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Publication date:
1996

Document Version
Publisher's PDF, also known as Version of record

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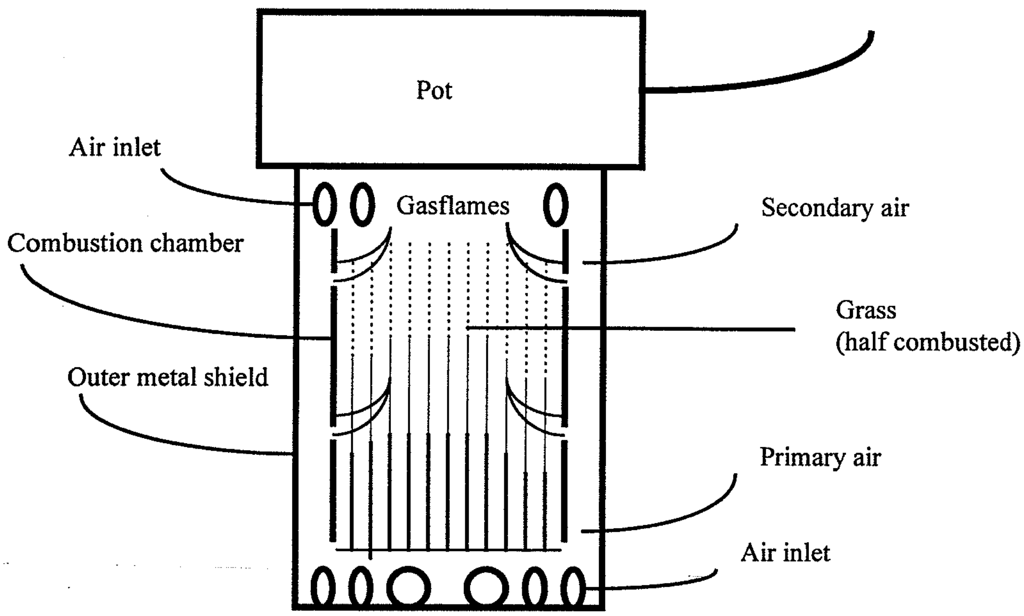
Stove peko pe

Per Siverts Nielsen



REPORT

R-003

1996

ISSN 1396-4011
ISBN 87-7877-001-7

DEPARTMENT OF BUILDINGS AND ENERGY
TECHNICAL UNIVERSITY OF DENMARK

IBE

Efficiency tests on the pyrolysis gasifier stove Peko Pe

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Report No. 003
ISBN: 87-7877-001-7
ISSN: 1396-4011

31st October 1996

Abstract

This paper presents results from water boiling tests on the pyrolysis gasifier stove Peko Pe, which has been developed by the Norwegian Paal Wendelbo. The stove efficiency determined vary between 21 and 29% when burning dry Danish woodchips (10% moisture) with an estimated caloric value of 16 MJ/kg. CO-emissions have been determined with varying distance between the stove and the pot to estimate the combustion efficiency. Efficiency tests performed in Adjumani refugee camp with grass as fuel show a stove efficiency of 25-29% with a caloric value of 14 MJ/kg. It has not been possible to determine the water content in the grass. In Adjumani refugee camp it was furthermore found that the stove was able to provide sufficient energy from solid combustion, after the pyrolysis was stopped, to boil water for additional 25-30 minutes with lid. This effect was not seen in the tests on woodchips in Denmark. Advantages and disadvantages of the stove compared to three-stone stoves are discussed and perspectives are outlined for further improvements of the stove.

Introduction

Biofuels are used by about half of the worlds population for cooking their meals, typically in the form of wood gathered from farm or forest lands. The intensive use of biomass is mainly due to lack of alternatives and the fact that firewood is often collected free.

There are, however, many adverse effects of using the traditional stoves, such as health effects from direct exposure to smoke from the fire. This exposure is one of the major reasons for acute respiratory infections, being the chief killers of children in developing countries and causing more episodes of illness than any other decease[1]. In some areas the lack of fuel imply cooking of less nutritious food and less cooking of drinking water. This also has adverse effects on human health.

[1] Smith, 1987: Biofuels, Air Pollution and Health, and Smith, 1991: The Health Effects of Biomass Smoke: A Brief Survey of Current Knowledge. Here from: Barnes et al., 1994: What makes People Cook with Improved Biomass Stoves?

When biofuels are abundant and sufficient land is available, the utilisation of biomass for fuel is not an environmental problem, but with a growing population the pressure on land is also increasing. A consequence of the use of biofuels for cooking is a slow degradation of forest and farm lands. This problem is especially severe in densely populated areas, such as refugee camps.

The reasons for the intensive use of biofuels for cooking in many developing countries are complex, and vary from area to area. In most areas, however, the lack of money to buy alternative fuels and stoves is a main cause of biofuel dependency. Lack of accessibility to the electricity grid prevents the use of electric stoves, and lack of sufficient infrastructure hinders the allocation of gas cylinders for LPG stoves and kerosene for kerosene stoves. Hence the dependency of biofuels for cooking is closely related to the overall development of infrastructure and to the economic level in society.

The energy chain

There are many options for reducing the biomass consumption in the food preparation process. Looking at the total energy chain from biofuel to the final meal, many technical improvements are possible. There are also many options which are non-technical. These are closely related to the cooking performance. In relation to technical options the choice of fuel, optimisation of heat transfer and efficient combustion processes are important. The non-technical options include the use of lid, skills in firing control and organisation of the food preparation process. In this report the focus will be on the technical aspects, but the non-technical issues are also important for a successful implementation of new stoves.

Measuring efficiency and emissions

The major part of households using biofuels for cooking use traditional three-stone stoves. The three-stone stoves have been regarded as rather energy inefficient, with an estimated efficiency of 5-10%, but new studies show a higher possible efficiency[2]. Some of the first improved stoves have been claimed to be much more efficient than the three-stone stoves, but actually were not. The wrong conclusion was among other things due to lack of a common method for measuring the efficiency of the stoves[3]. A common methodology only developed in 1982[4].

It is difficult to compare efficiencies of three-stone stoves from different laboratory tests, because the description of the tests do not provide sufficient details about specific heat transfer aspects, etc. Information is needed, for instance, about the distance between the fire and the pot in the tests, the moisture content in the fuel, the kind of wood which is used and whether the test is carried out in closed rooms or outside in the free air. These factors can easily change the efficiency data by an order of magnitude. Baya-Vuma cites the efficiency of three-stone stoves to be between 6 and 8%, but it has been

2 Dutt and Ravindranath, 1993:Bioenergy: Direct applications in cooking.
3 Baldwin et al, 1985: Improved Woodburning Cookstoves: Signs of Success.
4 VITA, 1985: Testing the Efficiency of Wood-burning Cookstoves - Provisional International Standards.

found to be 23% in laboratory tests with 25% moisture content of the biomass and the pot placed 7.5 cm above the base of the fire[5].

Data on combustion efficiency were not the only data missing in the 1980´ies with regard to understanding the biofuel problem. Data on health effects were also missing including health hazards which occur with direct exposure to the fire, especially when cooking is carried out indoor[6]. Even though these consequences are relevant when the food preparation process is studied, only few studies have addressed the issues and even less been able to determine real numbers. After it has been possible to get a framework for assessing the efficiency[7], emissions and the health effects[8], the stoves have been improved and the dissemination of improved stoves has increased[9].

The three-stone stoves

The three-stone stoves are very popular. When we exclude environmental and health effects they have several advantages. They have no cost and in areas where wood is collected free the use of the three-stone stoves are free. The stove is easy to make, use, and handle. The safety is also relatively high as children can see and feel the fire. The firing control is relatively easy, in skilled hands, because it is possible to use long logs which are pushed into the flames while they are burning in the other end. When heat no longer is desired the logs are easily pulled out and the fire stops. These advantages are difficult to compete with when wood is abundant and awareness of the environmental and health problems are low.

The central problem in obtaining high efficiency for the three stone stove in real life is the firing control.With three-stone stoves it is difficult to obtain the optimal distance between fire and pot and to keep the fire in optimal combustion state as heat is lost with large flames. In the worst case the pot is removed while the wood is burning and the energy is lost. The challenge of developing improved stoves is to take “bad” habits into account in the combustion process so that the “bad” and energy inefficient habits do not occur.

Improved stoves

Some simple improved stoves are variations of the three-stone stove, for instance "stones" may be built with clay and built with clay-walls between two of the "stones". This reduces the loss of heat mainly because of less exposure to wind. These stoves are relatively easy to disseminate as their use does not change cooking traditions very much. They do not, however, inspire to changes the bad habits from the cooking performance. In Ministry of Energy, Ghana (1991)[10] the main argument for the difference of 50% of

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5 Baya-Vuma, 1989: 10 Tears of Improved Stoves in the Sahel.

6 Smith, 1985: Biomass Fuels, Air Pollution and Health. In: Baldwin et al, 1985: Improved Wood burning Cookstoves: Signs of Success.

7 Supra note 4.

8 Smith, 1987: Biofuels, Air pollution and Health - a global overview.

9 Karekezi and Turyareeba, 1995: Woodstove dissemination in Eastern Africa - a review.

10 Ministry of Energy, Ghana, 1991: A report on Energy use patterns in Bolgatanga, Bawku East and Bawku West Districts of the Upper East Region of Northern Ghana.

biomass consumption per household between two villages is explained by the use of these two different three-stone stoves.

Normally, improved stoves demand changes in the cooking performance. An improved stove may, for instance, require to be fed with wood in a specific way. If this is done correctly then the losses will be reduced. However, if improved stoves are used wrongly the energy losses might be even larger than for three-stone stoves. The stove must be easy to handle, if the cook is going to use it. This is especially the case when the stoves are disseminated among users without any technical support.

Bussmann, 1987[11], says that the two most important motivations for the users to choose an improved stove are the rapidness of cooking and the economy. This will, however, vary from place to place and is very much related to the kind of food the cook prepares. It has also been argued that people want the taste from the fire, but considering how people prefer the LPG stoves, this may only be an excuse.

It is difficult to separate the efficiency loss of the combustion process and loss in the firing control in the energy chain, because the firing control is a central aspect which an efficient combustion process depends upon. If we compare the three-stone stoves with modern stoves like the electric and LPG stoves, it is obvious that the power of the modern stoves is easier to control. Smoke in the kitchen is reduced to a minimum by use of LPG stoves, and smoke is removed completely by use of electric stoves.

The pyrolysis gasifier stoves

The stove which is examined in this study is developed by the Norwegian Paal Wendelbo. It is basically a pyrolysis gasifier, which may be viewed as a new type of stove. A prototype of the stove has been tested at the Technical University of Denmark in 1995. The stove and the combustion process are illustrated in Figure 1.

The stove is made of two tins. The inner tin (the combustion chamber) is prepared with small air-holes in the bottom, in the middle and at the top. The outer tin is the shield on which the pot is placed. The holes in the combustion chamber are around 0.8 cm in diameter and the diameter of the tin is around 15 cm. The height of the tin is 20 cm. The outer tin has large holes (5 cm in diameter) in the buttom to let air in and large holes (5 cm in diameter) in the top to allow sufficient oxygen for the final combustion. When the biomass is burning and the volatiles pyrolyse and the gases reach the top holes, oxygen is drawn into the combustion chamber through the holes in the top by a draft inside the combustion chamber. The air is preheated when is passes from the buttom of the stove to the top holes in the combustion chamber. From the holes the oxygen in the air produces a gasflame when it is ignited. In the centre of the gas flames the temperature can reach 800°C. Due to the perfect burning of the volatiles, the stove is almost smoke free. Only in the first 1-2 minutes some smoke may appear.

11 Bussmann, 1987: Woodstoves, Theory and Applications in Developing Countries.

Four sets of tests have been carried out with the gasifier stove. The three sets were conducted in collaboration with Department of Energy Engineering at the Technical University of Denmark in 1995. A 500-liter oil barrel was established as a test chamber, where it was possible to determine the efficiency, the CO concentration and NMVOC emissions while combusting. The barrel was airtight in order to determine air inlet through an air meter. It was provided with a chimney to collect and measure the smoke. The barrel was equipped with a window for observing the combustion process.

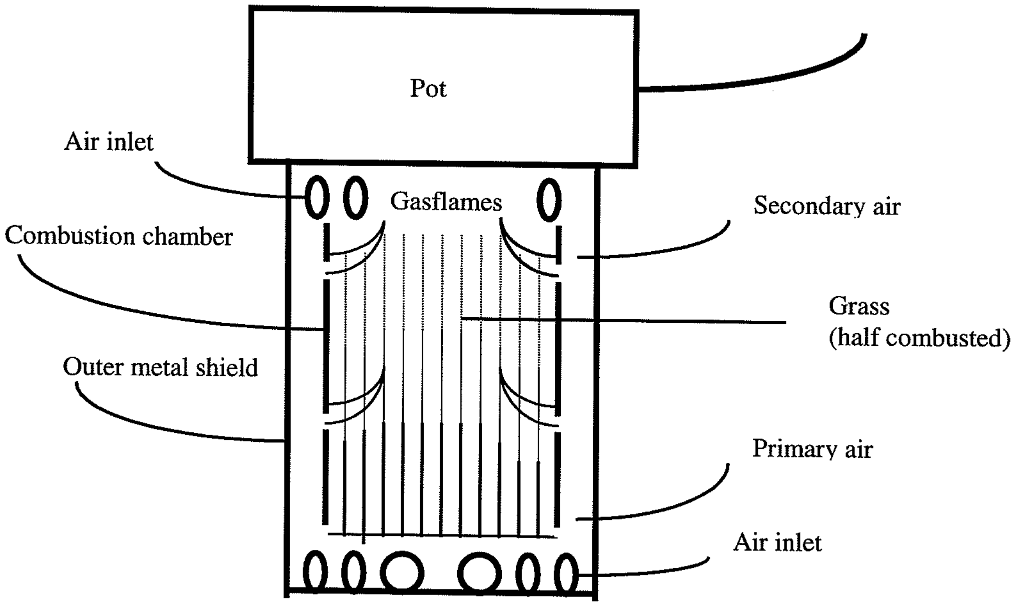

Figure 1. The pyrolysis principle in the stove while burning grass. The grass is placed vertically and the figure illustrates the combustion at a time 5-10 minutes after ignition where the upper part of the grass is burned. The grass is ignited from the top.

Determination of stove efficiency of the gasifier stove

The primary aim of the first tests was determination of the stove efficiency in water boiling tests. The first test session was carried out with beech chips. The results are shown in Table 1 where "heating time" is the time to heat 1 kg og water from 17°C to 100°C, and "boiling time" is the time where the water boils with lid. The tests were carried out with small changes in biomass use. It was, however, clear that the best results were obtained with 250 g of biomass for that model. But even with the same amount of biomass differences occur. The stove efficiency is estimated to be around 25-27% with an estimated caloric value for the wood of 16 MJ/kg. Looking at heating time and boiling time differences occur which are not easy to explain. However, many external parameters may affect the results, such as the ignition time, placing of burning chamber in the stove and placing of the pot. Even though these parameters have been considered carefully in the test performance, the results indicate that even small changes may have an influence. The power of the stove is calculated to be around 0.9 kW.

	Fuel (g)	Water (g)	Heating time (min)	Boiling time (min)	Efficiency %
Test1	300	990	6.5	10.5	24
Test2	250	1009	5.25	10.8	29
Test3	400	1000	8.3	17.2	22
Test5	250	1000	5.0	12.5	29
Test7	250	1000	7.0	12.0	26
Test8	250	1000	10.0	9.0	25
Test9	250	1000	7.0	11.0	25
Test10	250	1000	5.0	6.0	21

Table 1: Stove efficiency of the gasifier stove in water boiling tests. Wood chips are used with an estimated caloric value of 16 MJ/kg.

Measurement of CO-emissions

One of the hazardous emissions from combustion is CO-emissions. They are produced from incomplete combustion. Observations of the smoke while combusting with and without pot, indicated that the pot, when it was placed on top of the stove, was reducing the combustion efficiency and increased the production of CO. Tests were carried out and showed CO concentrations in the outlet of the chamber of 0.04% without pot and 0.06% with pot. New series of tests were made to determine the relationship between the distance between the stove and the pot, and CO-emissions.

The results of these tests are shown in Table 2. The distance between the top of the stove and the bottom of the pot was increased from 0 cm to 10 cm. The distance from the top of the stove to the top of the wood chips was 18 cm, hence the distance from biomass to the bottom of the pot is increased from 18 cm to 28 cm. The results indicate that the stove efficiency decreases with increasing distance between the pot and the stove, which is not surprising. However, the difference in distance is relatively small. At the same time CO-emissions were reduced with increasing distance. It should be mentioned that the window to the chamber was opened twice in the first 3 tests and only once in the rest. The stove efficiencies are not comparable to the results of the efficiency tests, as the air inlet was reduced to be able to measure the flow. The differences in the results are still significant.

CO is an acute toxic gas. CO has an affinity 300 times higher than O_2 which means that even with small concentrations of CO in the air CO accumulates in the blood and will only be released after some hours. A CO-concentration of 0.025% in the air leads to a concentration of CO-bound haemoglobin of 10% when relaxing and 18% when working. No symptoms occur at a concentration of 0-10% haemoglobin bound CO. But at a concentration above 10% CO causes headache, at higher concentrations coma and in very high concentrations dead. To avoid any symptoms the concentration of CO in the air should be below 0.01%. In our tests this means that the room should be more than 20 times larger than the test chamber of 500 litres (when the pot is placed directly on the stove). This corresponds to a volume of 10 m^3. Small houses in developing countries are not very much larger which means that the CO emission from the stove can be critical.

	Pot to stove distance (cm)	Stove Efficiency (%)	CO-concentration (%)
Test15	0	16.0	0.26
Test16	0	18.8	0.16
Test17	0	17.3	0.17
Test18	5	16.5	0.13
Test19	5	16.1	0.13
Test20	10	13.2	0.10
Test21	10	12.0	0.02

Table 2. The results of a test serie, where the distance between bottom of pot and top of stove is varied and CO-concentration measured for each test. The distance between the top of the stove and the biomass is 18 cm at ignition.

Measurement of NMVOC-emissions

Tests were also carried out to measure NMVOC in the air by taking samples from the smoke in the chimney. The measurements detected no content of particles. If a pot is used, the particles will be absorbed at the bottom of the pot. Without the pot, the particles might be absorbed by the inner surface of the chamber. A test was subsequently made by collecting particles at a filter 30 cm above the stove, when burning without the pot. Black particles were collected at the filter, but no NMVOC was detected.

Results of test in the Adjumani Refugee Camp

In the Adjumani Refugee camp a workshop was established in February 1995 with the aim of 1) teaching technicians to produce the stoves, 2) involving and training disabled people to be able to produce and sell the stoves, 3) training women in cooking on the stove and 4) stimulating and promoting dissemination of the stove in the refugee camp. The workshop was established in the compound of Accord, a UK NGO and the project was carried out by the Norwegian Association for the Disabled. The idea and responsibility for the stove project is in Paal Wendelboe´s hands.

Energy use patterns in the Adjumani Refugee Camp are similar to patterns throughout Uganda. Approximately 100,000 refugees have come from Southern Sudan, which have more than doubled the population of Adjumani. Most of the refugees have relatives in Adjumani.

As the refugees are dispersed into the Adjumani population, they have to depend on available resources. Many resources are imported, but woodfuel is taken from the same sources, mostly a woodland 3 kilometers Northeast of Adjumani. Wood is getting more and more scarce, but until recently the woodland has not diminished in area (Department of Forestry, 1994). Wood scarcity is becoming more and more critical, even though not yet acute. One problem with relation to refugees is that nobody knows how long they will stay in the area, and how many more will come. Therefore the situation may become critical.

A number of efficiency tests were carried out during the authors visit to the refugee camp in March, 1995. Paal Wendelbo had then been in the refugee camp for two months to develop the gasifier stove to be able to combust the abundance of grass available in the refugee camp, which in any case would be burned in bush-fires. A stove was developed which could gasify the grass similar to the one tested in Denmark. Measurements were carried out on different kinds of grass. Generally the thinner grass burned better than the thicker grass. Obtaining a complete combustion depends on many parameters, especially humidity. The combustion process is also affected by the wind.

In Adjumani refugee camp the stove was tested with 20 cm long straw of grass with two different diameters, 3-4 mm and 7-8 mm respectively. In Table 3 the results of stove efficiency tests carried out on the thin grass are shown. The stove is a larger version than the one used in Denmark. It uses around 0.6 kg of grass. These tests are also carried out with the water boiling test. The results show an efficiency of 25-29%. The water boiling test does not, however, give a good picture of how the stove will work in real life, with different types of cooking. It takes 15-20 minutes for 600 grams of grass to get 4 liters of water boiling and the biomass will burn for another 10-15 minutes keeping the water boiling. In the tests with grass we saw a charcoal effect after the flames have disappeared which was just sufficient to keep the water in the pot boiling for another 25-30 minutes with lid. Therefore a test to measure the temperature in the combustion chamber was carried out.

	Fuel (g)	Water (g)	Efficiency %
TestARC1	0.580	4,000	25.0
TestARC2	0.620	4,000	28.6

Table 3: Results of stove efficiency tests of the gasifier stove in a water boiling test in Adjumani refugee camp. Grass is used with an estimated caloric value of 14 MJ/kg.

The temperature was measured just below the pot, and in the centre of the combustion chamber. Furthermore the temperature of the water in the pot was measured. Figure 2 shows the temperature changes of the gasflames below the pot during a test and the temperature in the water. In this case the small stove was used with 600 gram of grass. The temperature below the pot rapidly reached 400 °C and the gasification and smokeless gas flame occurred after 1-2 minutes. Some smoke occurred when the flame was disturbed by the wind. The average temperature for the first 25 minutes is quite stable, but temperature measurement each 30 seconds shows that the temperature is rapidly changing between 400 and 600 °C. After 25 minutes the grass is burned, and after around 32 minutes the flames stop. After the flames have stopped the grass turns into a solid glowing mass and the temperature in the burning chamber rises to more than 1000 °C. Charcoal burns at around 800°C, oxidising CO to CO_2 provided that there is enough oxygen. The oxidisation occurs just above the coals and heat is mainly transfered as radiation. This radiated heat makes it possible to boil 4 litres of water for another 25 to 30 minutes with lid.

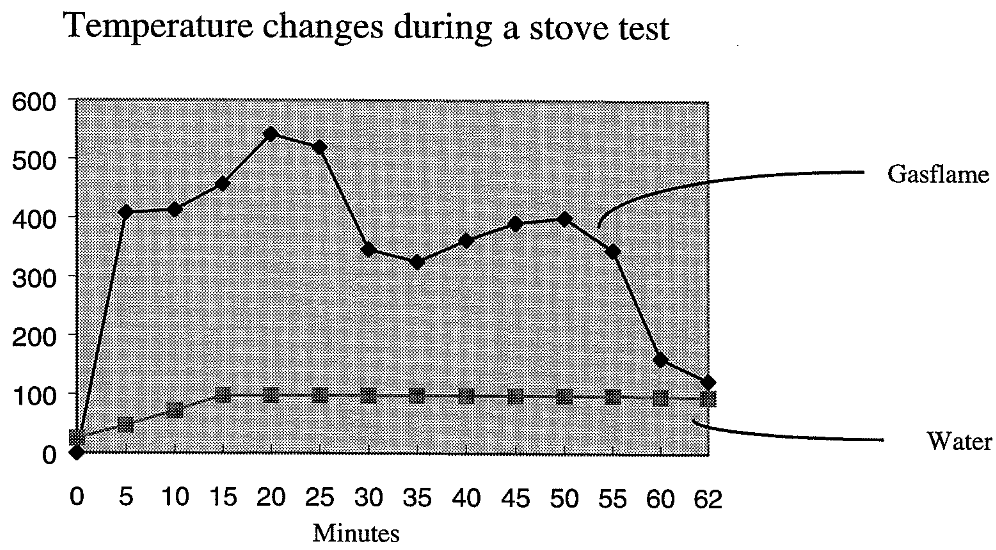

Figure 2. Temperature of gasflames below the pot and temperature in the water during the test.

Advantages - compared to the three-stone stove

The tests carried out on the Peko Pe pyrolysis stove indicate that:

- the stove burns without smoke when sufficient air is supplied
- the emissions of CO are low when sufficient air is supplied
- the stove is easy to ignite
- the stove is rapid in achieving boiling temperature
- when burning grass in Uganda the stove can provide heat enough to boil a meal in around 45 minutes after reaching the boiling temperature
- due to the reduced effect after 25 -30 minutes it is possible for the cook to leave the stove unattended
- the stove is relatively cheap to produce
- the stove is easy to move and carry around.

Disadvantages - compared to the three-stone stove

The tests carried out indicate that:

- metal is needed for producing the stove
- tools and some skills are needed to produce the stove
- the biomass needs some kind of treatment before it can be used in the stove. Which kind of treatment depends on the biomass source
- the stove needs to be produced relatively precisely to obtain the pyrolysis gases, and especially precisely to exploit the final solid combustion. It is not possible at this time to give detailed quantitative data for the construction requirements
- the stove needs dry biomass for achieving the pyrolysis process. The allowed moisture content has not yet been determined.

Conclusions

Four series of tests have been carried out on the pyrolysis gasifier stove. Three sets were conducted at the Technical University of Denmark and one test in Adjumani Refugee camp in Uganda. At the Technical University of Denmark a 500-liter oil barrel was used as a test chamber. It was possible to determine the efficiency, the CO concentration and NMVOC emissions in the chamber while combusting. The barrel was airtight in order to determine air inlet through an air meter and it was provided with a chimney to collect and measure the smoke.

The stove efficiency was found to be 25-27% when burning dry Danish woodchips with a moisture content of 10% and a caloric value of 15MJ/kg. The determination of CO-emissions indicates that there is not sufficient air supply to avoid production of CO. It means that in small closed rooms CO-emissions are too high to completely avoid health effects. No NMVOC were found in the smoke.

The efficiency tests in Adjumani refugee camp show a stove efficiency of 25-29% with an estimated caloric value for the grass of 14 MJ/kg. It has not been possible to determine the water content in the grass. Furthermore it was found in Adjumani refugee camp that the grass stove was able to provide sufficient energy through a solid combustion, after the pyrolysis was stopped, for boiling the water for an additional 25-30 minutes. This was not seen so clearly at the tests on wood chips in Denmark. The performance of the stove has to be changed in order to exploit the energy from the solid combustion on woodchips in Denmark.

Ideas for further improvement of the stove

There is a number of technical options for improving the stove. These include:

- the number of holes in the bottom, the middle and the top of the combustion chamber
- the distance between the combustion chamber and the outer shield
- the diameter and height of the combustion chamber
- studies of the variation of combustion efficiency and emission output depending on biofuel sources in order to examine the stove´s applicability in different climatic seasons. This include studies of the role of moisture percentage on the combustion efficiency and emission output.
-

Socio-economic studies to be carried out include:

- how is the stove received by the cook
- does the stove fulfil the cooks needs for preparing food
- which kind of food can be made on the stove
- can people afford to buy the stove
- can people afford to buy the fuel that is necessary
- to which extent are people willing to accept preparation of the biomass if necessary.

Acknowledgements

The stove tests at the Technical University of Denmark were performed in collaboration with Erik Kofoed and Jesper Schramm at the Department of Energy Engineering. Special thanks are due to Christian Morgen and Jan Jensen for assistance in completing the tests in Denmark. Thanks should also be given to the Norwegian Association for the Disabled and ACCORD for making the tests possible in Uganda.

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