PRODUCTION OF CHARCOAL AND ACTIVATED CARBON AT ELEVATED PRESSURE

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INTRODUCTION

With its wide range of properties, charcoal finds many commercial applications for domestic cooking, refining of metals (steel, copper, bronze, nickel, aluminum and electro-manganese), production of chemicals (carbon disulfide, calcium carbide, silicon carbide, sodium cyanide, carbon black, fireworks, gaseous chemicals, absorbents, soil conditioners and pharmaceuticals), as well as production of activated carbon and synthesis gas. In 1991, the world production of charcoal was 22.8 million cubic meters (3.8 million metric tons) (FAO, 1992) as shown in Table 1. Brazil is the world's largest charcoal producer---5.9 million cubic meters or one million metric tons was produced in 1991, most of which is used in steel and iron industry (Calle et al, 1992). African countries produced 45% of the world total amount of charcoal, where 86% of the wood-based energy is for domestic use (Khristova et al., 1993), most of which is inefficiently used. Charcoal is produced commercially in kilns with a 25% to 30% yield by mass on a 7 to 12 day operating cycle. Until recently, the highest yield of good quality charcoal reported in the literature was 38%.

Activated carbon has a wide range of applications, mostly as a purifying agent to remove trace quantities of undesirable species from gas or liquid phase, also as an economical media to recover materials. Some of the common applications are listed as follows: food industry, pharmaceutical industry, water purification, gas or air treatment, chemicals, oil refinery processing. Special applications of activated carbon are found in agriculture, as catalyst and catalyst support in chemical industry, for precious metal recovery and making batteries and military clothing, and in nuclear power stations. The consumption of activated carbon in industrialized countries in 1988 was 300,000 tons (Roskill, 1990), which was the majority of the world total.. The United States and Japan account for 60% of this consumption---130,000 tons for U.S. and 50,000 tons for Japan. The yield of activated carbon produced commercially is low (typically 10% to 12%) from raw material.

In this paper, an ASME code rated experimental system is presented for producing charcoal and activated carbon from biomass feedstock. Very high yield of high quality charcoal is obtained in short cooking time, while very low yield of tar is found in the process from this system.

EXPERIMENTAL

Six biomass species were employed in this work, namely, Eucalyptus, Kiawe, Leucaena, Coconut husk, Macadamia nut shells and Kukui nut shells. All these feedstocks were air dried, the moisture contents of which are listed in Table 2. Macadamia nut shells and Kukui nut shells retained their original sizes of about 25 mm in diameter in hemispheric shape when being fed into the reactor. The other feedstocks were cut into small pieces (about 60 mm X 25 mm X 25 mm) in order to fit the feeding port of the reactor.

The experimental apparatus is schematically shown in Fig. 1. The reactor is made of 168 mm diameter X 1200 mm long steel pipe welded with flanges on both ends. A 114 mm diameter stainless steel canister is used to load feedstocks and to unload the reaction products. The available volume of the canister is 7.5 liters (2 gallons). The internal heating source consists of two 4 kW electric heaters, which are mounted on the bottom flange of the reactor. The heaters are controlled by a temperature controller. The Watt-hour meter is used to measure the power consumption. A back pressure regulator controls the reactor pressure. Thermocouples are placed in the center line of the reactor for measuring the temperature profile of the biomass bed. The effluents are flared in an exhaust line. For production of activated carbon by a thermal activation process, a steam and air mixture is used. The steam generator is built to provide a maximum steam flow of 3 kg/hr at 5.4 MPa pressure. Air is provided by an air tank with flow rate of 4 kg/hr. The whole system is ASME code rated---a "State Special" unit, which is operated with permission of the Hawaii State Boiler Inspector.

Feedstock is manually fed into the reactor. The experiment terminates when temperature or pressure remains stable or after a second temperature rise is observed. The heating time is about 3 hours from cold start. A tar converter is placed at the exit port. Charcoal and feedstock are analyzed according to ASTM standards by Huffman Laboratory, INC. The heat contents of Kukui nut shells and Kiawe are assumed 22 MJ/kg, which are conservatively estimated according to data of Macadamia nut shells and of Redwood (heartwood), respectively. The heat content of Eucalyptus (Grandis) is obtained using the following equation (Graboski et al., 1981):

$$HHV=2.3236[(141C+615H-10.2N+39.95S)-(1-ASH)(17244H/C)+149] \quad (kJ/kg)$$

where HHV is the higher heating value on a dry basis, and C, H, N, S, ASH are the weight percent of carbon, hydrogen, nitrogen, sulfur and ash in the sample. Gas samples are analyzed using a gas chromatograph equipped with flame ionization and thermal conductivity detectors.

RESULTS AND DISCUSSIONS

The mass yield of charcoal is the ratio of dry charcoal to dry feedstock by mass. In Table 2 are shown the experimental results for mass yields of charcoal. All these species give very high mass yield---from 42% to 65%. The nut shells have higher mass yield than these wood species probably due to their higher fixed carbon content. For example, Macadamia nut shells has 23.7% fixed carbon content, while Eucalyptus (Grandis) 16.9% (Jenkins, 1989). Nevertheless, the mass yields of charcoal from these feedstocks are much higher than that produced from commercial kilns.

The energy yield, the ratio of heat content of dry charcoal to that of dry feed, is another indication of charcoal conversion. In Table 2 are also listed the energy yields of these charcoals. All of these give very high energy yield ranging from at least 64% to more than 88%.

The results of charcoal analysis are shown in Table 3. Samples for analysis are obtained from two extreme positions inside the reactor. Therefore, two sets of data are listed in the table. Generally speaking, charcoal closer to the heaters has higher fixed carbon (FC) content and higher heat content. Most of the charcoals have FC content and heating value lower than or close to British standard. However, after looking at the data from the previous work (Dai, 1993) which have higher FC content and heating value as well as very high mass yield, we conclude that the quality of these charcoals can be improved by a somewhat higher temperature cook. (This work is now in progress.) Moreover, Macadamia nut shell charcoal has FC content close to and heating value higher than British standard. Nevertheless, all these charcoals have higher FC content and higher heat content than commercial briquette charcoal, which implies that they are suitable for domestic cooking and their precursors are suitable raw materials for charcoal production.

Charcoal density is low due to its high porosity, which implies that charcoal is reactive and good for further pore development by activation process to make activated carbon. The bulk densities of charcoal are in the range of 45% to 65% of their raw materials. The bulk densities of Macadamia nut shells and Kukui nut shells are about 470 kg/m^3 and 510 kg/m^3, respectively. The shells sink in water.

From the temperature profiles in these experiments, it is found that under the reaction conditions, hemicellulose exothermicity occurs at about 275°C and cellulose exothermicity at about 350°C.

The result of gas analysis shows that the main gas species are H_2O, CO, CO_2, H_2 and CH_4. Other hydrocarbons are negligible. The typical molar ratio of CH_4, CO and CO_2 to H_2 is 1.7, 1.7 and 4.9.

Tar yield is very low, which reflects success of the reactor design and the tar converter. This also contributes to the high yield of charcoal.

Unfortunately, activated carbon production is now in process, and no information is available at this time.

CONCLUSION

Charcoal with very high yields of 42% to 65% has been produced from six biomass species in the newly built ASME code rated charcoal reactor. The nature of the feedstocks affect the yield and quality of charcoal significantly---the nut shells give higher yield and heat content of charcoal than wood species. Very low yield of tar is obtained in the process. Further work is now in progress to improve the uniformity of charcoal throughout the bed and to improve the quality of charcoal in terms of FC content and heating value while keeping mass yield still high.

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Table 1: The world annual production of charcoal for 1980 and 1991 (1000 cubic meter)

region	1980	1991
world	17117	22784
Africa	6883	10453
N.& C. America	821	904
S. America	6170	7480
Brazil	4779	5924

Table 2. Charcoal yields

Species	Mass yield (%)	Energy yield (%)	Feed moisture content(%)
Eucalyptus	46	67	15.7
Kiawe	53	>64	10.0
Leucaena	42*	66*	1.5*
Macadamia nut shells	51; 42*	76; 65*	13.5; 7.20*
Kukui nut shells	65; 62*	>84; >88*	12.1; 12.5*
Coconut husk	50	66	88.1

*data from the previous work (Dai, 1993).

Table 3. Charcoal evaluation

Species	Fixed carbon (%)	Volatile matter (%)	Ash (%)	HHV (MJ/kg)
Eucalyptus	53.1; 67.5	42.2; 30.9	4.66; 1.59	22.60; 28.62
Kiawe	57.4; 60.1	41.6; 30.9	0.95; 0.94	27.11; 26.08
Leucaena	67.6*	30.0*	2.34*	28.51*
Macadamia nut	68.9; 72.0	30.4; 27.1	0.74; 0.87	31.11; 31.74
shells	89.4*	9.37*	1.22*	32.43*
Kukui nut shells	52.3; 67.3	44.1; 29.2	3.55; 3.42	26.88; 29.71
	78.8*	18.4*	2.26*	31.13*
Coconut husk	56.7; 62.8	39.7; 26.7	3.63; 10.6	24.37; 26.18
Commercial briquette	46.5	36.4	17.2	22.8
Commercial Kiawe	69.8	28.3	1.96	29.7
Commercial Mesquite	86.8	9.04	4.17	31.8
British Standard (Paddon, 1987)	>75	<20	<7.0	>30.0

a *data from the previous work (Dai, 1993);

b The two numbers indicate samples from top and bottom of the reactor, respectively.

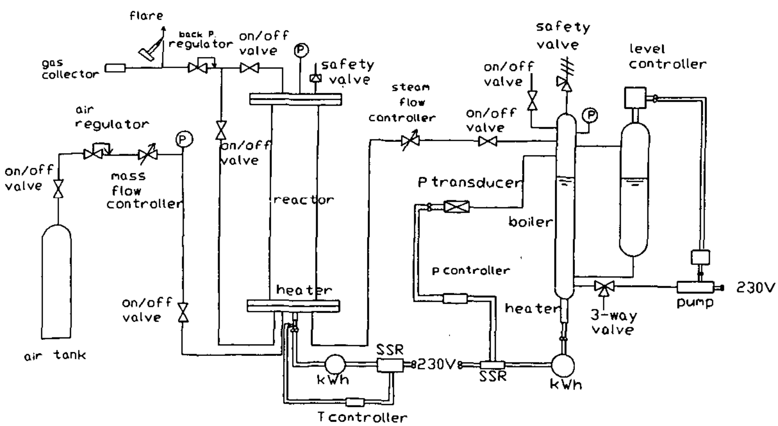

Fig. 1. Schematic diagram of the charcoal reactor