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Design of a cooker working with short rotation coppice willow based on the rocket stove principle

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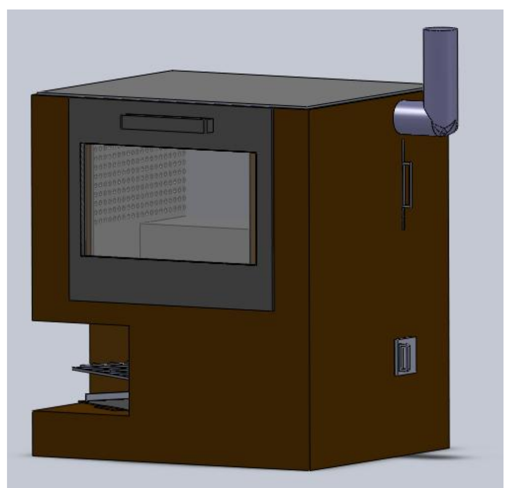
MSc Dissertation for Lammas Low Impact Initiatives Limited



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INTRODUCTION

The aim of this dissertation was to develop a project for the Lammas group (Lammas Low Impact Initiatives Limited) which has been supported by the Science Shop Wales Network. Further information about Lammas can be found at http://www.lammas.org.uk/.

The topic of this project was:

To develop a domestic-scale cooker which is run from short rotation coppice willow, designed on rocket stove principles.

Lammas is a community composed of nine families who desire to live in a sustainable energy environment, without using electricity or gas. Thus, they need to find a solution for their cooking facility and that is what this dissertation is dedicated to.

The rocket stove is a traditional improved wood burning stove. It works based on principles such as a uniform cross section along a well-insulated combustion chamber.

Short rotation coppice willow is a bio-fuel which is being grown as part of the Lammas project. The study of its combustion has led to the determination of the amount of fuel required in order to achieve the desired cooking temperatures.

The combination of the rocket stove principles, domestic cooker technology and the use of bio-fuel has led to the development of device that the community can use as an oven or as a hot plate.

By using Computational Fluid Dynamics (CFD) modeling software, the heat flow in the cooker was analyzed and used to design an oven with a uniform temperature distribution required for good cooking.

CFD software was used to study materials and to provide good insulation using ceramic clay on the outside, and a good cooking feature by using steel in order to conduct the heat to the oven and the hotplate.

With good insulation and the use of a chimney (a flue pipe outlet that will carry away all smoke) a clean indoor environment has been maintained.

Thus, by combining safety and efficiency, the proposed cooker will enable the community to build a cost-effective device which will help them in their everyday life.

CONTENT

In order to accomplish this project the following tasks were carried out:

- An understanding of the background theories behind this project.

  Knowledge about the combustion, fuel, rocket stove principles, and cooker technology.

- A design of the cooker

  Use the theories to design a cooker that satisfies the community's requirements by choosing the appropriate materials, configurations and design strategy.

- An analysis of the proposed design

  Run analysis with Computational Fluid Dynamics tools and run experiments and testing to check the suitability of the design.

- A critical view of the design and results

  A discussion of the suitability of the project in terms of cost and efficiency.

- Recommendations to build the cooker

  The dimensions and the materials for each part of the cooker.

RESEARCH PROJECT

Background research was carried out to develop the design. Thus, the study of cooking technology and of the energy supply has been carried out.

First, the rocket stove principles were analyzed in order to improve efficiency and reduce the gas emissions of the stove. These principles can be summarized with the Ten Design Principles from Dr. Larry Winiarki based on *Design principles for wood burning cook stoves*. From these principles, recommendations are made for the combustion chamber of the cooker. The rocket stove principles recommend good insulation around the fire, regulation of the heat by the amount of wood sticks (fuel) used, maintaining a constant cross section area through the opening and all along the combustion chamber, good air flow around the wood sticks and the use of a L-shape combustion chamber.

Then, a study of standard domestic cooker design was done in order to determine the characteristics that define this type of cooker. Thus, thanks to the information found, important points which affect the design were noticed. The oven must have a uniform heat distribution and be able to eliminate smoke. A fast heat circulation must occur in the cooker and heat sources on both sides of the oven must be set. In addition, heat must be conducted through the shelf supporting the food in the oven.

In addition, the energy supply of the cooker was studied. The fuel, short rotation coppice (SRC) willow in this case, has been defined as willow which has grown for three years and thus has achieved a good energy content value. SRC has the advantage of being fast growing, being produced nearby, and as a biomass, does not increase the atmospheric carbon. Lammas has three plantations of willow on the site using three different techniques as can be seen in the followings figures:

Willow plantation in Lammas Eco Village, using the technique where the willow have been mulched with straw and hay (left), using the technique where the willow have been planted through sheet plastic (middle) and using the technique where the willow have been planted through woven plastic mulch (right)

Then, the heat which can be produced by SRC was studied. The characteristic value of the fuel has been found such as the calorific value 18MJ/kg and the density $420kg/m^3$. As the dimension of the cooker will determine the amount of fuel that can be fed in, the opening of the combustion chamber has been set as 400mm wide. The wood sticks provided by Lammas are cut with a length of 60mm and with a diameter between 5mm and 50mm. Thus, eight faggots of 50mm diameter can be fed into the chamber, which leads to an amount of fuel of:

$V = n \, . \, l \, .(\pi \, . \, d^2) / 4$

$V = 8 \times 0.6 \times (\pi \, . \, 0.05^2) / 4$

$V = 9.43 dm^3$

Using the density, this volume is about 3.96kg. Then, based on research on similar cooking systems, it has been assumed that this amount of fuel will take one hour to burn. Thus, the heat produced by the cooker is found as:

Heat = m . Cv

Heat = 3.96 [kg/h] x 18 [MJ/kg]

Heat = 3.96/3600 [kg/s] x 18 [MJ/kg]

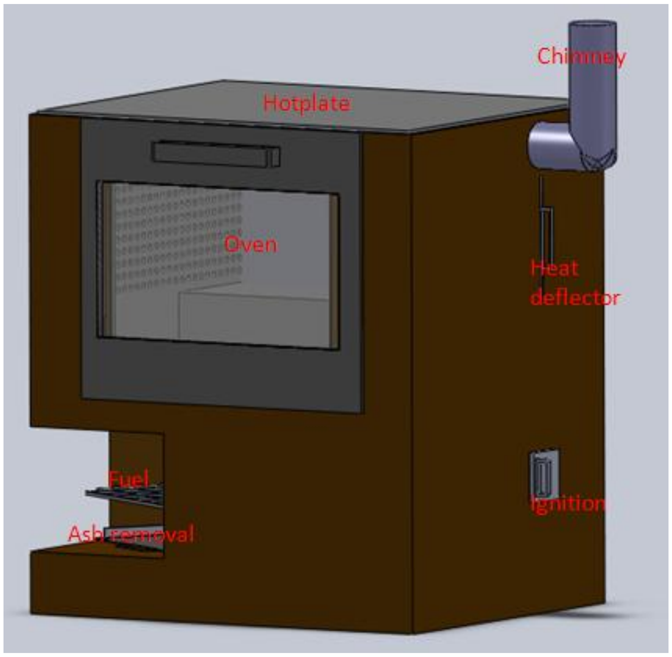
Heat = 19.8kW

Finally, the combustion process was studied. The excess air that would have to be provided to achieve combustion has been found to be 220%. The amount of air that must go through the combustion chamber has been calculated as 18.68m^3/hour.

RESEARCH DESIGN

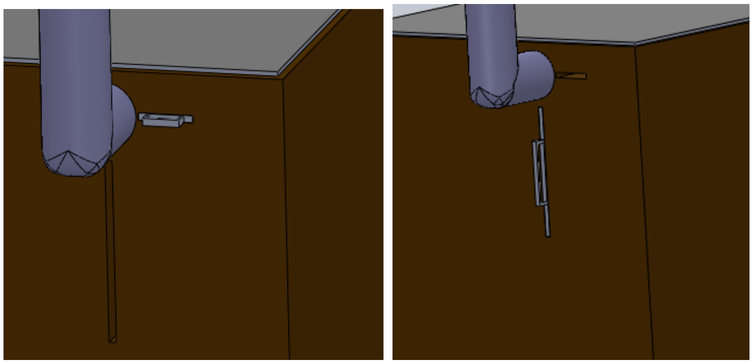
Thanks to the previous background study, a cooker design was created. The cooker design is composed of the following parts:

- The combustion chamber
- The oven
- The cooking hot plate
- The door of the oven
- The outside frame
- The chimney
- The device to change the use from oven to cooking plate



Representation of the final design modelled on SolidWorks

The combustion chamber follows rocket stoves principles. The oven box has been designed along the lines of a standard domestic cooker. The cooking hot plate is a single plate which provides a range of cooking temperatures as can be seen below. In addition, a system has been designed in order to enable the user to choose between using the hotplate or the oven. This system uses sliding plates inside the cooker which act as deflectors in order to make the heat go either to the hotplate or to the oven.



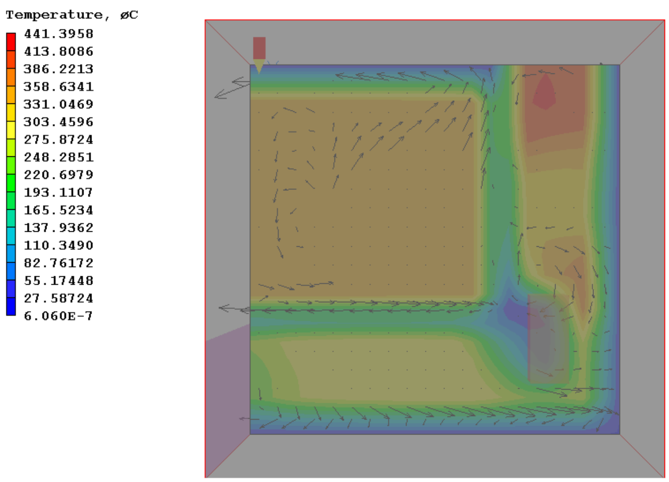
Cooker used as an oven thanks to the device slides in the cooker which deflects the flows to the oven (left) and cooker used as a hotplate thanks to the device slides in the cooker which deflects the flows to the hotplate(right)

There are two types of material used in this cooker. First, there is insulation, such as for the combustion chamber and the outside frame of the cooker. The rocket stove is based on a well insulated combustion chamber and the insulation has to meet safety requirements. In order to achieve that, clay bricks have been employed for their properties, their cost and their availability in the Lammas site. The second type of material is used to conduct the heat. Heat must be transmitted from the flame to the cooking areas: the oven and the hotplate.

To confirm the material choice and to determine the thickness and the efficiency of the device heat transfer calculations were carried out.

Research Results

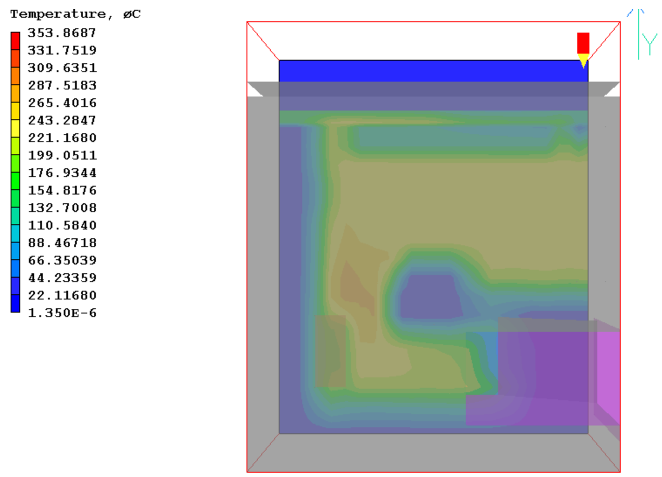
In order to check the suitability of the design, the heat flow in the cooker was studied using Computational Fluid Dynamics (CFD) software: Phoenics software programme with the additional module Flair. Different simulations were carried out as the design was being defined. An initial simulation with a simple geometry was conducted in order to verify the information from the rocket stove principles.



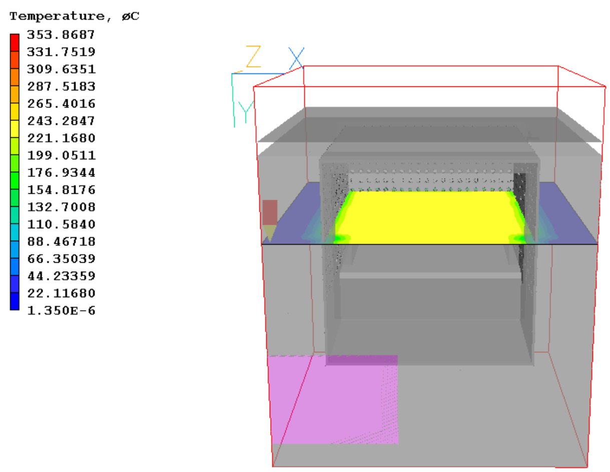
Temperature distribution in the first simulation, view from the side

The simulation confirmed the efficiency of the rocket stove principles. In fact, there is an increase of temperature above the flame thanks to the L-shape constant cross section chamber.

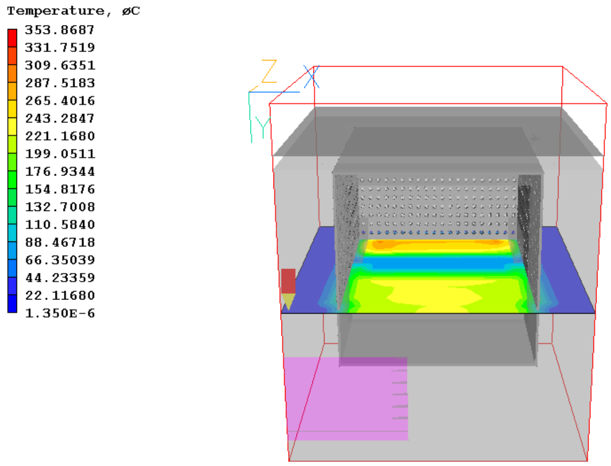
After a series of simulations of different configurations, the final design was developed. All the parts are set in their materials, steel or clay. The oven box was designed such as its fit around the flame, providing a uniform heat distribution with an area, above the fire, where the temperature is higher.



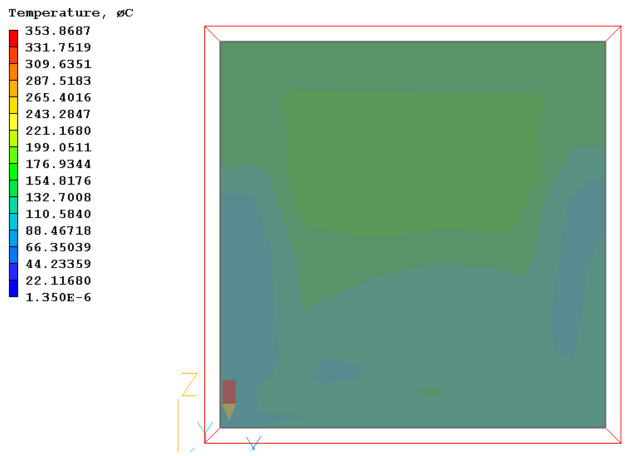
Temperature distribution in the final design, view from the side



Temperature distribution in the final design, view inside the oven showing a uniform heat distribution



Temperature distribution in the final design, view inside the oven, on the edge above the flame showing a high temperature region



Temperature distribution in the final design, view on top of the hotplate showing a range of temperature of cooking

The uniform heat distribution in the oven comes from the heat flowing around the oven which has been inspired by the electric cookers which have heating unit on both sides.

The heat from the flame flows in and around the oven and goes to the hotplate. The heat distribution on this hotplate was found to be higher at the back and lower temperature at the front.

The cooker developed in this project has provided an oven with a temperature of 240°C allowing a small area of 280°C. The hotplate offers a range of temperature from 210 °C to 110°C. Thus, different cooking techniques can be accomplished with this cooker.

The control of the temperature is achieved by the amount of fuel fed into the chamber. The user might not necessarily want to use the oven and the hotplate at the same time. Thus, some iron plates are used as deflectors to divert the heat either through the cooker or to the hotplate which will lead to an increase in temperature in either of these cooking facilities.

The efficiency of the cooker has been evaluated by the study of materials leading to the energy balance of the system and the calculation of the heat lost through the cooker casing and the flue. The overall result is quite low; an efficiency of 28%. On the other hand the CFD software modeling has shown that the temperature difference between the combustion chamber and the cooking area is small, which means that the cooker is very efficient in terms of heat conduction.

REFERENCES

These are the main references used for this project:

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