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Small Scale Briquetting and Carbonisation of Organic Residues for Fuel

Dr.-Ing. Heino Vest (2003)

Deforestation and firewood shortage are growing problems in many countries of the South. The energy and fuel shortage in these countries is not only a problem of the rural areas but also of the densely populated poor margins of medium and large cities. While the traditional types of fuel (fire wood and charcoal) become more and more exhausted, modern fuels (paraffin, coal, mineral oil, electricity) are not affordable for the majority of the poor.

At the same time, the generation of organic waste in urban areas poses a growing challenge to the local waste management system. Organic waste (30-50% of the total waste) is not only a problem because of its large volume but also because it causes bio-chemical reactions on landfill sites leading to the formation of landfill gas (methane) and leachates that pollute atmosphere and groundwater. In rural areas, agricultural residues (straw, rice and coffee husks, coconut and groundnut shells, bagasse, coir dust, etc.) are generated in large volumes and often not utilised at all.

Both urban and rural organic residues and wastes could be used as alternative domestic fuel if offered in an acceptable form and at a reasonable price. Briquetting and carbonisation are common processes to transfer the organic waste into appropriate domestic fuel.

1. Introductory remarks

The fuel crisis in many parts of the developing world caused by an increasing shortage of traditional fuel (firewood, charcoal) creates a need for alternative sources of domestic fuel. Agricultural and forestry residues in rural areas and parts of the organic waste generated in urban areas (e.g. waste paper) are such alternative sources of energy.

Nevertheless, organic wastes from agriculture, forestry and urban dwellings are generally not directly suitable to be used as domestic fuel. Low density, inconvenient shape, high moisture content, low calorific value, etc. are some of the hampering factors. Further processing such as shredding, densification (compaction) and shaping (further on called briquetting), and carbonisation (pyrolysis) are needed to transform the various types of organic waste into an acceptable form of domestic fuel.

There have been numerous attempts in industrialised and developing countries to briquette agricultural and forestry residues for fuel. Not all of them were successful. Until today, fuel from agricultural and forestry waste plays only a minor role in the worldwide supply of energy and heat.

Briquetting and/or carbonisation plants – especially when run on a large scale basis – require a stable supply of raw material which could only be granted by e.g. large farms and frequent harvesting campaigns. Success also depends on good access to the customer, whether it is supplying to a few large scale consumers or to a great number of small consumers. From the technical point of view, the alternative fuel produced must be competitive in its combustion properties, in its transport and storage requirements, and of course in its price. People are only willing to change to a new fuel if it is reliable, convenient and cheap.

Small scale production and application of fuel from agricultural, forestry and urban organic waste seem to have a comparative advantage, because they require less investment, are flexible in respect to fluctuation in raw material supply, type and quality, and even more important, are often poverty driven, which lowers the acceptance barrier against the new fuel. A thorough investigation into the availability of raw material, the consumer habits, the access to technology and the limiting cost factors is compulsory before starting briquetting and carbonisation projects.

Although the present paper also gives some hints on the social acceptance and economic aspects of briquettes, it mainly concentrates on the technical aspect of briquetting and carbonisation. A variety of examples of shredding, briquetting and carbonisation techniques from around the world are presented here.

2. Sources of raw material

The main raw material sources are:

- **Field residues**, such as:
    - maize, wheat, rice, millet, sorghum straw
    - cotton residues
    - banana leaves
    - forestry residues like dead trees, leaves and branches
    - reed and sedge, weeds
    - etc.
- **Process residues**, such as:
    - Sugar-cane bagasse
    - coffee and rice husks
    - coconut and groundnut shells
    - coir dust
    - tree barks, saw dust and shavings
    - charcoal dust
    - etc.
- **Domestic and industrial organic waste**, such as:
    - waste paper and cardboard
    - furniture waste

Depending on the amount of raw material available, the type of fuel to be produced and the availability of funds and technical know-how, different shredding, briquetting and carbonisation techniques are applied.

3. Technical options for shredding, briquetting and carbonisation

Fuel produced from organic waste should be homogeneous, compact, dry, and of high carbon content to be applicable as domestic fuel. The ash content and its composition also play a certain role, particularly if the fuel is burned in industrial boilers.

Depending on the type of raw material, the three major processes – shredding, briquetting and carbonisation – can be applied in different sequences. In some cases it might be advisable to carbonate the residue prior to shredding and briquetting while other residues request shredding and briquetting prior to carbonisation. Other applications do not need a carbonisation step at all.

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3.1 Shredding

Due to the large variety of agricultural, forestry and domestic organic residues and a limited number of briquetting (and carbonisation) techniques it is important to homogenise and condition the feed material for the subsequent processes.

The most important conditioning step is shredding. Only small size particles and homogenous material are adequate to be fed into the compaction device. Material with a high water content (e.g. reed, sledge) is much easier to dry after shredding.

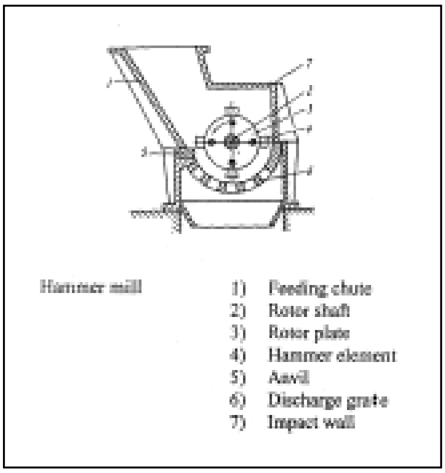
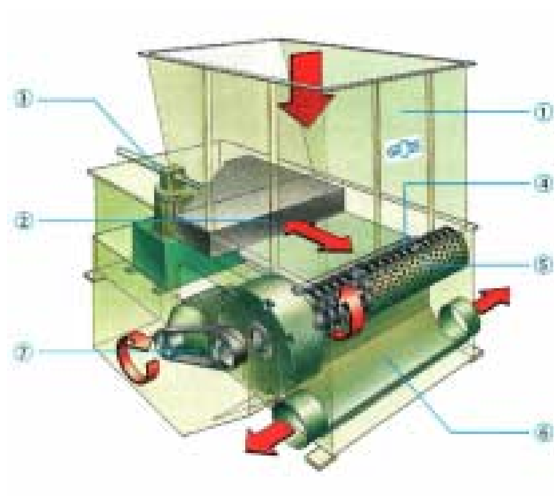


Fig. 1: Hammer mill for brittle feed material

Fig. 2: Cutting mill for flexible soft feed material

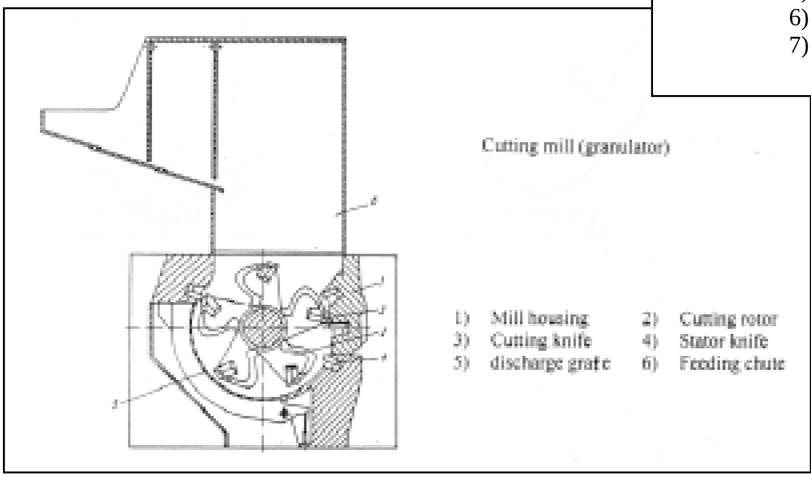
Depending on the brittleness of the raw material (e.g. coconut shell compared to fresh leaves or straw), hammer or cutting mills are used for shredding. While a hammer mill (Fig. 1) uses mainly impact forces for the comminution process, cutting mills (Fig. 2) cut the material into pieces.

Fig. 3 shows a modern cutting mill with a cylindrical cutting rotor suitable for a variety of feed material (e.g. waste paper, wood residues, etc.).



2) Feeding slide
3) Hydraulic cylinder
4) Cutting rotor
5) Outlet screen
6) Chip transport pipe
7) Drive

Fig. 3: Modern universal cutting mill with cylindrical cutting rotor /1/



← Fig. 2: Cutting mill for flexible soft feed material

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In many developing countries local craftsmen and workshops are able to manufacture shredders for agricultural waste locally.

Picture 1 shows a mobile shredder for agricultural residues from Mali.

Pic. 1: Mobile shredder for agricultural residues from Mali /2/

3.2 Briquetting

The briquetting technologies can be divided into:

- High pressure compaction
- Medium pressure compaction assisted by a heating device
- Low pressure compaction with a binding agent.

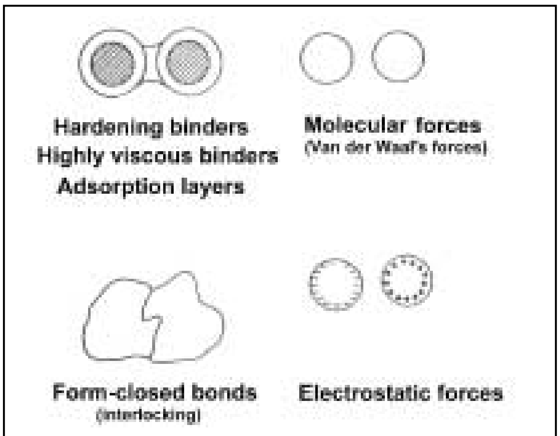


Fig. 4: Binding mechanism /3/

Depending on the type of material, the pressure applied and the binder used, different binding methods are used.

The physical properties (moisture content, bulk density, void volume and thermal properties) of the biomass are the most important factors in the binding process of biomass densification.

The densification of biomass under high pressure results in mechanical interlocking and increased adhesion/cohesion (molecular forces like van der Waal's forces) of the solid particles, which form intermolecular bonds in the contact area.

Additives of high viscous bonding media (binders), such as tar, molasses and other molecular weight organic liquid can form bonds very similar to solid bridges. Adhesive forces at the solid/liquid interface and cohesion forces within the solid are used for binding. Lignin of biomass/wood which is deliberated under high pressure and/or temperature can also be assumed to help binding in this way.

Apart from lignin, which is gained from the feed material itself, other free atoms or molecules (e.g. moisture) can be attracted from the surrounding atmosphere to form thin adsorption layers. They also support the formation of bonds between the individual particles.

High and medium pressure compaction

High and medium pressure compaction normally does not use any additional binder. Normally, the briquetting process bases either on screw press or piston press technology. Fig. 5 gives simplified sketches of both types of technology.

Other briquetting technologies are less applicable in developing countries because of high investment costs and large throughputs, e.g. roller-presses to produce pellets or briquettes.

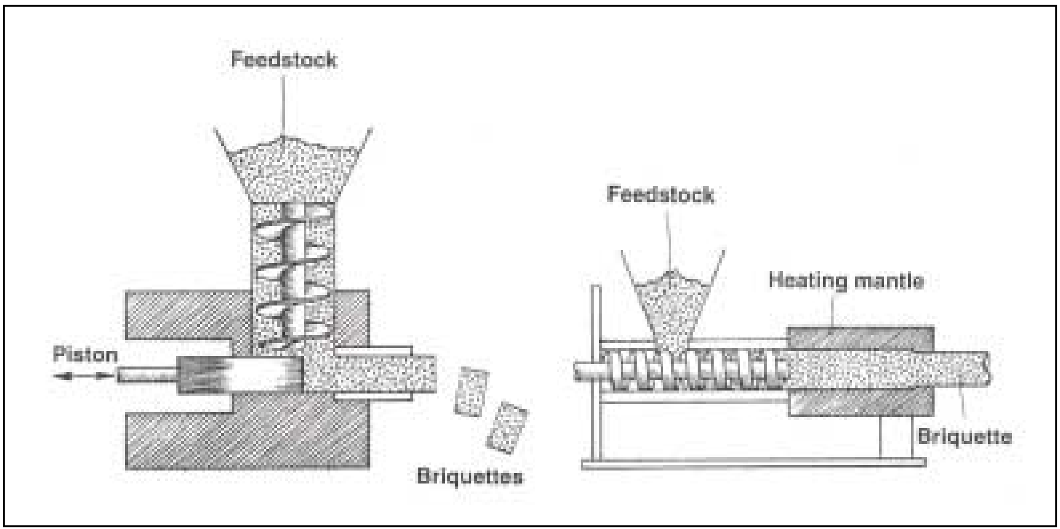


Fig. 5: Simplified sketch of screw press and piston press technology /4/

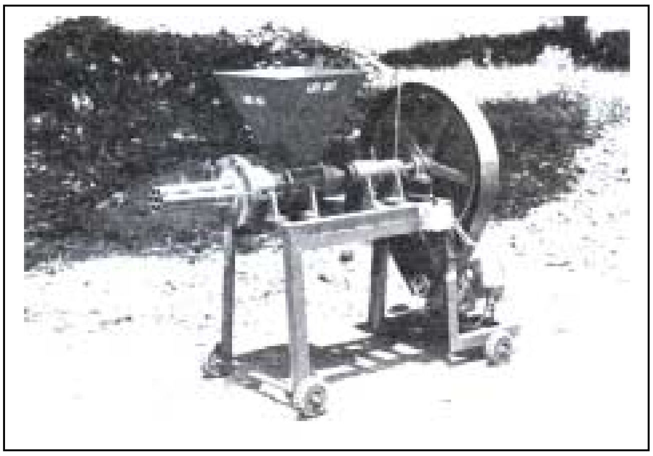
- **Screw press**

In a screw press or screw extruder, the rotating screw takes the material from the feed port, through the barrel, and compacts it against a die which assists the build-up of a pressure gradient along the screw. Thus, the extruder features three distinct zones: feed, transport, and extrusion zones. The important forces that influence the compaction of the feed material play their role mostly in the compression zone near to the extrusion die.

The frictional forces between feed material and barrel/screw, the internal friction in the material and external heating device (of the extrusion zone) cause an increase in temperature (up to 300°C), which softens the feed material. Lignin from the biomass is set free and acts as gliding and binding agent. The speed of densification, the energy consumption of the press and the quality of the briquettes produced depend on:

- flowability and cohesion of the feed material
- particle size and distribution
- surface forces
- adhesiveness

Pictures 2 and 3 show different models of screw extruders and their product (Pic. 4).



Pic. 2: Locally manufactured screw extruder from Thailand /5/

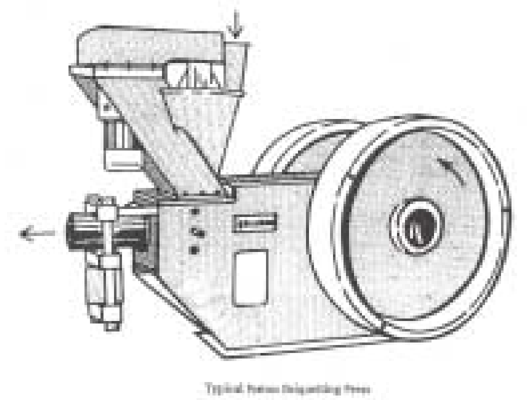
Pic. 3: Locally manufactured screw extruder from Mali /2/

Pic. 4: Extruder briquettes from Thai Production /5/

➢ Piston press

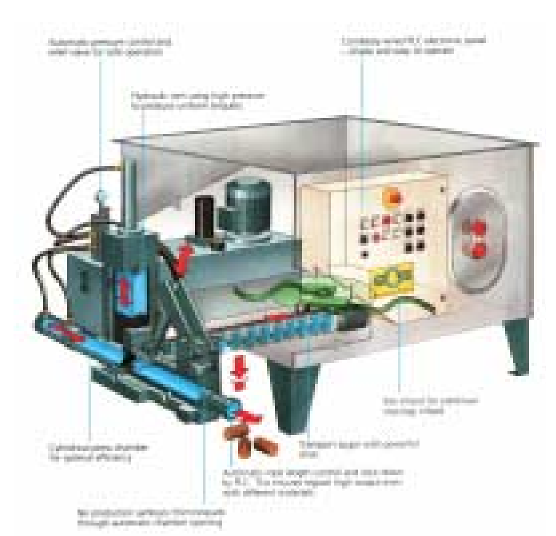
Piston presses punch the feed material into a die with very high pressure, either mechanically by a reciprocating ram powered by a massive flywheel, or by a hydraulically driven piston. Thereby, the mass is compressed and forms a very dense briquette. Some modern (hydraulically operated) machines apply pressure not only in longitudinal but also in radial direction.

Picture 5 shows a mechanically driven piston briquetting press.



Pic. 5: Mechanical piston briquetting Press /6/

Picture 6 shows a modern hydraulically operated piston briquetting press.



Pic. 6: Hydraulically operated piston press /1/

Comparison of a screw extruder and a piston press

	Piston press	Screw extruder
Optimum moisture content of raw material	10-15%	8-9%
Wear of contact parts	low in case of ram and die	high in case of screw
Output from the machine	in strokes	continuous
Power consumption	50 kWh/ton	60 kWh/ton
Density of briquette	1-1.2 gm/cm³	1-1.4 gm/cm³
Maintenance	high	low
Combustion performance of briquettes	not so good	very good
Carbonisation to charcoal	not possible	makes good charcoal
Suitability in gasifiers	not suitable	suitable
Homogeneity of briquettes	non-homogeneous	homogeneous

Tab. 1: Comparison of a screw extruder and a piston press /6/

Screw presses produce high quality briquettes with a homogenous structure and good combustibility, and they require only little maintenance. The main disadvantage is that the wear of the screw leads to elevated spare part costs.

Low pressure compaction

Low pressure briquetting needs a binding agent to assist the formation of bonds between the biomass particles. There are various binding agents in use which can be divided into two main groups: organic and inorganic binders. The most important binders are:

- **Organic binders**
  - Molasses
  - Coal tar
  - Bitumen
  - Starch
  - Resin
- **Inorganic binders**
  - Clay
  - Cement
  - Lime
  - Sulphite liquor

During the compaction process the briquettes are brought into shape without giving them substantial strength. Only after a subsequent curing step (drying, burning, chemical reaction, etc.) the "green" briquettes will develop the required strength and stability.

Some interesting low pressure compaction methods for briquettes from biomass are described in the following text.

➢ Hand moulded briquettes

Hand moulds are the simplest devices to form small quantities of briquettes. Picture 7 shows hand moulds used in Mali for the production of briquettes from waste charcoal dust and molasses as binding agent.

The briquettes reach their final strength after drying in the sun or a gentle heat treatment in a curing furnace.

Pic. 7: Hand moulds for charcoal dust and molasses binder in Mali /2/

A wide spread semi-mechanised method to form briquettes from mineral coal is found in China. Ground coal is mixed with water and approximately 20% of clay binder and formed into so-called honeycomb briquettes by a mechanised briquetting press (Picture 8).

Pic. 8: Chinese semi-mechanised briquetting press /7/

The "green" briquettes reach their final strength and stability after drying some days in a dry environment.
A very interesting method to form briquettes from biomass was found in Kenya and Benin. There, biomass of fine particle size (saw dust, rice husks, wood shavings, charcoal dust, etc.) was mixed with approximately 20% of (waste) paper pulp and formed into briquettes in a manually operated piston press (Picture 9).

The briquettes (Picture 10) were dried in the sun and gained strength due to the property of paper fibre in building up hydrogen bonds among themselves and the biomass.

Pic. 9: Manual briquetting press for biomass and waste paper in Benin /8/

Pic. 10: Manually produced briquettes from biomass and waste paper in Benin /8/

3.3 Carbonisation

In principle, briquettes made from the various types of biomass can be used as fuel without any subsequent carbonisation. Nevertheless, the burning of briquettes of this type has some disadvantages, for example

- Reduced ignition and burning properties
- Increased generation of smoke
- Low heat value
- Not stable under wet condition

Therefore, it is often advisable to add a carbonisation step in order to produce a type of charcoal briquettes.

The production of carbonised briquettes from agricultural residues may follow two possible production sequences:

a) Carbonisation→grinding→briquetting
b) Grinding→briquetting→carbonisation.

Carbonisation is an incomplete pyrolysis (Pyrolysis = heating of organic material in the absence of oxygen to a temperature of 900-1000 °C to transfer all hydrocarbons into gaseous compounds). During carbonisation the feed material is heated only until approximately 600 °C.

During the process, burnable gases like CO, CH_4, H_2, formaldehyde, methanol, formic and acetic acid as well as non-burnable gases like CO_2 and H_2O and liquid tar are released. The off-gas of the process is of high energetic value and can be used to balance the energy and heat demand of the carbonisation.

Depending on the type of feed material two types of carbonisation furnaces are in use.

Coarse material of medium size (coconut and groundnut shells, tree bark, etc. or briquettes fine material) is carbonised in continuously working **shaft furnaces**.

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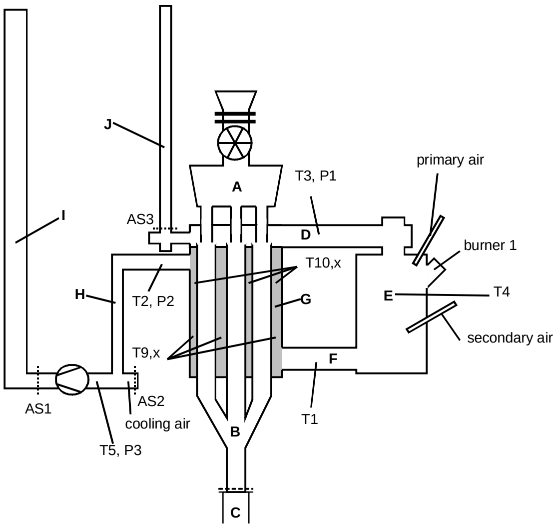
Carbonisation of fine material takes place in **rotary kilns** or stationary vessel equipped with a stirring device (for example a screw feed).

The vessels are usually heated externally using natural gas, liquid fuel or the off-gas of the carbonisation process itself. Figure 6 gives a sample of an experimental shaft furnace in Malaysia, while figure 7 shows a screw carboniser operating on a pilot scheme in The Senegal.



A: feed system
B: discharge system (screw conveyors)
C: collecting drum
D: pyrolysis gas
E: combustion
F: flue gas
G: reactor
H: exhaust gas
I: chimney
J: emergency chimney

Fig. 6: Continuously operating shaft furnace for the carbonisation of coarse organic residues /9/

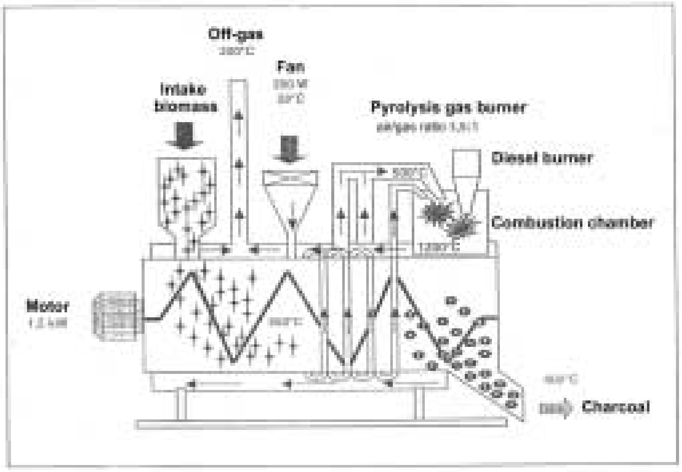


Fig. 7: Screw carboniser, system “Pro Natura” for fine feed organic feed

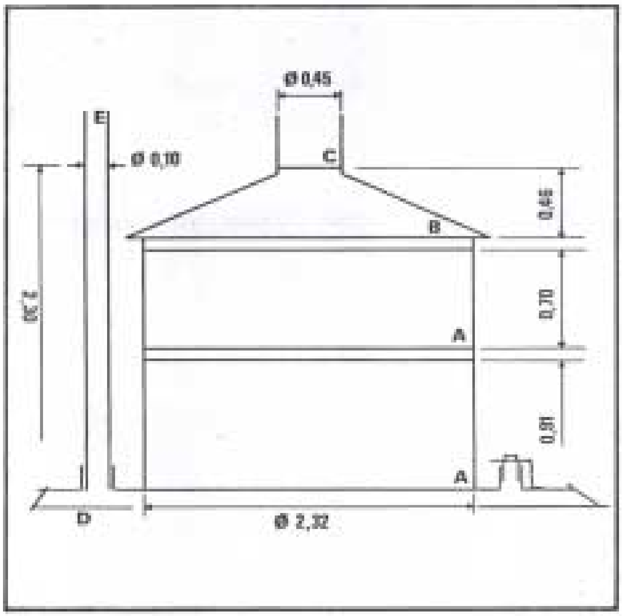


Fig. 8: Improved reverse draught charcoal kiln with an iron sheet housing /11/

Small amounts of large to medium size pieces of organic material such as pieces of wood, timber cut-offs or pre-fabricated briquettes can also be carbonated in traditional charcoal kilns or chamber furnaces. Figure 8 shows an improved tradition charcoal kiln with an iron sheet housing.

Picture 11 shows a chamber furnace manufactured and used in Mali for the carbonisation of extruded briquettes.

Pic.11: Chamber furnace for the carbonisation of briquettes from agricultural residues in Mali /2/

A very interesting design of a small scale carbonisation or charring kiln for shredded sugarcane trash was developed in India (see figure 9).

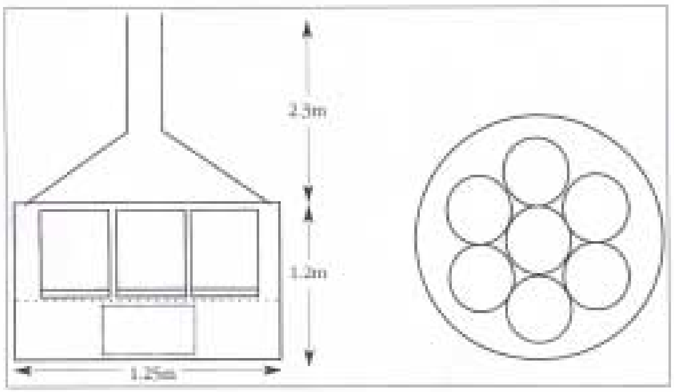


Fig. 9: Charring kiln for fine agricultural residues /12/

The kiln is basically a cylindrical brick and mud structure, with a grid made of steel bars fitted near the bottom. The space below the grid is the combustion chamber, where one part of the trash is burned to generate the required heat for the carbonisation process. A chimney fits on top of the oven to provide the draught for keeping the fire going in the oven.

Depending on the size, the oven contains 7 to 14 closed retorts at a time. To remove and load retorts in the oven, the chimney has to be lifted up. Each retort holds 3 kg of trash, and yields 1 kg of char at the end of the charring time, which normally takes 40 minutes.

Whatever process is applied to carbonise medium to small size agricultural waste, the charred material needs a subsequent grinding and briquetting step for which an appropriate binder is required.

4. Environmental considerations

Carbonisation takes place under absence or restriction of oxygen. Apart from the emission of CO_2, NO_X and dust, products of incomplete combustion (PIC), such as CO, vaporous and liquid C_XH_Y, soot and acids like formic and acetic acid are released. So-called polycyclic aromatic hydrocarbons (PACs) are emitted, which are known to be highly carcinogenic.

The best protection of the environment is offered by afterburning systems, which transform all incomplete combustion products (CO, C_XH_Y, soot, PAC) into CO_2 and H_2O. Modern designs even use the calorific energy of the off-gas to generate the necessary heat for the carbonisation process itself (see again figure 6 and 7).

In India, pyrolysis gas burners have been tested, which burn the off-gas of carbonisation (pyrolysis) processes (see figure 10 and 11). The basic operation steps of theses carbonisation units are:

- Carbonisation chamber is filled with, for example, wood pellets
- Pellets are lit on top
- Pellets are allowed top burn for a few minutes until pyrolysis has moved down into the column and spread over the entire top surface
- Top cover with burner is placed on carbonisation chamber
- Emitting air and gas mixture is lit in the burner
- Flame is sustained until pellets are turned completely to charcoal
- Carbonisation chamber is sealed and allowed to cool
- Charcoal is removed.

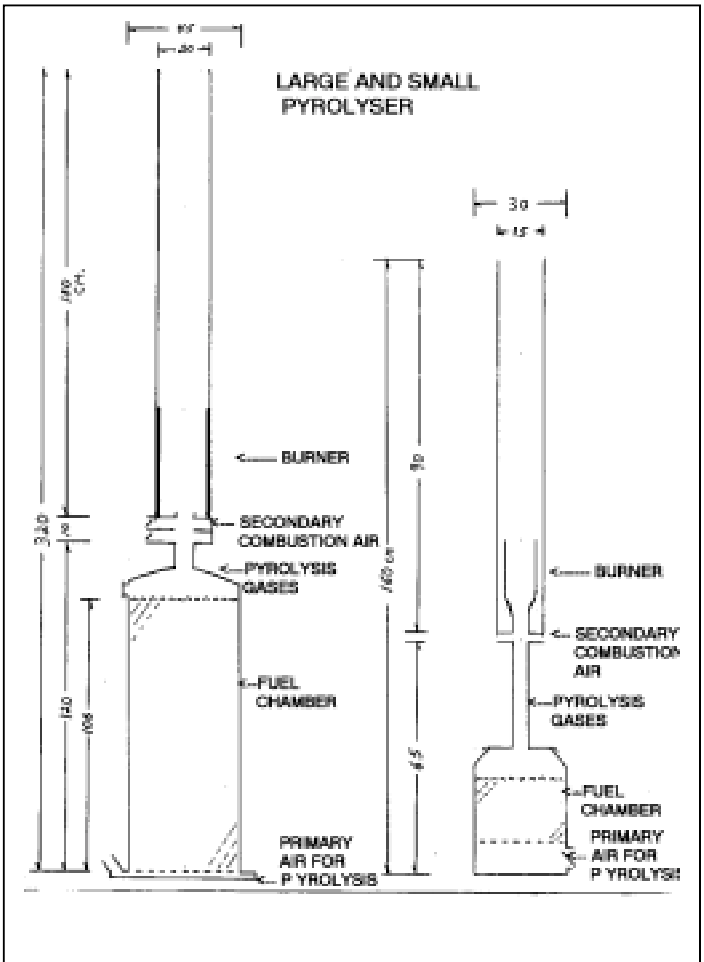


Fig. 10: Principle of charcoal production (top-down process) using a pyrolysis burner to afterburn the pyrolysis gases /13/

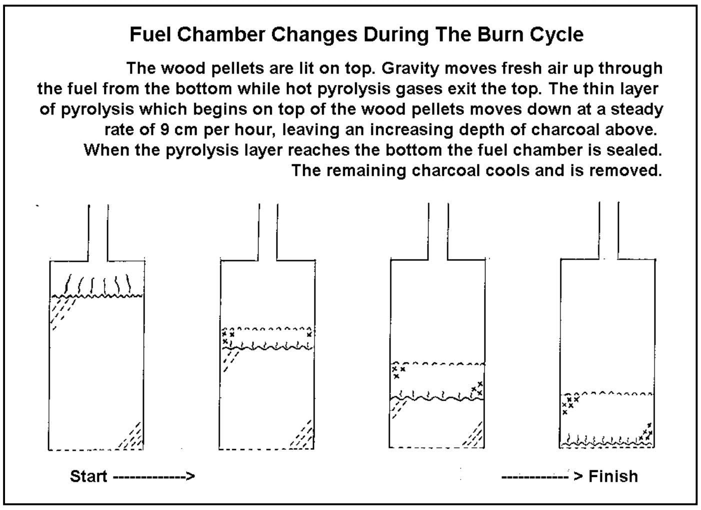


Fig. 11: Carbonisation sequence

5. Conclusions

Residues from agriculture and forestry are a valuable source of raw material for the production of domestic fuel.

Normally a grinding, briquetting and carbonisation step is involved. The sequence in which these steps are applied depend on the type of raw material used and the type of fuel produced. For all steps and levels of productivity appropriate technologies are available, which often have their origin in the developing countries themselves.

Off-gases which are generated during the carbonisation process have to be taken care of. They should either be used as fuel gas to maintain the carbonisation process itself, or should be afterburned to avoid the emission of incomplete combustion products.

To be marketable, domestic fuel from agricultural and forestry residues must be cheaper then tradition charcoal or other competing fuels. The local conditions – availability of raw material, technology and man power as well as the price level of alternative fuels – decide whether a production of domestic fuel from agricultural or forestry residues is economically viable.

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