)	21	11	Stove more dry wood dry, small logs started with hot char small fire
Stove 6 Herbs	Test 2 (July 20th 2009) very windy (27.5 C)	Cold (6)	47	7	Stove wet wood not too dry, small logs 1st fire of the day, 1st use of the stove ever started with palm leftovers
		Warm (7)	20	18	Stove wet wood not too dry, small logs 2nd use of the stove started with hot coal (2.4kg of water boiled)
	Test 2 (July 21th 2009) windy (26.5 C)	Cold (19)	19	7	Stove still humid wood dry, small logs started with hot coal
		Warm (20)	18.4	7	Stove still humid wood dry, small logs started with hot coal

Stove 6 Herbs	Test 2 (July 23th 2009) windy (27.8 C)	Cold (31)	33	7	Stove more dry wood dry, small logs 1st fire of the day started with palm leftover (hard to start)
		Warm (32)	15	8	Stove more dry wood dry, small logs started with hot coal
Stove 7 Rice husk	Test 2 (July 20th 2009) very windy (27.5 C)	Cold (8)	29	5	Stove wet wood not too dry, small logs 1st use of the stove ever started with hot coal
		Warm (9)	19	11	Stove wet wood not too dry, small logs, big flames 1st use of the stove ever started with hot coal
	Test 2 (July 21th 2009) windy (27.9 C)	Cold (21)	23.5	9	Stove humid wood not too dry, small logs 1st fire of the afternoon started with palm leftovers (no char to start)
		Warm (22)	14.53	10	Stove humid wood not too dry, small logs started with hot char
	Test 2 (July 23th 2009) very windy (28.8 C)	Cold (33)	28.21	8	Stove more dry wood dry, small logs started with hot char (small fire)
		Warm (34)	14.35	9	Stove more dry wood dry, small logs started with hot char

Stove 8 Fitting	Test 2 (July 20th 2009) windy (27.5 C)	Cold (12)	17.2	7	Stove still wet wood dry, small logs 1 use of the stove ever started with hot coal (lots)
		Warm (13)	23	11	Stove still wet (wet/dry visual line at about 10cm from the top of the stove) wood dry, small logs started with hot coal
	Test 2 (July 22th 2009) windy (28.2 C)	Cold (29)	26.3	7	Stove still humid wood humid hard to start started with hot char
		Warm (30)	21.42	11	Stove still humid wood humid started with hot char
	Test (July 24th 2009) windy (28.8)	Cold (41)	16	16	Stove more dry wood humid (water escape) started with hot char (hard to start)
		Warm (42)	14	10	Stove more dry wood humid started with hot char
Stove 9 Chicken wire	Test 2 (July 20th 2009) windy (27.5 C)	Cold (14)	17.2	9	Stove still wet (less than the others) wood dry, small logs 1 use of the stove ever started with hot coal
		Warm (15)	13	7	Stove still wet wood dry, small logs started with hot coal

Stove 9 Chicken wire	Test 2 (July 20th 2009) windy (27.5 C)	Cold (23)	13.36	8	Stove dry wood dry, small logs started with hot char
		Warm (24)	12	10	Stove dry wood dry, small logs started with hot char
	Test (July 24th 2009) windy (28.8 C)	Cold (37)	28	11	Stove more dry wood dry, small logs 1st fire of the day started with palm leftover (no char)
		Warm (38)	13	10	Stove more dry wood dry, small logs started with hot char
Stove 10 Grate	Test 2 (July 21th 2009) not windy (26.5 C)	Cold (16)	31	8	Stove still wet wood humid, small logs 1 use of the stove ever, 1st fire of the day (hard to start) started with palm leftovers
		Warm (17)	20.54	8	Stove still wet wood humid, small logs started with hot coal
	Test 2 (July 22th 2009) windy-rainy (28.2 C)	Cold (27)	23	8	Stove humid wood dry, small logs started with palm leftover (hard to start, small fire)
		Warm (28)	14.53	7	Stove humid wood dry, small logs started with hot coal

Stove 10 Grate	Test 2 (July 23th 2009) windy (28.8 C)	Cold (35)	23	12	Stove more dry wood dry, small logs started with hot coal (hard to start) small fire
		Warm (36)	16	12	Stove more dry wood dry, small logs started with hot coal
New in Gobé	Test (July 29th 2009) not windy (26.2 C)	Cold (45)	51	15	Stove very wet (only 3 cloudy/rainy days of drying) wood dry, big logs 1st fire ever, started with hot coal and straw (mass negligible)
		Warm (46)	19	8	Stove very wet wood dry, big logs 2nd fire ever, started with hot coal
		Warm (47)	19	9	Stove still wet (wet/dry visual line at about 10cm from the top of the stove) wood dry, big logs 3rd fire ever, started with hot coal

* palm leftover: after producing palm oil with the nuts the leftover is dried and use as fire starter because of their flammable properties due to the oil that cannot be extracted manually.

Appendix 3: Parboiling Test on the new Insert

FIRST parboiling - July 23, 2009		
General information	Ambient air temperature	27.8°C
	Stove Type	Husk Mixture (ref to Project 1)
	Warm or Cold start?	Warm
Rice	Variety	Nerica 1
	Mass (wetted paddy)	33.1 kg (38 - 4.9)
Water	Initial Volume	9 L
	Water left after parboiling?	Yes
Cover	Type of Lid:	Original Cauldron's Lid
	Use of Cloth on top of rice?	No
	Use of Cloth at Circumference?	No
	Use of Rocks/Wood as weights?	No

Observations

0 minute: the lid is not totally fitted to the cauldron. There are some gaps between the two.

9 minutes: the first steam losses were observed. The fire is running good.

12 minutes: steam escapes continuously from the cauldron's rim.

Great quantities of steam are lost.

22 minutes: first verification of the paddy rice. The grains are opened on top.

23 minutes: the insert is lifted from the cauldron.

Analysis of the rice layers

A first layer (12 cm deep) was completely parboiled. The rice in the middle of this layer was parboiled as much as the sides.

A second layer was not well parboiled. The grains were mostly unopened and the color had not changed. The middle of this layer was not parboiled and it was cold.

The bottom of the insert was not parboiled and it was more humid then the second layer.

Subsequent modifications after first parboiling test

After the results of the first parboiling, some changes were made to try to fix the problems. The parboiling process had obviously occurred differently than with the currently-used insert. The rice had been parboiled from the top of the insert towards the bottom. Very little parboiling occurred from the perforated sides to the middle. Small perforations which would not let the vapor particles penetrate the rice mass could explain this phenomena. Therefore, the insert was brought to the WARDA metal shop where the technician opened the wholes with a 2.5mm drill bit. 2.5 mm was quite bigger than the previous 1mm and the rice grains we were using could not pass through it easily.

After this first test, the cauldron's lid did not look like it was that fitted to the cauldron. Therefore, a lid that could fit properly on any cauldron number 25 was designed. It is basic and simple, but fits better. The lid consist of a circular metal sheet (0.5 mm thick) that has be cut each 10 cm and folded to follow the cauldron's rim. This lid was then used on the village and for further testing at WARDA.

SECOND parboiling - July 24, 2009 (13h37)		
General information	Ambient air temperature	27.8^{o}C
	Stove Type	Fitting (ref to Project 1)
	Warm or Cold start?	Cold *
Rice	Variety	Nerica 1
	Mass (wetted paddy)	27.2 - 4.9 = 22.3 kg
Water	Initial Volume	8 L
	Water left after parboiling?	Yes
Cover	Type of Lid:	Home Made Lid
	Use of Cloth on top of rice?	Yes
	Use of Cloth at Circumference?	No
	Use of Rocks/Wood as weights?	No

**The stove has had 1 hour to cool down. It was not warm.
Observations 0 minutes: There is a lot of smoke coming out of the stove. 6 minutes: first steam losses observed 9 minutes 40: a lot more steam coming out. Almost as much as with the cauldron's lid. There are drops of water condensing on the folded part of the lid. 16 minutes 50: part from the stove falls. (The entrance top part) 30 minutes: even more steam coming out then with the cauldron's lid. The lid is not well sitting on the cauldron. Some parts of the lid were lifted from the cauldron's rim because of the distorted metal used to do the lid. More steam is coming out of those places than anywhere else around the cauldron. 40 minutes: the insert is lifted.
Analysis of the rice layers The whole batch is well parboiled. The first layer (13 holes deep) was completely parboiled. There was no difference between the middle and the side rice. After that, there was a minor difference in the condition of rice, but everything was parboiled. The bottom layer (2 last holes) was hot, but the grains were less opened and were more humid.

Subsequent modifications after second parboiling test

No major modifications were made. Only the lid was improved with wood pieces acting as weights and cloth to stop the steam from escaping.

THIRD Parboiling - July 24, 2009		
General information	Ambient air temperature	27.8^{o}C
	Stove Type	Fitting (ref to Project 1)
	Warm or Cold start?	Warm
Rice	Variety	Nerica 1
	Mass (wetted paddy)	26 - 4.9 = 21.1 kg
Water	Initial Volume	8 L *

	Water left after parboiling?	Yes
Cover	Type of Lid:	Home Made Lid
	Use of Cloth on top of rice?	Yes
	Use of Cloth at Circumference?	Yes
	Use of Rocks/Wood as weights?	Yes
* Water directly was added to the remaining water after last trial. Water was therefore warm.		

Observations

8 minute 10: first sign of steam losses (at the attachment of the cloth)

11 minutes 39 : a lot more steam then before, but less than last trial

16 minutes: steam is now coming out all the side of the cauldron

20 minutes: first verification. I drop the thermometer in the water. It was decided that the rice should be taken out even if parboiling was not complete to save the thermometer from boiling water.

Analysis of the rice layers

The first layer (down to the 7e row of holes) was well parboiled. Deeper, the middle was cold and un-parboiled. The rice that was not parboiled was put back on the fire for 15 minutes to finish the process. Very little water was left.

Subsequent modification after third parboiling test

The monitoring of the degree at which the rice was parboiled is difficult. Most times, the rice is not parboiled in the center and at the bottom of the insert. There is a need for a way to monitor the parboiling process. A big metallic spoon was bought to allow the user to dig in the paddy rice and access if the rice in the center bottom part is parboiled.

FOURTH Parboiling - July 29, 2009 *		
General information	Ambient air temperature	26.2oC
	Stove Type	Gobé (old) (ref to Project 1)
	Warm or Cold start?	Warm
Rice	Variety	Nerica 1
	Mass (wetted paddy)	26.6 - 4.9 = 21.7 kg
Water	Initial Volume	8 L **
	Water left after parboiling?	Yes
Cover	Type of Lid:	Home Made Lid
	Use of Cloth on top of rice?	Yes
	Use of Cloth at Circumference?	No
	Use of Rocks/Wood as weights?	Yes
* In Gobé. New insert. ** The water was boiling when the insert was finally put in the cauldron.		
Observations 0 minutes: the jute bag prevents the lid from being fitted even with the weights. 6 minutes 50: a little more steam coming out then with the old insert 24 minutes: first verification ... not ready. Fire is dead. Utilization of the big spoon to check if the rice is parboiled in the center. It doesn't necessarily work very well, but it helps a little bit. 30 minutes: second verification. Insert is lifted from cauldron.		
Analysis of the rice layers The first layer is parboiled until the 14th row of holes. The last few centimetres are not parboiled, but are warm.		

Parboiling with the currently used insert (in the village) - July 29, 2009		
General information	Ambient air temperature	26.2oC
	Stove Type	Gobé (old) (ref to Project 1)
	Warm or Cold start?	Warm
Rice	Variety	Nerica 1
	Mass (wetted paddy)	(24.4 + 13.4)= 37.8 kg
Water	Initial Volume	More than 10 L *
	Water left after parboiling?	Yes
Cover	Type of Lid:	Currently Used Insert's Lid
	Use of Cloth on top of rice?	Yes
	Use of Cloth at Circumference?	Yes (between insert/cauldron)
	Use of Rocks/Wood as weights?	Yes
*The water was boiling when the insert was finally put in the cauldron.		

Observations

0 minutes: the cauldron (with water) is put on the fire

7 minutes: steam is coming out of the cauldron, but the insert is not yet in. (the women are washing the rice...)

10 minutes 15: the first part of the rice is put in the insert (24.4 kg)

13 minutes 08: the second and last part of the rice is put in the insert (13.4 kg)

14 minutes: jute bag and lid are installed

15 minutes: fire is running good

17 minutes: steam escaping from the top opening

28 minutes 40: wood is burning outside of the stove

30 minutes: steam escaping in great quantities from all the side.

33 minutes 50: first verification of the rice. Steam escapes when verification occurs.

40 minutes 22: second verification of rice

41 minutes: rice is scooped out of the insert

Analysis of the rice layers

Everything is parboiled.

Appendix 4: Convective and Latent Heat Losses

Convective heat losses

Assumptions:

- Both inserts are made of the same material. The heat transfer coefficient of that material with the air is 14,2 W/m^{2}K (mild steel and air from the Engineering Toolbox, 2005).
- Constant ambient temperature at the time of parboiling is 28^{o}C. (It is the average temperature for the months where parboiling occurs [December to February] according to Météo Media, 2010.
- The system is at equilibrium for most of the parboiling and that the temperature of the paddy rice inside on the wall of the insert and just under the lid is approximately 75^{o}C.

The convective heat loss will then be calculated by:

$$Q_{convection} = k*A*\Delta T$$

For both systems: k = 14,2 W/m^{2}K and ΔT = (75-28) = 47^{o}C or 47 K

In the old system, there are two possible convective heat loss surfaces:

1) From the lid

$A_{lid\_old} = \pi * (d_{lid\_old}/2)^2 = \pi * (55 \text{ cm} *1 \text{ m} /100\text{cm} /2)^2 = 0{,}2376 \text{ m}^2$

$Q_{conv\_old\_lid} = k * A_{lid\_old} * \Delta T = 14{,}2 * 0{,}1736 * 47 = 158{,}6 \text{ W}$

2) From the insert's walls

(conical frustrum from: Weisstein, Eric W)

$A_{wall\_old} = \pi * (r_1+r_2) * ((r_1-r_2)^2 + h^2)^{½} = 0{,}4136 \text{ m}^2$

Where r_1 = 55 cm or 0,55 m

r_2 = 47,02 cm or 0,4702 m

h = 25,5 cm or 0,255 m

$Q_{conv\_old\_wall} = k * A_{wall\_old} * \Delta T = 14{,}2 * 0{,}4136 * 47 = 276{,}0 \text{ W}$

$Q_{conv\_old} = Q_{conv\_old\_lid} + Q_{conv\_old\_wall} = 158{,}6 + 276{,}0 = 434{,}6 \text{ W}$

In the new MRT design, there is only one possible convective heat loss surface:

1) From the lid

$A_{lid\_new} = \pi * (d_{lid\_new}/2)^2 = \pi * (47{,}02 \text{ cm} *1 \text{ m} /100\text{cm} /2)^2 = 0{,}1736 \text{ m}^2$

$Q_{conv\_new\_lid} = k * A_{lid\_new} * \Delta T = 14{,}2 * 0{,}1736 * 47 = 115{,}9 \text{ W}$

Reduction of convective heat losses = Q_{conv_old} - $Q_{conv\_new\_lid}$ = 434,6 – 115,9 = **318,7 W**

Percent reduction = 318,7/434,6 = **73,3%**

Latent heat losses

Assumptions:

- At any time in the parboiling, the pressure and steam inside the cauldron is equal between the old system and the new one.
- All openings have the same thickness.
- The distribution of steam losses is constant over the perimeter at one time.

Therefore, the amount of steam losses reduction will be directly proportional to the reduction in the perimeter of the openings.

In the old system → 2 openings:

2) between the lid and the insert at diameter d_{1old} = 55,00 cm

   $P_{1old} = \pi * d_{1old} = \pi * 55{,}00 \text{ cm} = 172{,}79 \text{ cm}$

3) between the insert and the cauldron at diameter d_{2old} = 47,02 cm

   $P_{2old} = \pi * d_{2old} = \pi * 47{,}02 \text{ cm} = 147{,}72 \text{ cm}$

Total Perimeter: $P_{old} = P_{1old} + P_{2old} = 172{,}79 \text{ cm} + 147{,}72 \text{ cm} = 320{,}51 \text{ cm}$

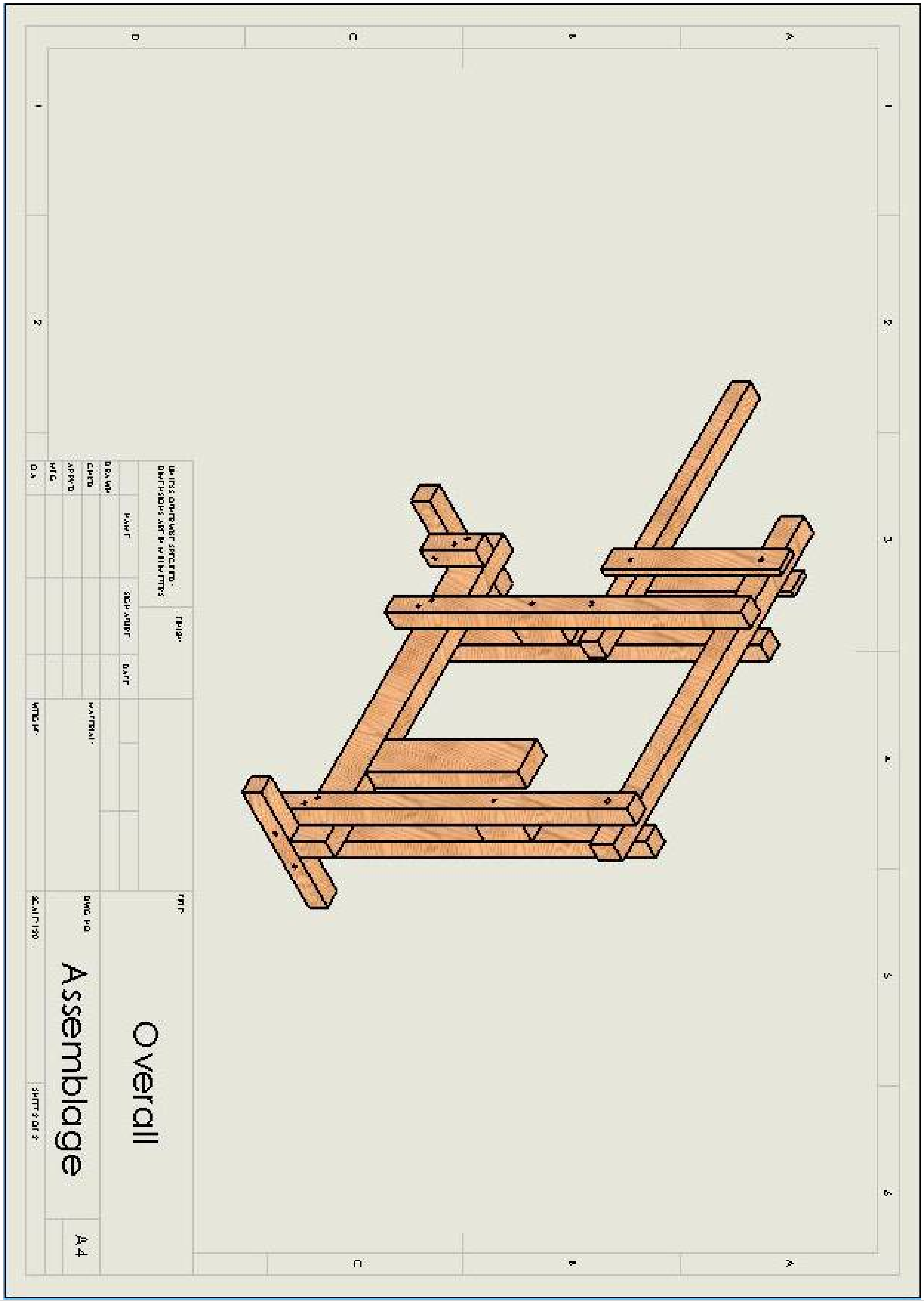
In the new MRT design → 1 opening:

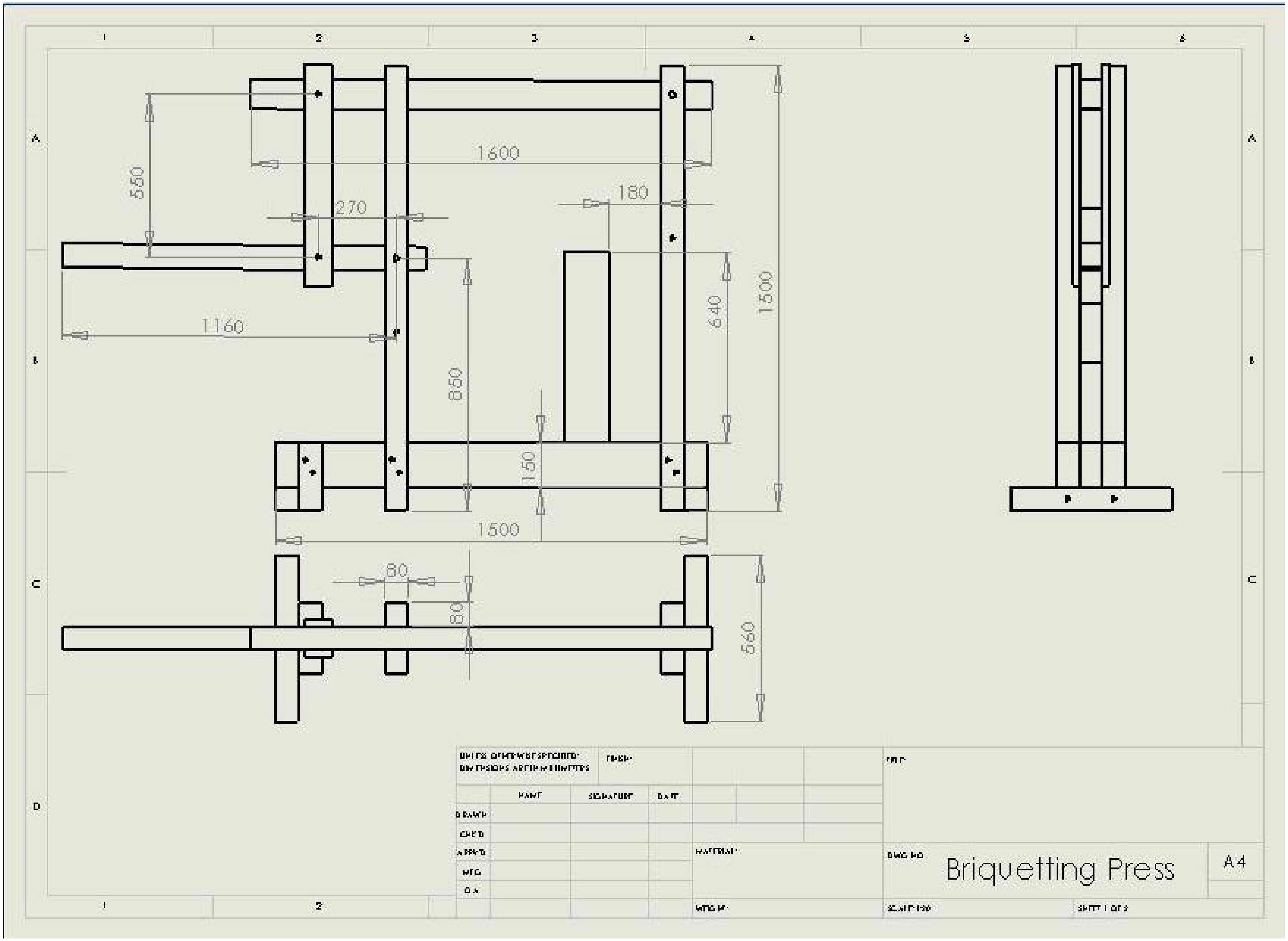
1) between the lid and the cauldron at diameter d_{new} = 47,02 cm

Total Perimeter: $P_{new} = \pi * d = \pi * 47{,}02 \text{ cm} = 147{,}72 \text{ cm}$

Reduction of latent heat losses = $(P_{old} – P_{new}) / P_{old}$ = (320,51 – 147,51)/320,51 = **54,0%**

Appendix 5: Plans of the Briquetting Press





1600
550
270
180
1160
850
640
1500
150
1500
80
80
560
Briquetting Press
A4