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Charcoal production processes: an overview

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1. Introduction

Recent advances in knowledge about the production and properties of charcoal presage its expanded use as a renewable fuel, reductant, adsorbent, and soil amendment [1]. Biomass pyrolysis is a fundamental thermochemical conversion process that is of both industrial and ecological importance. In Thailand, transition in the demographic and industrial trends has sparked a renewed interest in urban household energy consumption [2]. According to the country's energy consumption statistics from the department of alternative energy development and efficiency, the trend of charcoal consumption has increased in the last five years [3]. Charcoal is mainly used in the household sector, with a total of about 4.2 million households [4]. The rural area represents about 97% of the total charcoal consumption. The main objectives of this review is to give an overview of some technologies performed to produce charcoal both worldwide and in Thailand and also to characterize the charcoal physicochemical and energy properties.

The largest share of the overall charcoal production in the world is produced in different types of batch kilns. Modern industrial processes for charcoal production operate at atmospheric pressure, and most of them use wood as the feedstock. The most ancient of which are the pit or mound turf kilns. Three types of heating to initiate the carbonisation and maintain high temperatures during the processes are generally used [5] : Internal heating where part of the raw material is burnt under controlled air flow, ii) External heating where the retort is heated from the outside and no oxygen enters the reactor and iii) Heating with recirculated gas where pyroligneous vapours are burnt in an external combustion chamber and directed into the reactor where it is in direct contact with the raw material (Figure 1).

2. Internal Heating

More than 90% of the charcoal technologies employ internal heating based on the partial combustion of the feedstock to manufacture charcoal. In this category one finds the kilns which are made of concrete or brick. The kiln design is simple and the investment costs are usually low.

2.1 Traditional wood carbonization technologies

These kilns are the most widespread kilns worlwide, due to its simplicity and low cost, especially for small producers [6]. They are recommended for flat sites and, in general, are built with baked bricks, clay and sand mortar. Normally, more than one kiln is used and they are disposed as batteries or tandems [7]. The operation of the kiln starts with the firewood loading, followed by carbonization and unloading of charcoal. The use of dry firewood is essential for good carbonization, because the firewood moisture directly influences the yield of the kiln.

The following section is a succinct description of some charcoal processes applying these different fundamentals principles of heating.

The constraints of the traditional technologies for charcoal production concern the difficulty in the mechanization of firewood loading and charcoal unloading. During unloading, charcoal fragmentations can occur. These kilns are mostly without any instrumentation to control the process with a negative impact on the gravimetric yield and productivity. It depends on the shape of the kiln, a high heterogeneity in the drying, pre-pyrolysis and the pyrolysis profiles are observed (Figure 2).

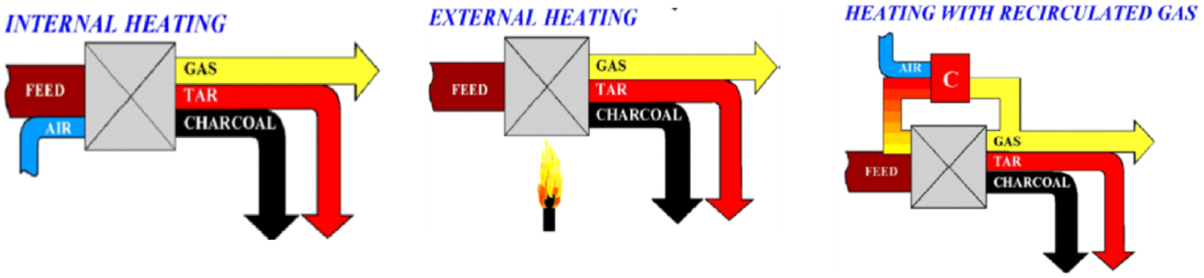

Figure 1. Different principles of heating to produce charcoal [5].

Figure 2. Traditional kilns in Brazil and Cambodia.

Figure 3. Charcoal producers location in Thailand [19].

Table 1. Charcoal characteristics from different biomasses: MC=Moisture Content; VM = Volatile Matters; FC = Fixed Carbon: HHV = High Heating Value. w.b = wet basis

Region	Type of feedstocks	Proximate analysis (w.b%)				
		MC	VM	FC	Ash	HHV ($kcal.kg^{-1}$)
Central	Mangrove	1.66	29.15	67.53	1.66	6,799.38
Northeast	Rain Tree	1.47	18.22	78.52	1.79	6,823.12
South	Rubber	1.11	15.24	78.98	4.67	7,373.73

In Thailand, most of them are similar to the one used in the other countries. Figure 3 shows the location of the main producers in different regions of Thailand. In the Northeast region, charcoal producers used pit kiln. The mound turf kiln is made from stake of wood covered with sawdust or rice husk. The mound turf kiln consume the simple process to produce charcoal by using branches to support the layer of earth and smouldering wood to controlling access air and reducing heat loss during the process. The kilns used by Central region producers are brick kilns using the principle of internal heating Based on the partial combustion of the feedstock. The kilns size about 4.5-5 meter height and a 5 to5.5 meter diameter. The kilns have one main door opening to load and unload charcoal. After loading, the door can both close with simply brick over and sealed with mud during the carbonization process. The vents around the base of kiln are used to controlled air infiltration. Only on way smoke can exhausted from the kiln by the hold on the top of the kiln called “eye hold” [8]. These kilns are the most widespread kilns worldwide, due to its simplicity and low cost, especially for small producers. If they are well controlled, these kilns can produce higher quality of charcoal for yields [9].

Measurable and important physical characteristics of biomass including moisture, volatile matter, fixed carbon, ash, and HHV are shown in Table 1. These values comprise the proximate and ultimate analyses first standardized in the coal industry and then adopted by biomass researchers.

2.2 Industrial technologies

In a larger scale, the most commonly used technology are the Missouri kiln mainly which are encountered mainly in Brazil. They are made of poured concrete and have rectangular or square shape with a volume capacity of 180 m^3 up to 800 m^3 (Figure 4). These technologies are mechanized in order to improve their capacity of charcoal production. The kilns are properly loaded with round wood mainly from eucalyptus plantations and doors at each end allow the use of front-end loaders for charging and discharging. An adapted logistic has been developed by the multinational group to produce large amount of charcoal.

Along each side of the kiln are four chimneys with air vents, and on the roof there are six to eight air vents which can be sealed during the cooling period. In the centre of the kiln, are laid brands from previous burns partially charred and dried in order to ignite the kiln. Part of the wood are burnt within the kiln to carbonise the reminder. The charcoal yield from a Missouri kiln may vary from 20 to 30% depending on operational conditions and feedstock used. The cycle time varies from 7 days to more than 30 days in a warm climate [5]. New researches in order to improve the production of charcoal are carrying out on i)cooling phase time reduction, ii) size increasing and iii) hot gas treatment. Capacity increased up to 2000 m^3 and cooling time reducing from weeks to days. Recently, the larger Missouri kiln based concept in the world has been launched in Brazil with a capacity of 2000 m^3 (FAP2000, Brazil [20]) connected to a gas incinerator (Figure 5). This kiln can produce 10.000 t of charcoal a year.

A recent innovation to improve cooling phase was developed by Veradas system [21]. It consists in 16 kilns are set up in 4 integrated structures (Figure 6). Each integrated structure is cover by a roof aiming to protect the kilns from damage caused by sun, rain and other weather situations. In each integrated structure the kilns are linked one to another by outside pipelines to allow hot smoke transfer. The thermic energy from the smokes will help to dry wood resulting in a better conversion wood/charcoal – the called yield (in tons of charcoal per tons of dry basis wood).

Figure 4. Brick kilns in Brazil.

Figure 5. Larger charcoal kiln with 2000 m^3 capacity coupled to with gas incineration (Brazil).

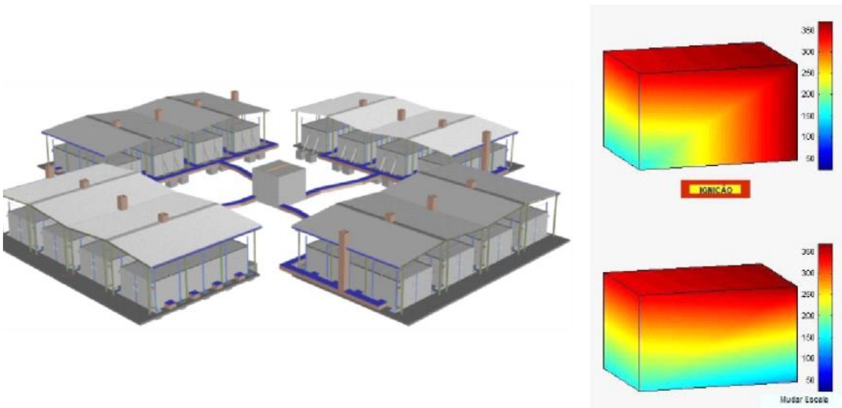

Figure 6. Schematic Verada System with 4 integrated structure coupled to a removed top roof + Carboraad software temperature control (Brazil).

The kiln roof has no dome shape. It is an exclusivity of VEREDAS SYSTEM once the kiln roof is done by carbon steel panels. The panels are covered by thermic insulating plates. Both panels and thermic insulating plates are removable. The insulating material is removed when the carbonization ceases aiming to accelerate the charcoal cooling process increasing the kiln productivity. The carbon steel panels are removed when the cooling process ceases aiming to unload charcoal and reload wood to new batch 100% made by machines. The developer claims a total cycle of 192 hours (8 days) is set up as following: i) 4 hours: wood load and kiln maintenance, ii) 20 hours: kiln ignition plus wood drying, iii) 72 hours: wood carbonization, iv) 92 hours: charcoal cooling and v) 4 hours: charcoal unload. This new technology is supposed to give 35% in terms of yield. It means 9.3 tons/batch or 390 tons/kiln/year. A standard plant of 16 kilns is project to produce about 6240 tons/year of charcoal with maximum 4% moisture content and about 75% fixed carbon. The scientific control of wood drying, carbonization and charcoal cooling is done with the software CARBORAAD which is running since year 2010 at several Brazilian charcoal producers with proved results in average of 25% gains of productivity compared with the actual standard brick kilns of any kind.

In Europe, most of charcoal kilns are steel retort. Among these technologies, the CML process [10] is one of the most spread in France. A production plant is a standardized unit comprising 12 production kilns linked to a system of depollution which incinerates the waste gases (Figure 7).

Charcoal is produced in cylindrical kilns fitted with a lid at the top, and a discharge hatch in the base. Entry of air is controlled by manual valves positioned at the base and around the lower sides of the kilns. A computerized system, developed by the CIRAD, permits both the continuous monitoring of the carbonization process, and the control of the production. The total cycle time for one batch is 20 hours, with 1 hour for charging/discharging, 6 to 8 hours for carbonisation and 14 to 15 hours for cooling. The charcoal yield is 22-24% on dry basis depending on feedstock used. The central combustion chamber makes it easy to recover heat from the system for wood drying or electricity production (Figure 8). One plant with 12 CML retorts has a production capacity of 2- 3.000 tons/year. 15000 tons of dry wood is necessary to produce 3000tons of charcoal per year. The flow of the pyrolysis gaz is 6 tons per hour with a calorific value (PCI) of 2.3 MJ/kg that gives a capacity of 3,6 MW th. With a conversion yield of 10% in a steam boiler and steam turbine or steam engine unit, the installed power is 360 kWe.

Figure 7. CML Process (France).

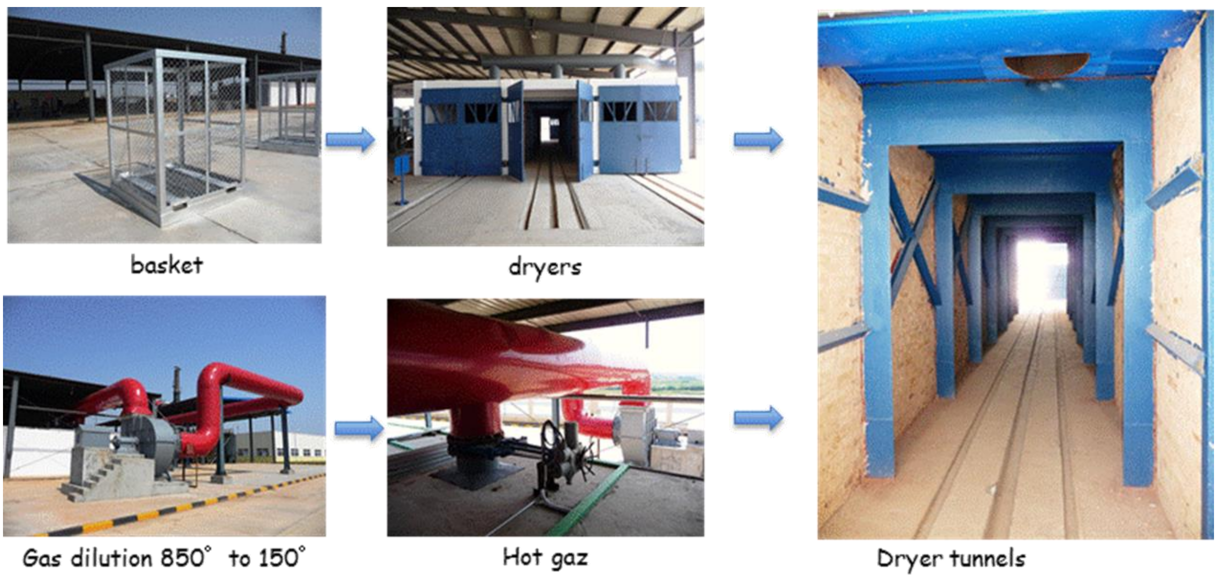

Figure 8. Dryers using diluted gas from CML incinerator (China).

Figure 9. Charbon Engineering (Netherland), VMR (France) and Sol Carbon (Belgium) technologies using external heating.

3. External heating

We remind in these processes, part of the pyroligneous vapours are burnt in an external combustion chamber and directed into the reactor where it is in direct contact with the raw material. These technologies are few and expensive compare to the previous one. Their production capacity varies from 3 to 10.000t/year. Figure 9 Shows 3 technologies developed in Europe: Carbon engineering (Netherland), VMR (France) and Sol Carbon (Belgium).

The Charbon engineering technology [11] is the most spread even if the number of units at this time is very lilmited (3). This technology is a twin retort system is a semi-continuous production module, with a capacity of 1.000 tons of charcoal per furnace per year. One module consists of two retorts, placed in an insulated oven, which is mounted on an armed concrete floor and placed in a hall. The hall should be provided with a monorail and overhead crane that enables lifting the retort vessels into and out of the carbonization unit. A modified fork-lift and often also a woodcutter are necessary.

In each of the two retorts a vessel with dried fresh wood is to be placed alternately. Carbonization of one vessel usually takes about between eight hours. When one vessel has reached the carbonization temperature (ca. 500°C), thermal decomposition takes place, and pyrolysis gasses are emitted from the vessel. These gasses are combusted in-situ to provide the heat supply for heating up the other vessel (Figure 10). LPG is used to provide heat for the initial process start-up. After carbonization, the hot vessels are left for a 35 hours cooling period before emptying.

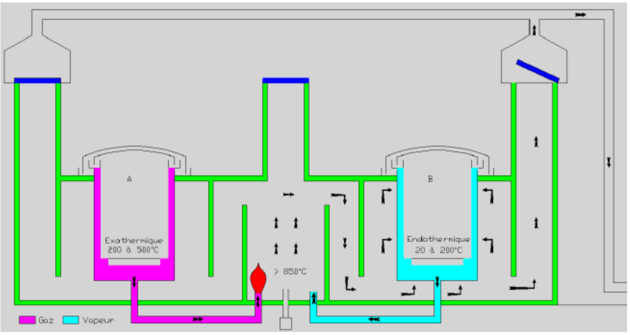

Figure 10. Pyrolysis gases flow in the module: red = pyrolysis; blue = drying.

Wood and residues from sawmills or similar wood processing industries are suitable. Particle size required is 10 to 30 cm, the wood has to be dried prior to carbonization. Vessels with fresh wood are placed on a pre-drying platform, and dried from the pyrolysis off-gases to acceptable moisture content levels (20%on a wet basis).

4. Heating with recirculated gas

The Lambiotte carbonisation process is the most known continuous process. The retort has the shape of a vertical cylinder with a fed opening at the top and a discharge cone at the bottom. Wood is transported to the top of the retort by a hoist and enters the retort through a lock-hopper. On its way down, the wood passes three zones, that is, the drying, the carbonisation and the cooling zone. This technology has been widely cited and described in the literature [5, 12].

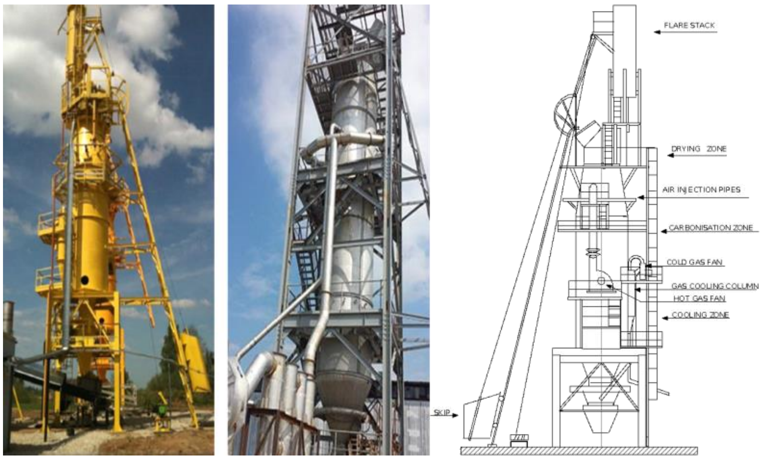

Figure 11. Lambiotte technologies (Latvia).

The DPC technology [13] in Brazil uses the principle of heating with recirculated gas as well. This technology can produce from 3000 up to 15.000t/year of charcoal, depending on the desired capacity of the charcoal plant [14-15]. The basic concepts of the DPC process are:

1 – Utilization of the emitted gases – condensable and nom condensable – as a source of the thermal energy required by the carbonization process.

2 – Utilization of gases emitted during the pyrolysis step as a heat carrier for the endothermic stage of the pyrolysis.

3 – The functions of wood drying, pyrolysis and the charcoal are performed simultaneous and independently into at least three reactors (Figure 12**)**. The emitted gases during pyrolysis with a significant heating value are burned in a combustion chamber, generating hot gases which are transported to the reactor performing the wood drying. In the DPC process charcoal can be made from virtually any material. Wood, straw, coconut shells, bones, babassu, palm coconut, Elephant grass and a variety of other biomass can be used. Average charcoal yield is estimated around 34% on dry basis.

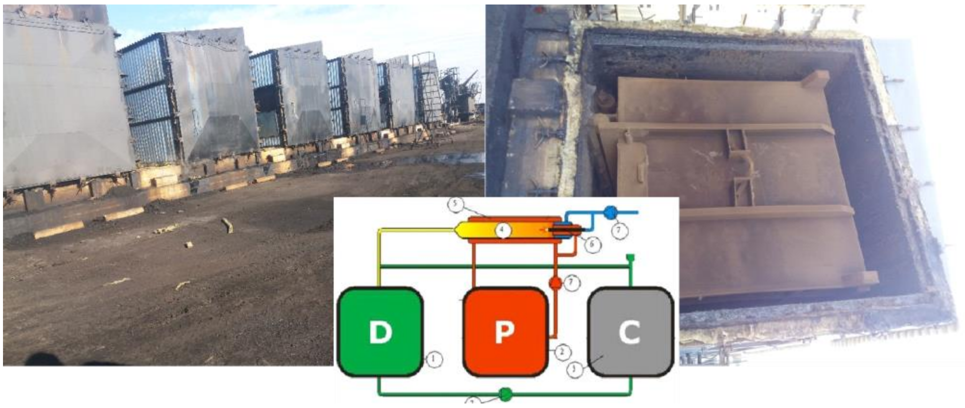

Figure 12. DPC technology: D=drying – P= pyrolysis – C = cooling (Brazil).

Name	CK-1 «EKKO»
Productivity, tons per month: on freshly cut wood pre-dried wood on briquettes	 20-30 30-40 40-50
Maintenance staff for 1-3 kilns, ppl.	2-3
Power consumption, no more than, kW per hour	1
Firewood consumption of the furnace, no more than*, m^3/24 hours	0,3
Dimensions, 20ft container, m: length (with afterburner) width height	 5,8 (7,0) 2,3 2,3
Duration of the complete cycle, h	6-20
Weight, tons	10

Figure 13. Characteristics for charcoal productivity of the CK-1 kiln (Bulgaria).

Figure 14. Carbonex technology overall view – unloading charcoal – cogeneration (France).

The mobile charcoal kiln CK-1 EKKO [16] is a similar technology recently developed by GreenPower Company. The charcoal kiln consists of 2 chambers connected to the chimney with a deflector, and to the furnace. The monthly productivity of the charcoal kiln is from 25 to 50 tons (Figure 13), depending on the parameters of the raw material (briquette or wood, breed, moisture, fraction, density), organization of the production process (qualification level of personnel, mechanization and automation, logistics).

Carbonex [17] is the latest technology on the market totally automated. This company developed, designed, built and started a complete installation from the preparation of wood; reception, cutting and drying, to high-efficiency charcoal and electricity production (1.4MWe) from the pyrolysis gases. The conversion of exhaust gases and tar into electricity is done by the Conventional Rankine Cycle (CRC) or the Organic Rankine Cycle (ORC).

5. Conclusion

Global charcoal production is expected to continue increasing in coming decades. The charcoal sector, which is largely informal, generates income for more than 40 million people. The envirnmental and social impacts of charcoal production and consumption are Extensive and intertwined, such that an integrated view is essential in policy making [6]. A recent report [18] presented policy options for creating a climate-smart charcoal sector, such as developing national policy frameworks for the sustainable management of the charcoal value chain; reforming land tenure and increasing resource access to attract new investments in a greener, healthier charcoal value chain; and making the charcoal value chain a specific component of nationally determined contributions to the mitigation of climate change. In Thailand, a new study supported by the National Science and Technology Development Agency (NSTDA) aims to establish a country status report on charcoal production, demand & supply and usage. It consist in i) investigate existing charcoal production methods found in Thailand and abroad, ii) improve charcoal production techniques in term of yield and quality and iii) promote and extend such appropriate charcoal production technologies. Base on survey and charcoal analysis, a current status report of charcoal production including charcoal making process will be available this year.

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