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BACHELOR'S THESIS

Developing Biofuels Production from Food Industry
Wastes in the Rural Area of Kenya.

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| Koulutusala Tekniikan ja liikenteen ala | |
| Koulutusohjelma Energiatekniikan koulutusohjelma | |
| Työn tekijä(t) Teijo Turpeinen | |
| Työn nimi Selvitys etanolin tuotantomahdollisuudesta ruokateollisuuden jätteestä Kenian maaseudulla. | |
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| <p>Tiivistelmä</p> <p>Tässä opinnäytetyössä selvitetään biodieselin tuotannossa tarvittavan etanolin tuotantomahdollisuutta erilaisista paikallisen ruokateollisuuden jätteistä, sokeripitoisista hedelmistä, marjoista ja hedelmämehuista. Etanoli on tarkoitus tuottaa käymisprosessilla hiivan avulla. Sopivassa hapettomassa tilassa hiiva pilkkoo hedelmissä olevan sokerin hiilidioksidiksi ja etanoliksi. Käymisprosessin jälkeen kiinteät osat erotetaan nesteestä. Erottelun jälkeen etanoli tislataan vedestä ja muusta aineesta, tarvittavaan etanolipitoisuuteen asti. Tislauksen ja väkevöinnin jälkeen etanolia voidaan käyttää biodieselin tuotantoon tai ajoneuvojen polttoaineena. Työn tavoitteena on selvittää onko etanolin tuotanto mahdollista.</p> <p>Tulokset: etanolin tuotanto on mahdollista.</p> <p>Tässä opinnäytetyössä määritetään myös erilaisten kiinteiden polttoaineiden ominaisuuksia, kuten savukaasupitoisuuden, tuhkapitoisuuden, kalorimetrinen lämpöarvon, tehollisen lämpöarvon saapumistilassa ja kosteuden. Polttoaineina ovat hiileksi muutettu croton-pähkinän kuori, briketiksi puristettu croton-pähkinän kuori, Keniasta löytyvä yleinen polttopuu, Keniasta löytyvä yleinen puuhiili.</p> <p>Työn tavoitteena on selvittää ovatko Croton brigetti ja Croton hiili turvallisempia polttoaineita kuin tyyppilliset polttoaineet.</p> <p>Tulokset: Puuhilellä on parempi tehollinen lämpöarvo saapumistilassa kuin Croton hiilellä, mutta Croton hiili tuottaa vähemmän vaarallista savukaasua kuin puuhiili. Croton brigetin ja polttopuun ominaisuudet ovat melkein identtiset.</p> | |
| Avainsanat Etanoli, Croton, Puuhiili, Polttopuu | |
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| <p>Abstract</p> <p>In this thesis the possibility of producing ethanol, from local food industry's sugary fruits, berries and fruit juices, for the production of biodiesel, is determined. This ethanol can also be used as a fuel for motor vehicles. Ethanol is supposed to be produced by fermenting the sugary crops with the presence of yeast. In suitable anaerobic conditions the yeast will convert sugar into ethanol and carbon dioxide. After the fermenting process the solid particles will be removed. After separation the ethanol will be distilled from the water and the other content, into the required alcohol content. After distillation and dehydration process this ethanol can be used in biodiesel production or as a fuel for vehicles.</p> <p>The goal of the experiment was to see if the production of ethanol is possible.</p> <p>Result: The ethanol production from sugary fruits and fruit juices is possible.</p> <p>In this thesis the attributes of different kind of solid fuels that are used in households, e.g. the gross calorific value, lower heating value, moisture, ash content and flue gas content, are defined. The fuels used are carbonized husks from croton nut, husks from croton nut that are compressed into briquettes, typical Kenyan firewood and typical Kenyan charcoal.</p> <p>The goal of the analysis was to determine if the croton husk briquette and the carbonized croton husks are safer fuels than the original fuels.</p> <p>Results: Charcoal has better lower calorific value than the Carbonized croton husk but the carbonized husks produce less dangerous flue gas than charcoal. The properties of Croton husk briquettes are almost equal to firewood.</p> | | | |
| <p>Keywords Ethanol, Croton, Charcoal, Firewood,</p> | | | |
| | | | |

Foreword

In the face of rising need for biofuels and the need to protect the global environment from climate change and pollution, the need to improve production capacity of carbon-free biofuel production is essential. Especially the need to find ways which doesn't replace farmland or rainforest as a growing area for crops that are necessary for biofuel production. Recycling, reusing and finding new uses for by-products are the key elements to reduce rare material losses and to prevent any harm done to the environment.

The biofuel industry can be a way to improve the economics of developing countries, such as Kenya, because these countries have the environment for growing suitable crops and cheap labor. As these countries develop, they will need more and more energy for industry and transportation. This energy need could be filled with renewable energies, such as solar power and biofuels. All we have to do is provide the methods and tools for these people.

I hope that the results of this research can be applied in other biofuel production factories. I hope that the quest for finding new methods for environmentally friendly fuels will continue.

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1 INTRODUCTION

The client, Horizon Business Ventures, produces plant oil from many kind of different seeds. This plant oil is then processed into biodiesel by transesterification process, which requires ethanol or methanol. Currently the client doesn't refine the plant oil into biodiesel due to high price of methanol and ethanol but rather sells the raw plant oil as it is with lower profit.

The client was looking for a cheaper alternative for high price methanol, so I proposed making the ethanol by ourselves out of fruit waste that local food industry was throwing away. So the goal of the project was to determine if ethanol can be produced from the fruit waste with fermentation method.

1.1 EMPLOYER AND FACILITIES

Horizon Business Ventures is a daughter company of Help Self Help Centre. Help Self Help Centre owns multiple companies including the food factory, which supplies the fruit waste.

The Horizon Business Ventures manufactures many different kinds of products, some of the products are made using the waste from the biodiesel process. The products include:

- Biodiesel
- Crude plant oil (Croton)
- Plant oils from different seeds
- Soil fertilizer
- Animal feed
- Bio-Drop (for skin care)
- Bio-Mist (crop spray)
- Bio-Fume (liquid soil fertilizer)
- Seed cake (for processing)
- Husks from nuts (fertilizer)

The company is committed to manufacturing products which are environmentally friendly, safe and reasonably priced. Horizon Business Ventures also run a motel, bar and restaurant in its property.

Facilities include:

- Oil factory
- Fertilizer and animal feed factory
- 3 warehouses
- Motel
- Bar and restaurant

2 INTRODUCTION TO ETHANOL PRODUCTION

Ethanol is an alcohol that has similar properties as gasoline, this makes ethanol a good contender to replace gasoline or at least an alternative fuel for blending. The densities of ethanol and gasoline are quite similar but the energy content of ethanol is about 30% lower. Since ethanol contains molecular oxygen that promotes more complete combustion, the difference in energy content does not become a major concern at low level of alcohol blends in gasoline.

Ethanol is also used as a catalyst in transesterification process, which is one process to transform crude plant oil into biodiesel.

Depending on the type and nature of feedstock, the pre-processing steps or operations may differ but there are basically three processes that are common for all three types of feedstocks: (a) fermentation of the sugars into ethanol; (b) distillation to separate the aqueous ethanol (95%) from the fermented mash; and (c) dehydration to produce anhydrous ethanol (>99.5%) suitable for blending with gasoline. In the case of starchy and cellulosic feedstocks, pretreatment through saccharification or hydrolysis is required in order to convert them to sugars that can be fermented by yeast into ethanol [Filemon.]

3 FERMENTATION

Fermentation is a series of chemical reactions that converts sugars to ethanol in the presence of suitable strain of yeast, which feed on the sugars. Ethanol and carbon dioxide are produced as the sugar (glucose) is consumed. [Filemon.]

Ethanol can be produced by the fermentation of carbohydrates from various feedstocks. The feedstocks fall under three main categories: sugar bearing feedstocks such as sugar cane and fruits, starchy feedstocks such as cassava or corn, and cellulosic feedstocks such as wood and agricultural residues such as bagasse. The production technologies for the first two types of feedstocks are fully mature and well-developed and are commercially available from various suppliers. However, the processing of cellulosic materials into ethanol using either acid or enzymatic hydrolysis is not yet fully developed commercially but is rapidly becoming technically and economically viable [Filemon.]

3.1 Sugar bearing feedstock

The production of ethanol from sugary crops is quite straightforward process: add sugary crops, yeast, water and nutrients into fermentation tank, inside the tank there should be anaerobic conditions. The only required preprocess is crushing or at least reducing the size of the crops, so the fermentation could happen faster and more completely. Ammonia or other nutrients are added to provide nutrients to the yeast and to control the pH. The fermentation process can take from 5 to 15 days depending on the yeast, temperature, pH, sugar content and nutrients.

3.2 Starchy Crops

For the production of ethanol from starchy crops e.g. corn, there are two main processes in commercial use: dry milling and wet milling. In the dry milling process the entire corn kernel is ground into flour, which is referred to as "meal." The meal is then made into slurry by adding water. Enzymes are added to the mash to convert starch to dextrose, which is a simple sugar. Ammonia is added to control the pH and to provide nutrient for the yeast, which is added later. The mixture is processed at high temperatures to reduce the bacteria levels and transferred and cooled in fermentation tanks. This is where the yeast is added and conversion from sugar to ethanol and carbon dioxide takes place [Filemon.]

The process of wet milling takes the corn grain and steeps it in a dilute combination of sulfuric acid and water for 24 to 48 hours in order to separate the grain into many components. The slurry mix then goes through a series of grinders to separate the corn germ. Corn oil is a by-product of this process and is extracted and sold. The remaining components of fiber, gluten and starch are segregated using screen, hydrochloric and centrifugal separators.

The gluten protein is dried and filtered to make a corn gluten meals co-product, which is used as a feed ingredient for poultry broilers. The steeping liquor produced is concentrated and dried with the fiber and sold as corn gluten feed to the livestock industry. The heavy steep water is also sold as a feed ingredient. The starch and remaining water can then be processed by fermenting into ethanol through a similar process as dry milling. The production of ethanol from corn using the wet mill process has become the technology of choice since it provides more product diversity and flexibility [Filemon.]

3.3 Cellulosic biomass

To produce ethanol from cellulosic feedstocks, several pre-treatment steps are necessary to convert cellulose into simple sugars that can be converted into alcohol using the conventional yeast fermentation process [Filemon.]

The first step is mechanical preparation through size reduction to make the material easier to handle and more susceptible to the subsequent pre-treatment steps. For example, agricultural residues go through a grinding process and wood goes through a chipping process to produce smaller and more uniform particle size. This is followed by acid pre-treatment. In this step, the hemicellulose fraction

of the biomass is broken down into simple sugars. A chemical reaction called hydrolysis occurs when dilute sulfuric acid is mixed with the biomass feedstock. In this hydrolysis reaction, the complex chains of sugars that make up the hemicellulose are broken, releasing simple sugars. The complex hemicellulose sugars are converted to a mix of soluble five-carbon sugars, xylose and arabinose, and soluble six-carbon sugars, mannose and galactose. A small portion of the cellulose is also converted to glucose [Filemon.]

The next step is cellulose hydrolysis. In this step, the remaining cellulose is hydrolyzed to glucose. In this enzymatic hydrolysis reaction, cellulose enzymes are used to break the chains of sugars that make up the cellulose, releasing glucose. [Filemon.]

Cellulose hydrolysis is also called cellulose saccharification because it produces sugars. The cellulose enzymes needed for this process may be produced in-house in a separate enzyme production facility or may be purchased from outside suppliers. The glucose is converted to ethanol through yeast fermentation, as discussed earlier. The yeast feeds on the sugars and as the sugars are consumed, ethanol and carbon dioxide are produced. [Filemon.]

The hemicellulose fraction of biomass is rich in five-carbon sugars, which are also called pentoses. Xylose is the most prevalent pentose released by the hemicellulose hydrolysis reaction. As glucose is converted to ethanol by yeast fermentation similar to those used in the first two types of feedstocks, the pentose (mainly xylose) is subjected to a different type of fermentation. In pentose fermentation, *Zymomonas mobilis* or other genetically engineered bacteria are used instead of yeast. Hydrous ethanol is recovered from the fermented mash through distillation and anhydrous ethanol is produced after dehydration, as in the previous processes described earlier.

Lignin and other byproducts of the biomass-to-ethanol process can be used to produce the electricity required for the ethanol production process. Burning lignin actually creates more energy than needed and selling electricity to outside users improves the economic viability of the process [Filemon.]

4 DISTILLATION

The ethanol concentration in the fermented mash can attain a level of only 4% to 10% depending on the operating conditions and the strain of yeast being used. Ethanol is therefore recovered through distillation but only hydrous ethanol of about 95-96% can be produced through steam distillation of the fermented mash due to the formation of water-ethanol azeotrope. The product ethanol is withdrawn from the top of the distillation column while the spent fermented mash called distillery slops is withdrawn from the bottom and sent for further treatment before final disposal or reuse. To make ethanol fully miscible with gasoline, it is necessary to further remove the residual water to produce anhydrous ethanol with a concentration of at least 99.5%. To attain this concentration, the hydrous ethanol has to undergo a suitable dehydration process or operation [Filemon.]

5 DEHYDRATION

There are at least three widely-used dehydration processes to further remove water from the azeotropic ethanol-water solution. The first process that was used in many of the earlier ethanol plants is the so-called azeotropic distillation or ternary distillation process (as opposed to a binary or two component distillation process). It consists of introducing a third component, benzene or cyclohexane, to the azeotropic solution which forms a heterogeneous azeotropic mixture in vapor-liquid-liquid equilibrium. When this mixture is distilled, anhydrous ethanol is produced at the bottom of the distillation column. Another early method is called extractive distillation, which consists of adding a ternary component that increases the relative volatility of ethanol [Filemon.]

Because distillation processes are energy intensive, a third method has been developed and accepted in majority of modern ethanol plants. This process uses molecular sieves to remove water from ethanol. In this process, ethanol vapor under pressure passes through a bed of molecular sieve beads. The pores of the beads are such that they allow the absorption of water but not ethanol. Two beds are normally used in parallel to allow the regeneration of one bed while the other is in use. This dehydration technology can save significant amounts of energy (up to 840 kJ/l) compared to conventional azeotropic or extractive distillation processes [Filemon.]

6 EXPERIMENT EQUIPMENT

The ethanol will be produced by fermenting sugary fruits, berries and fruit juices in suitable anaerobic conditions, this will be done in a 50 liter sealed container where a suitable air-lock is installed. The mash will be then distilled, for this purpose a heater from the transesterification process of biodiesel production is used (Figure 1). A vacuum pump and heat control are available in the distiller so it's suitable and safe for the experiment. For ethanol dehydration process spherical 3A zeolite is the best option due to its safety and reusability.



Figure 1. Distiller.

7 EXPERIMENTS

Experiments are conducted in the biofuel production facility in Naro Moru, Kenia. Sugary fruits and fruit juices are collected from local jam factory, which is one of the companies that belongs to Help Self Help Centre enterprise.

7.1 First experiment

The first experiment was started by acquiring suitable utensils and the fruits and juices. The sugar content of the fruits and juices is already determined in the jam factory, peels from tree tomato fruits 33-34% and the cactus juice 23-25%. The amount of sugar in the fermentable mash should be around 221 grams of sugar per liter of mash, so the fruits are weighed and appropriate amount will be added to achieve the sugar content for 45 liters of mash. Then water is added until the mash amount is that 45 liters. For this first experiment 180 grams of instant yeast (*Saccharomyces cerevisiae*) is added.

The pH of the mixture is around 3.4 to 3.2, so potassium hydroxide (KOH) is added to change the pH to 6.2 - 6.4 and to provide nutrients. Before the mixture is ready the container must be adjusted, a hole in the lid is made and a hose is pushed through that hole and attached with silicon. To achieve the water-lock, small amount of water is added to the hose, so the pressure from the container can exit but the air cannot enter the container. After the mixture is mixed and stirred, the lid of the container is placed and sealed with silicon. The container is then placed outside where the temperature can vary, this affect to the speed of the process, suitable facilities for the container couldn't be found. Temperature varied from 18 degrees Celsius during the night to 39 degrees Celsius during the day. The container is then left alone until the fermentation process is over.

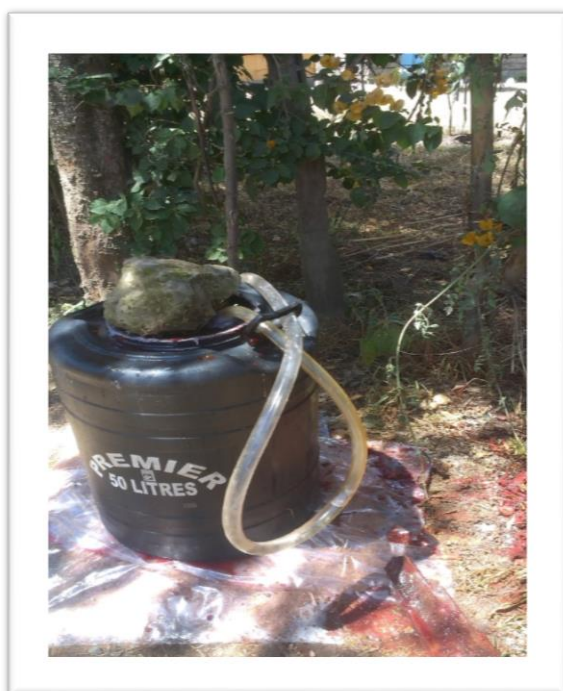


Figure 2. 50 l Fermentation tank.

Unfortunately due to breakdown of the distiller and the repairing time of it, the mash of the first experiment overstayed and went bad, the results are not available from this experiment. But from this experiment we found some needs of improvement, like the connection of the water-lock with silicon is inefficient and it leaks (Figure 2.). Improvements were made for the second experiment (Figure 3.).



Figure 3. Improved 50 l Fermentation tank.

7.2 Second experiment

The second experiment was started by improving the fermentation tank. For this experiment orange peels (Figure 4.) and strawberry waste were acquired. The sugar contents are: Orange peels 22 % and strawberry waste 20%. For this experiment the amount of sugar in the fermentable mash was 14,5 % so 22,20 kg of orange peels and 8,15 kg of strawberry waste are placed in fermentation tank. Then water was added until the mash amount was 56,25 kg. For this experiment 160 grams of instant yeast (*Saccharomyces cerevisiae*) was added.

The pH of the mixture was around 3.5 to 3.7, so 50 grams of potassium hydroxide (KOH) are added to change the pH to 4.3 – 4.5 and to provide nutrients. The mixture was then stirred, container closed and placed outside. Temperature varied from 15 degrees Celsius during the night to 35 degrees Celsius during the day. The container was then left alone until the fermentation process was over.



Figure 4. Orange peels.

Unfortunately the distiller refused to work and this batch was also discarded.

8 END OF ETHANOL EXPERIMENTS AND CONCLUSION

Unfortunately the experiment was cancelled due to malfunction of the distiller and because the possibility to get suitable parts for the distiller are challenging in the rural areas in Kenya.

The results from these experiments are encouraging because the fermentation reaction happened inside the fermentation tank. The efficiency of the process is unknown due to lack of measuring equipment for the ethanol mash. Because the fruit and berry waste is considered free of charge, I would say that the ethanol manufacturing from these raw materials is economically reasonable and the manufacturing equipment is not too expensive.

9 SOLID FUEL INTRODUCTION

The client, Horizon Business Ventures is planning to introduce two new products to the market, Croton husk briquette and Carbonized croton husk. The Croton husk briquette would compete with typical firewood and Carbonized Croton husk would compete with charcoal. These solid fuels are normally used in households for heating and cooking. So the abilities of the products must be determined and compared to their rivals. Abilities to determine are, calorific value, ash amount, moisture and flue gas content. From these analyses we can determine the safety of the new products and the replaceability of the old fuels, with new ones.

The Croton husk briquette and Carbonized croton husks are made of the same by-product, of bio-diesel process, croton husk (Figure 5.). By using these two new products we can reduce the amount of wood used as a fuel and by doing that reduce the deforestation. By utilizing this by-product the client can bring more revenue to the company.



Figure 5. Croton husks.

10 FUELS

10.1 Firewood (Pine)

Pine (Figure 6.) is one of the most typical heating and cooking fuels in Kenya, it can be found from the most parts of the country. Unfortunately cutting down trees causes deforestation and soil erosion.



Figure 6. Pine sample

10.2 Croton husk briquette

Croton husk briquette (Figure 7.) is made from the husks of croton tree nuts. Croton trees can be found from Kenya and South-East Africa. The husks are by-products of the biodiesel production,

where the seeds are recovered and pressed into oil. The husks are first crushed into size of $< 5\text{mm}$ then they are fed into the briquette machine, which compresses the crushed husks into a briquette. The machine uses heat in the compressing process which allows the substances inside the husks to react, this binds the crushed husk into a briquette, and so additional binding ingredient is not needed.



Figure 7. Croton husk briquette.

10.3 Charcoal

Charcoal (Figure 8.) is probably the most used heating and cooking fuel in Kenya. It is made of wood using carbonization process.



Figure 8. Charcoal.

10.4 Carbonized croton husk

Carbonized croton husk (Figure 9.) is made of croton husks using carbonization method. This new product could replace the charcoal and by doing this could help to preserve forests.

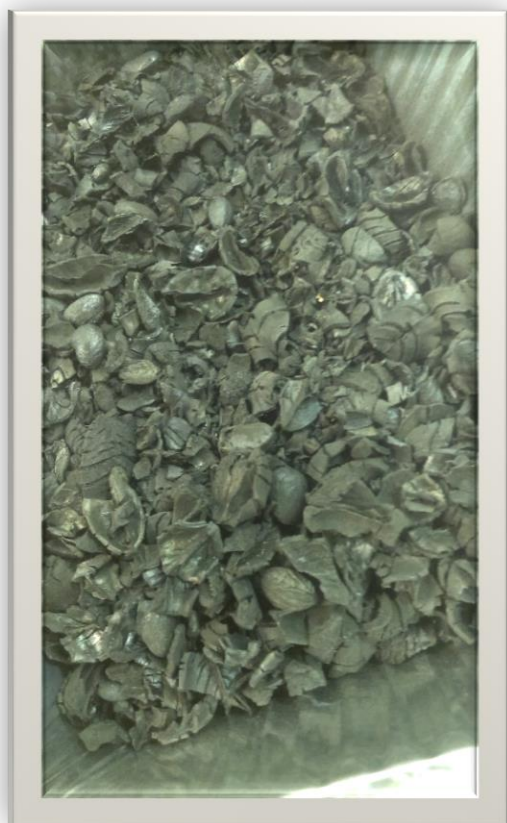


Figure 9. Carbonized croton husk.

11 FUEL ANALYSIS METHODS

11.1 Higher heating value or gross calorific value

The high heating value - HHV is the amount of heat generated with the total and complete combustion of fuel, at assumption that the combustion products are cooled to the initial temperature of the components involved in the combustion process, and the water condenses. [Dryjańska]

A bomb calorimeter is used to determine the calorific value of fuel and from that the gross calorific value can be calculated.

11.2 Lower heating value

The lower heating value – LHV is numerically equal to difference between the high heating value and the amount of heat required to the separation of water contained in fuel, and also the water produced in the hydrogen combustion process. [Dryjańska]

11.3 Moisture

Moisture expresses the amount of water in the fuel. The moisture is analyzed by using moisture analyzer. Moisture affects the properties of fuels by reducing the burning and ignition properties and the heat energy received. Also the storage conditions are affected by moisture.

11.4 Ash content

This test method covers the determination of ash, expressed as the percentage of residue remaining after dry oxidation at 550 to 600°C. The ash content is a measure of the mineral content and other inorganic matter in biomass. This measurement can be used to calculate how much ash each fuel produces.

11.5 Flue gas emissions

From this analysis the toxicity of the flue gases can be determined. The new fuels, croton husk briquette and carbonized croton husk, are compared against the traditional fuels, firewood and charcoal.

12 EQUIPMENT AND METHODS

All the test for the solid fuels were performed in the laboratory of Savonia University of Applied Sciences, in Varkaus Finland. The tests were carried out by Ari Mikkonen and Teijo Turpeinen.

Equipment that was used for the analysis:

- Crushing mill Retsch SM100 (Figure 10.)
- Moisture analyzer A&D MS-70 (Figure 11.)
- Bomb calorimeter Parr 6200 (Figure 12.)
- Oven (Figure 13.)
- Flue gas content analyzer Gasmeter (Figure 14.)

First the samples were crushed in the crushing mill to size less than 2 mm, separately, and the mill was properly cleaned between the samples.

The second process was the moisture analysis, where 1 gram of crushed sample was spread onto a tin vessel and then placed into the machine which heats the sample and analyses the moisture. Procedure was repeated twice for each fuel.

Thirdly, 1 gram of crushed sample was prepared for the bomb calorimeter by compressing it into a pellet by force of 100 newton. The charcoal and carbonized husk samples could not be pressed into pellets so those were left into a crushed form. The sample was then inserted into the bomb calorimeter and the moisture and precise sample weight was given to the machine. The calorimeter then burns the sample and measures how much the water inside the machine heats up, from here the machine calculates the heating value for the fuel. The flue gas from the sample is captured into a flue gas bag and analyzed later. The procedure was then repeated for every sample.

The fourth step was the ash content. Here 1 gram of crushed sample is placed into oven cup and put into the oven for heating and oxidation. 4 samples of each fuel were prepared for the ash content analysis. The samples were weighed before and after the oven and the difference was then calculated, this difference tells the amount of ash produced.

The fifth step is the flue gas content analysis. The flue gas that was captured into the bag from the bomb calorimeter, is fed into the heater which heats it to 180°C. From the heater the flue gas goes into the flue gas content analyzer, where infrared-light is fed through the flue gas stream. Every molecule reflects different wavelength and the machine captures the reflected wavelengths and calculates the amount of molecules inside. The procedure is then repeated to every sample.



Figure 10. The crusher.

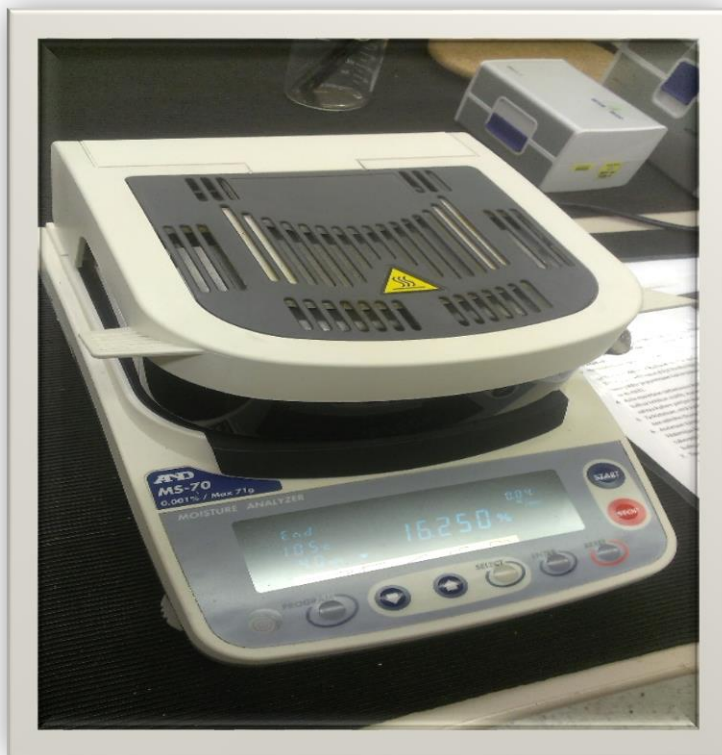


Figure 11. The moisture analyzer



Figure 12. The bomb calorimeter



Figure 13. The oven



Figure 14. Flue gas content analyzer

13 RESULTS

The heating values, moisture and ash content of the fuels are shown in the Table 1 and 2. The Charcoal has the highest lower heating value 28,33 MJ/kg and the Croton husk briquette has the lowest. The lower calorific value is more important than the gross calorific value, because the value gives more accurate information of the fuels when they are burned in the arrival condition. The firewood produces least amount of ash per weight and the Croton husk briquette the most amount. The comparison of flue gas contents between Firewood and Croton briquette can be found from Table 3 and the comparison between Charcoal and Carbonized croton can be found from Table 4, the higher value is represented in red. The measurement method does not directly represent the real burning method, because in the measurement the burning was helped with excess oxygen and this is not likely in a real burning situation.

From these tables we can see that Firewood and the briquette produce the same amount of dangerous molecules but a different kind of, same for the Charcoal and Carbonized croton. Firewood produces more carbon monoxide and sulfur dioxide than the Croton briquette (see Picture 1 and Picture 4) but less nitrogen oxide and nitrogen dioxide (Picture 2 and 3). From Picture 1 we can see that the amount of carbon monoxide that Charcoal produces is really high compared to other fuels and in this case especially to its rival the Carbonized croton.

The original research certificates can be found in the annex 2.

Table 1. Heating values, moisture and ash content of fuels.

| Firewood | | | | | | | |
|-----------------------------|--------------------------|-------------------------|------------|--------------------|----------|---------|--|
| Gross Calorific Value MJ/Kg | High Heating Value MJ/Kg | Low Heating Value MJ/Kg | Moisture % | Ash per 1 gram (g) | Ash % | | |
| 20,62 | 19,04 | 15,6 | 16,25 | 0,0084 | 0,84 | | |
| | | | 15,832 | 0,0083 | 0,83 | | |
| | | | | 0,0089 | 0,89 | | |
| | | | | 0,0085 | 0,85 | | |
| Average | 20,62 | 19,04 | 15,6 | 16,041 | 0,008525 | 0,8525 | |
| | | | | | | | |
| | | | | | | | |
| Croton husk briquette | | | | | | | |
| Gross Calorific Value MJ/Kg | High Heating Value MJ/Kg | Low Heating Value MJ/Kg | Moisture % | Ash per 1 gram (g) | Ash % | | |
| 18,98 | 17,48 | 15,39 | 10,523 | 0,1049 | 10,49 | | |
| | | | 10,441 | 0,0985 | 9,85 | | |
| | | | | 0,1002 | 10,02 | | |
| | | | | 0,1009 | 10,09 | | |
| Average | 18,98 | 17,48 | 15,39 | 10,482 | 0,101125 | 10,1125 | |

Table 2. Heating values, moisture and ash content of fuels.

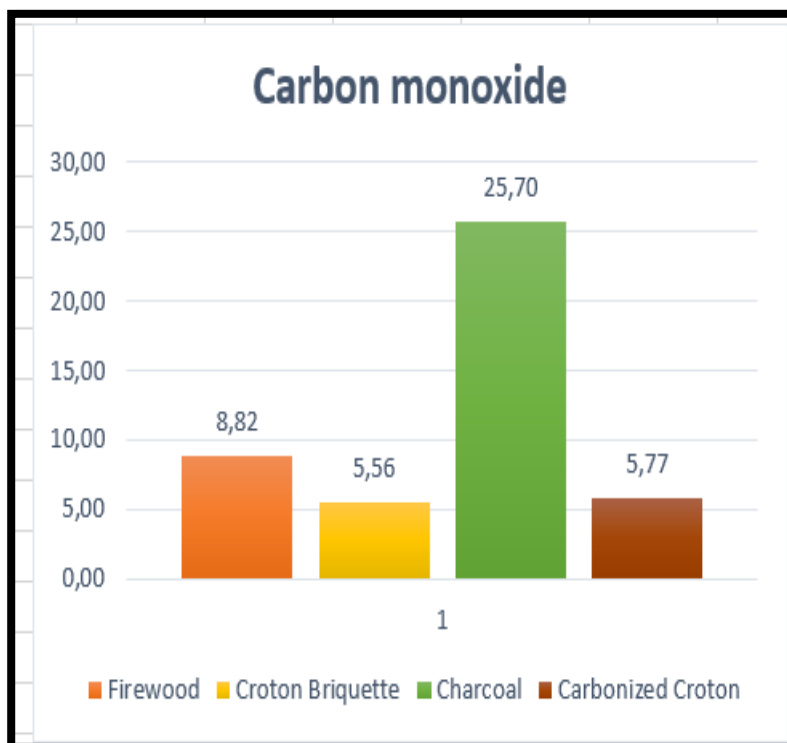
| Charcoal | | | | | | | |
|------------------------|-----------------------------|--------------------------|-------------------------|------------|--------------------|--------|--|
| | Gross Calorific Value MJ/Kg | High Heating Value MJ/Kg | Low Heating Value MJ/Kg | Moisture % | Ash per 1 gram (g) | Ash % | |
| | 31,85 | 30,44 | 28,33 | 6,709 | 0,0233 | 2,33 | |
| | | | | 6,013 | 0,0228 | 2,28 | |
| | | | | | 0,023 | 2,3 | |
| | | | | | 0,0234 | 2,34 | |
| Average | 31,85 | 30,44 | 28,33 | 6,361 | 0,023125 | 2,3125 | |
| Carbonized Croton husk | | | | | | | |
| | Gross Calorific Value MJ/Kg | High Heating Value MJ/Kg | Low Heating Value MJ/Kg | Moisture % | Ash per 1 gram (g) | Ash % | |
| | 29,21 | 27,78 | 25,3 | 9,273 | 0,0781 | 7,81 | |
| | | | | 7,126 | 0,0748 | 7,48 | |
| | | | | | 0,0707 | 7,07 | |
| | | | | | 0,0744 | 7,44 | |
| Average | 29,21 | 27,78 | 25,3 | 8,1995 | 0,0745 | 7,45 | |

Table 3. IR-measured flue gas contents of Firewood and Croton husk briquette.

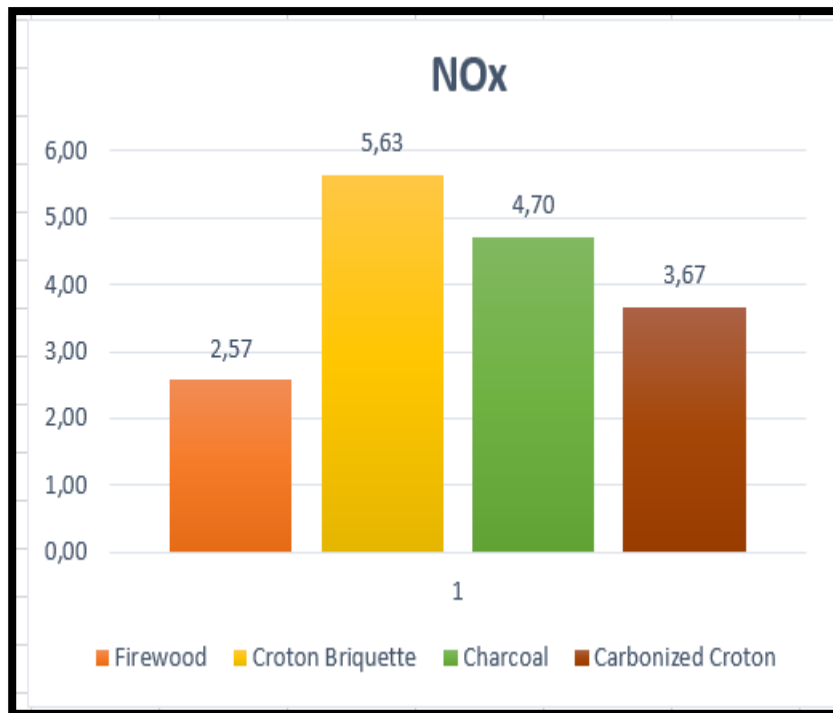
| | Unit | Firewood | Standard error of the mean | Croton Briquette | Standard error of the mean |
|-----------------------|-------|----------|----------------------------|------------------|----------------------------|
| Water vapor H2O | vol-% | 0,74 | ± 0,003 | 0,60 | ± 0,005 |
| Carbon dioxide CO2 | vol-% | 7,10 | ± 0,289 | 7,53 | ± 0,209 |
| Carbon monoxide CO | ppm | 8,82 | ± 0,354 | 5,56 | ± 0,132 |
| Nitrogen monoxide NO | ppm | 1,02 | ± 0,139 | 1,59 | ± 0,128 |
| Nitrogen dioxide NO2 | ppm | 1,55 | ± 0,243 | 4,04 | ± 0,280 |
| Nitrous oxide N2O | ppm | 1,40 | ± 0,076 | 1,01 | ± 0,042 |
| Sulfur dioxide SO2 | ppm | 1,57 | ± 0,271 | 0,88 | ± 0,181 |
| Ammonia NH3 | ppm | 0,85 | ± 0,060 | 0,69 | ± 0,055 |
| Hydrogen chloride HCl | ppm | 0,55 | ± 0,091 | 0,33 | ± 0,063 |
| Hydrogen fluoride HF | ppm | 0,55 | ± 0,101 | 0,46 | ± 0,078 |
| Methane CH4 | ppm | 3,17 | ± 0,059 | 4,22 | ± 0,068 |
| Ethane C2H6 | ppm | 0,05 | ± 0,028 | 0,02 | ± 0,013 |
| Propane C3H8 | ppm | 3,54 | ± 0,133 | 3,70 | ± 0,114 |
| Ethylene C2H4 | ppm | 0,07 | ± 0,035 | 0,02 | ± 0,010 |
| Hexane C6H14 | ppm | 2,07 | ± 0,093 | 2,57 | ± 0,075 |
| Formaldehyde CHOH | ppm | 4,19 | ± 0,197 | 0,24 | ± 0,043 |
| NOx | ppm | 2,57 | ± 0,301 | 5,63 | ± 0,295 |

Table 4. IR-measured flue gas contents of Charcoal and Carbonized croton husks.

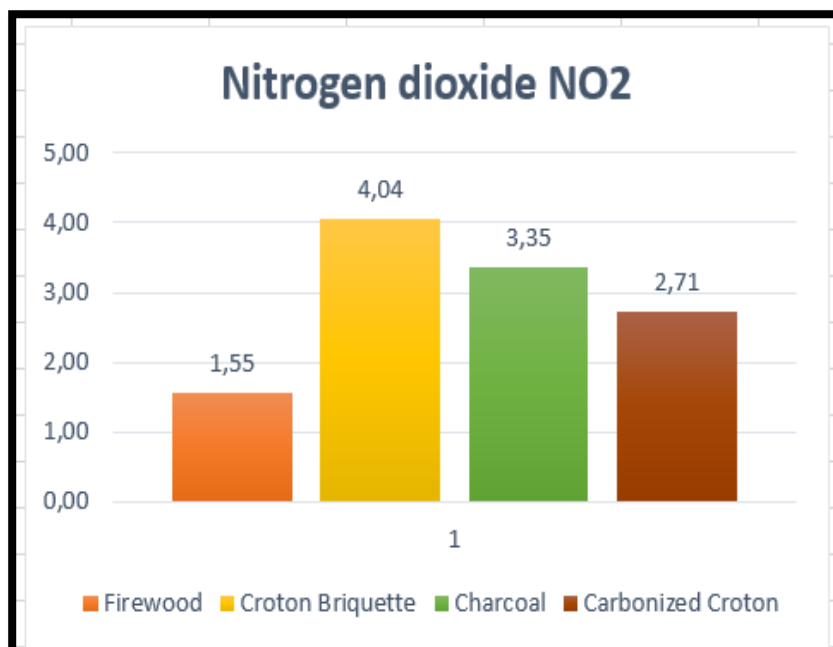
| | Unit | Charcoal | Standard error of the mean | Carbonized Croton | Standard error of the mean |
|--|-------|----------|----------------------------|-------------------|----------------------------|
| Water vapor H ₂ O | vol-% | 0,65 | ± 0,004 | 0,66 | ± 0,003 |
| Carbon dioxide CO ₂ | vol-% | 12,51 | ± 0,563 | 11,89 | ± 0,391 |
| Carbon monoxide CO | ppm | 25,70 | ± 1,101 | 5,77 | ± 0,154 |
| Nitrogen monoxide NO | ppm | 1,35 | ± 0,133 | 0,95 | ± 0,104 |
| Nitrogen dioxide NO ₂ | ppm | 3,35 | ± 0,280 | 2,71 | ± 0,266 |
| Nitrous oxide N ₂ O | ppm | 1,74 | ± 0,074 | 1,21 | ± 0,044 |
| Sulfur dioxide SO ₂ | ppm | 0,21 | ± 0,089 | 0,11 | ± 0,057 |
| Ammonia NH ₃ | ppm | 1,11 | ± 0,060 | 0,95 | ± 0,053 |
| Hydrogen chloride HCl | ppm | 0,47 | ± 0,089 | 0,54 | ± 0,086 |
| Hydrogen fluoride HF | ppm | 0,59 | ± 0,101 | 0,62 | ± 0,098 |
| Methane CH ₄ | ppm | 2,65 | ± 0,054 | 2,20 | ± 0,054 |
| Ethane C ₂ H ₆ | ppm | 0,13 | ± 0,048 | 0,03 | ± 0,019 |
| Propane C ₃ H ₈ | ppm | 3,05 | ± 0,144 | 3,35 | ± 0,109 |
| Ethylene C ₂ H ₄ | ppm | 0,13 | ± 0,043 | 0,07 | ± 0,032 |
| Hexane C ₆ H ₁₄ | ppm | 2,21 | ± 0,100 | 2,16 | ± 0,074 |
| Formaldehyde CHO | ppm | 0,16 | ± 0,030 | 0,12 | ± 0,025 |
| NO _x | ppm | 4,70 | ± 0,322 | 3,67 | ± 0,293 |



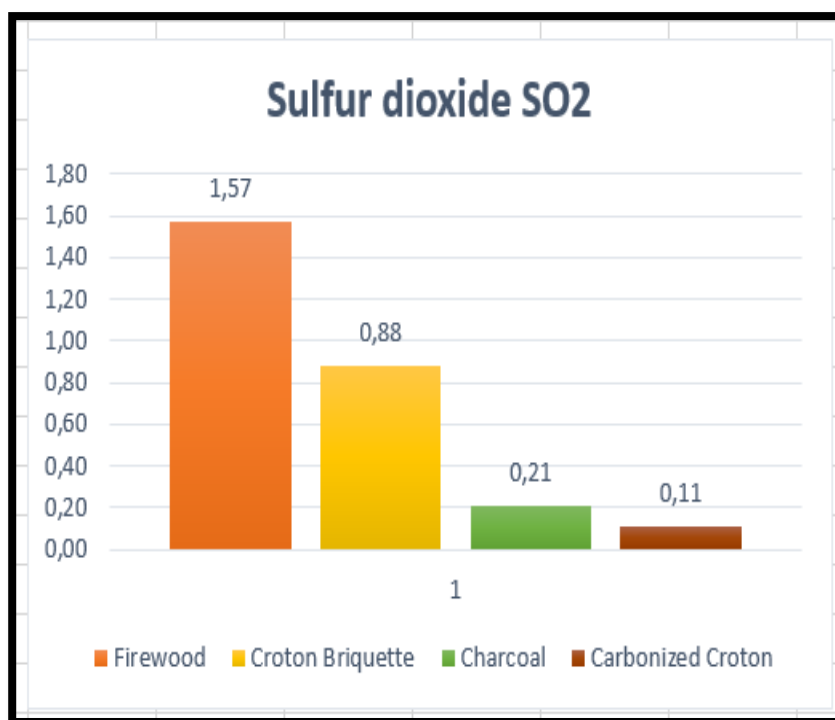
Picture 1. Carbon monoxide.



Picture 2. Nitrogen oxide.



Picture 3. Nitrogen dioxide.



Picture 4. Sulfur dioxide.

14 CONCLUSIONS

The first pair, firewood and Croton husk briquette. As we can see from the Table 1 the lower calorific values for the both fuels are almost the same, only 1 % difference for the firewood's favor. The Croton husk briquette leaves behind more than 10 times more ash than firewood, that ash could be used as a fertilizer. There has also been signs that the Croton husk briquette gives out lot of smoke before it catches fire but after the flames come out the smoke reduces drastically.

It cannot be said that the attributes of either fuel are better than the other fuel. The impact that firewood has to the environment reduces its attractiveness as a fuel. Because the Croton husk briquette is made of by-products and it doesn't increase deforestation makes it a good competitor for the firewood.

The second pair is charcoal and Carbonized croton husk. As is shown in the Table 2 the charcoal has better lower calorific value than the Carbonized croton husk, 11% better. The Carbonized croton husks produce about three times the amount of ash that charcoal produces, there is a possibility to utilize this ash as a fertilizer, but the content of the ash must be determined. The husks also left behind violet color to the ash sample cups, the reason for the color is unknown (Annex 1).

From the Table 4 we can see the dangerous molecules of the flue gases from the fuels. The Carbonized croton husk reduces dramatically the amount of dangerous molecules in the flue gas, compared to charcoal. Carbonized husks produce 39% less hazardous flue gas than charcoal. The flue gas from the charcoal contains almost 5 times more carbon monoxide than the Carbonized husks. Also the NO, NO₂ and SO₂ values of the Carbonized husks are lower than charcoals. There is no significant difference in the ignition properties of the two products.

Based on these results, it can be said that the Carbonized croton husks are a safer fuel than the charcoal, on the matter of dangerous molecules in the flue gas. The charcoal contains higher heating value than the Carbonized husks but the flue gas content and the impact to the environment reduces the appeal of charcoal. The Carbonized croton husks are more suitable as a heating and cooking fuel than charcoal, because often in Kenya people cook inside the house and are affected by the flue gases.

15 CONCLUSIONS AND PROPOSALS FOR THE CLIENT

The goal of the ethanol experiment was to determine if the ethanol production from fruit waste was possible. The production of ethanol is possible but the costs of production are unknown.

I would recommend the client to continue the ethanol research and possibly start their own production as soon as the equipment is fixed.

The goal of the solid fuel experiment was to determine the properties and safety of the Croton briquette and Carbonized croton husks compared to firewood and charcoal. The Croton husk briquette is an equal rival to the firewood and the Carbonized croton husks are a safer fuel than charcoal, but have lower calorific value.

For the client I would say that the new fuels have good properties and they are ready for the market. The positive environmental impact can be used as a marketing advantage. Also the safer flue gas content of the Carbonized husks can be a huge marketing benefit. As these fuels are both produced from the by-products of the factory, the utilization of these products can bring revenue for the client.

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[Dryjańska] MSc. Aleksandra Dryjańska. Lower heating value. Report of Laboratory of metrology. Reference made 22.01.2016.
http://www.imiue.polsl.pl/dokumenty/106_M-8.ang.pdf

ANNEX 1: FIGURE OF THE ASH SAMPLES

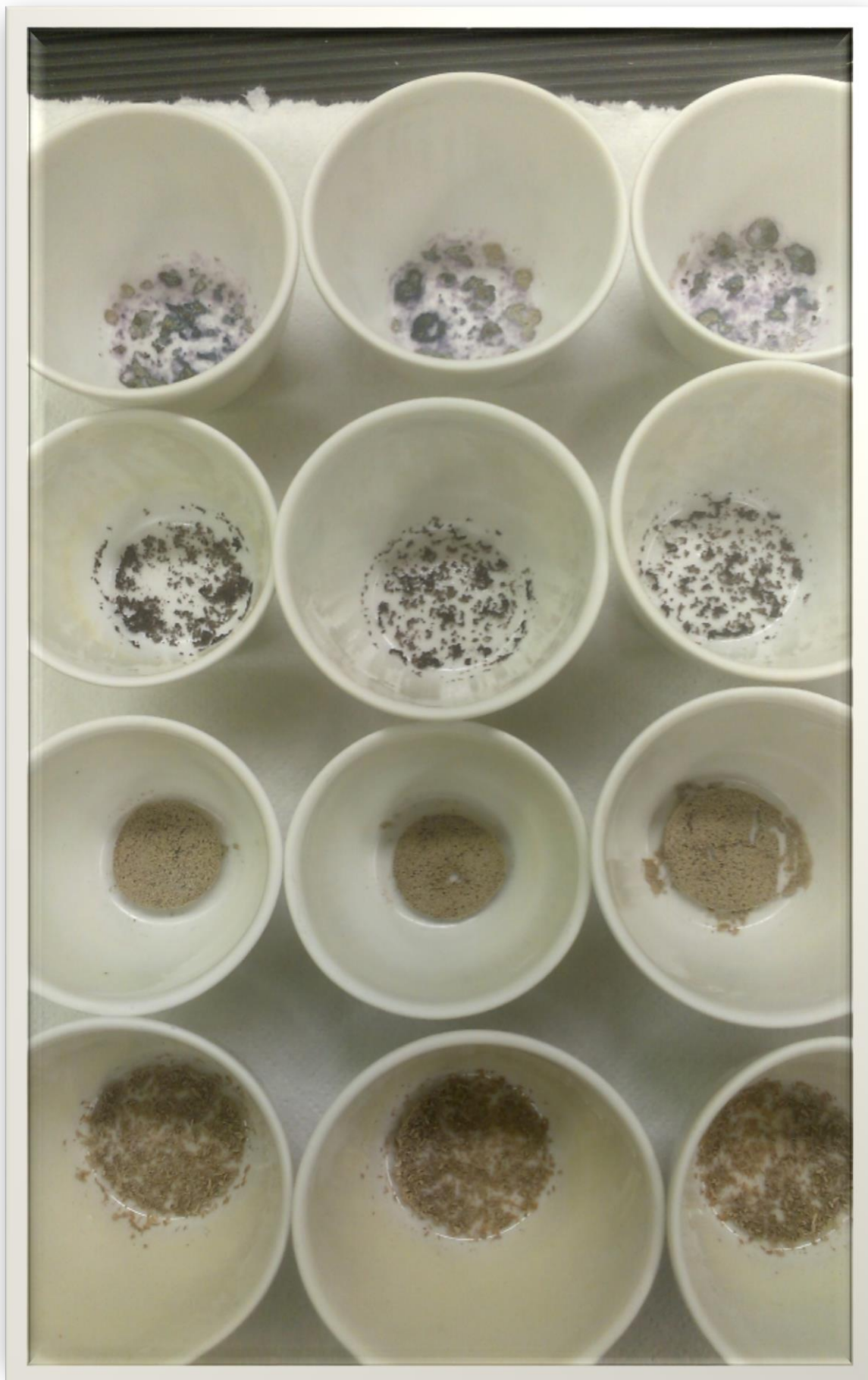


Figure 15. Ash samples. From top to bottom: Carbonized croton husks, charcoal, Croton husk briquette, firewood.

ANNEX 2: RESULT CERTIFICATES



Tutkimustodistus

Opiskelijantie 3 78211 Varkaus

Opinnäytetyö

Teijo Turpeinen



Näytetunnus: Firewood

Näyte saapui laboratorioon: 16.11.2015

Näytteen analysointi pvm 16–17.11.2015

Tutkimusnumero: ENE15-Teijo-001

Näytteen kuvaus: Polttopuu

Näytteen massa, g: 150

| Määritys | | Tulos | Yksikkö |
|--------------------------------------|-----------------|-----------------|---------|
| Kalorimetrinen lämpöarvo | | 20,62 | MJ/kg |
| Tehollinen lämpöarvo | | 19,04 | MJ/kg |
| Tehollinen lämpöarvo saapumistilassa | | 15,60 | MJ/kg |
| Kokonaiskosteus ** | | 16,0 | m- % |
| Kuiva-aineen tuhkapitoisuus | | 0,9 | m- % |
| Määritys | Analysointi pvm | Menetelmä | |
| Lämpöarvo | 16–17.11.2015 | SFS-EN 14918* | |
| Kuiva-aineen tuhkapitoisuus | 16–17.11.2015 | SFS-EN 14775*** | |

*Tehollisen lämpöarvon laskemisessa näytteen vetypitoisuutena käytetty arvoa 6,1 %.

Jauhetun näytteen partikkelikoko < 2 mm.

** Kosteus määritetty ainoastaan pikakosteusanalyssaattorilla ***

Tuhkamäärityksessä lämpötilat ISO 1171:n mukaiset.

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Näytetunnus: Croton briquette
 Näyte saapui laboratorioon: 16.11.2015
 Näytteen analysointi pvm 16–17.11.2015
 Tutkimusnumero: ENE15-Teijo-002
 Näytteen kuvaus: Pähkinän kuorta
 Näytteen massa, g: 150

| Määrittäminen | | Tulos | Yksikkö |
|--------------------------------------|-----------------|-----------------|---------|
| Kalorimetrinen lämpöarvo | | 18,98 | MJ/kg |
| Tehollinen lämpöarvo | | 17,48 | MJ/kg |
| Tehollinen lämpöarvo saapumistilassa | | 15,39 | MJ/kg |
| Kokonaiskosteus ** | | 10,5 | m- % |
| Kuiva-aineen tuhkapitoisuus | | 10,0 | m- % |
| Määrittäminen | Analysointi pvm | Menetelmä | |
| Lämpöarvo | 16–17.11.2015 | SFS-EN 14918* | |
| Kuiva-aineen tuhkapitoisuus | 16–17.11.2015 | SFS-EN 14775*** | |

*Tehollisen lämpöarvon laskemisessa näytteen vetypitoisuutena käytetty arvoa 6,1 %.

Jauhetun näytteen partikkelikoko < 2 mm.

** Kosteus määritetty ainoastaan pikakosteusanalysointilaitteella ***

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Näytetunnus: Charcoal

Näyte saapui laboratorioon: 16.11.2015

Näytteen analysointi pvm 16–17.11.2015

Tutkimusnumero: ENE15-Teijo-003

Näytteen kuvaus: Puuhiili

Näytteen massa, g: 150

| Määritys | | Tulos | Yksikkö |
|--------------------------------------|-----------------|-----------------|---------|
| Kalorimetrinen lämpöarvo | | 31,85 | MJ/kg |
| Tehollinen lämpöarvo | | 30,44 | MJ/kg |
| Tehollinen lämpöarvo saapumistilassa | | 28,33 | MJ/kg |
| Kokonaiskosteus ** | | 6,4 | m- % |
| Kuiva-aineen tuhkapitoisuus | | 2,3 | m- % |
| Määritys | Analysointi pvm | Menetelmä | |
| Lämpöarvo | 16–17.11.2015 | SFS-EN 14918* | |
| Kuiva-aineen tuhkapitoisuus | 16–17.11.2015 | SFS-EN 14775*** | |

*Tehollisen lämpöarvon laskemisessa näytteen vetypitoisuutena käytetty arvoa 6,1 %.

Jauhetun näytteen partikkelikoko < 2 mm.

** Kosteus määritetty ainoastaan pikakosteusanalysaattorilla ***

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Näytetunnus: Carbonized Croton Husk

Näyte saapui laboratorioon: 16.11.2015

Näytteen analysointi pvm 16–17.11.2015

Tutkimusnumero: ENE15-Teijo-004

Näytteen kuvaus: Biohiili

Näytteen massa, g: 150

| Määrittys | | Tulos | Yksikkö |
|--------------------------------------|-----------------|-----------------|---------|
| Kalorimetrinen lämpöarvo | | 29,21 | MJ/kg |
| Tehollinen lämpöarvo | | 27,78 | MJ/kg |
| Tehollinen lämpöarvo saapumistilassa | | 25,30 | MJ/kg |
| Kokonaiskosteus ** | | 8,2 | m- % |
| Kuiva-aineen tuhkapitoisuus | | 7,2 | m- % |
| Määrittys | Analysointi pvm | Menetelmä | |
| Lämpöarvo | 16–17.11.2015 | SFS-EN 14918* | |
| Kuiva-aineen tuhkapitoisuus | 16–17.11.2015 | SFS-EN 14775*** | |

*Tehollisen lämpöarvon laskemisessa näytteen vetypitoisuutena käytetty arvoa 6,1 %.

Jauhetun näytteen partikkelikoko < 2 mm.

** Kosteus määritetty ainoastaan pikakosteusanalysointorilla ***

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