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A bamboo charcoal production method to reduce cycle time and increase yield

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Abstract: This study reports a new carbonisation process to reduce the cycle time and increase the yield for mass production of bamboo charcoal. Conventional Japanese Schwartz type earth mound bamboo kiln uses solid biomass incineration to generate heat to reach carbonisation stage and then some of the bamboo charge in the kiln to further raise the temperature. This method takes long cycle time and is low in charcoal yield. In the current study, the syngas generated from the updraught [updraft] fixed bed gasifier is fully burnt in the embedded combustor. This design results in very high temperature and virtually oxygen free flue gas from solid biomass. The hot and reductive flue gas is forced to circulate in the kiln to carbonize the bamboo. Temperature distribution in the kiln is found to be uniform. All the bamboos in the kiln are converted into high quality charcoal with high fixed carbon. The charcoal yield consequently increased by more than 10 per cent. The carbonisation time is effectively reduced to 8 h compared to the conventional 240 h.

Key words: Bamboo, charcoal, updraught, fixed bed gasifier.

INTRODUCTION

Charcoal is an effective adsorbent for reducing organic chemicals, chlorine, lead, moisture and unpleasant odours in effluents. Innovative applications of bamboo charcoal in the textile, building, food, medicine, gardening, and animal farming are also actively pursued (Hosokawa *et al.*, 1991; Minamide *et al.*, 1992; Akada *et al.*, 1993; Abe *et al.*, 2001).

Like wood charcoal, bamboo charcoal is made in various kinds of carbonisation kilns. Earth mound kiln dominates small-scale production and brick kilns are adopted in large-scale production. The Brazilian beehive kiln, the Argentine half-orange kiln, and the Missouri kiln burn part of the wood charged within the kiln to carbonize the remainder (FAO, 1987). However, Schwartz type earth mound kiln, widely adopted by Japanese bamboo charcoal makers, uses the hot flue gases from an external

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incinerator for drying and heating the wood to start carbonisation (FAO, 1987; Shenkel *et al.*, 1998). Long carbonisation period (a few days to a few weeks), lack of process control and low charcoal yield are some of the major disadvantages of conventional charcoal making systems (Hung *et al.*, 2000; Huang *et al.*, 2004).

The present study has attempted to use a modified updraught [updraft] fixed bed gasifier with embedded combustor to generate high temperature and oxygen free flue gas for carbonisation, to produce charcoal from various kinds of solid biomass including bamboo. The integration strategy of the biomass-fed gasifier and Japanese Schwartz type earth mound bamboo charcoal kiln has been investigated and technological feasibility of the proposed integration of the two systems evaluated.

SYSTEM DEVELOPMENT

Japanese Schwartz type earth mound bamboo kiln

Conventional Japanese Schwartz type earth mound kiln is usually built using local clay soil. The kiln consists of front incineration chamber and rear carbonisation chamber. Flue gas generated in the incineration chamber is drafted through the carbonisation chamber and exhausted through a small opening in the lower rear wall to the stack (Fig.1). The height of the kiln is about 1m, width less than 1.5 m and length 2 m. The volume of the kiln is about 3 m^3. The roof, which is a unique feature of the kiln, has a shape of a turtle to facilitate flue gas movement.

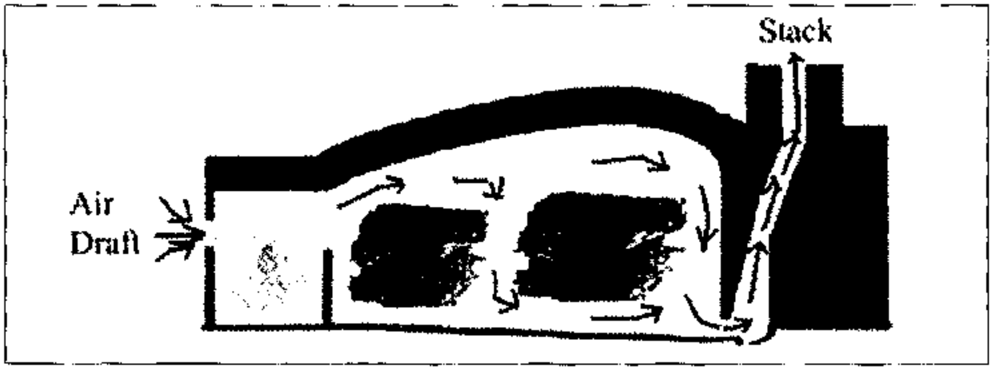

Figure 1. Schematic diagram of a Japanese Schwartz type Earth Mound Kiln.

Biomass fed updraught fixed bed gasifier with embedded combustor

Gasification approach is considered environmental friendly as compared to the direct combustion or incineration approach in converting solid biomass into energy. However, all gasification methods produce highly viscous and acid tars. Complex de-tar process becomes necessary component for any type of gasification system. This study utilizes a newly designed updraught fixed bed gasifier (Figs. 2,3) which combusts the syngas inside the reactor and avoids the whole de-tar process. The schematic diagram (Fig. 2) shows that biomass is fed at the top of a cylindrical reactor, and a grate at the

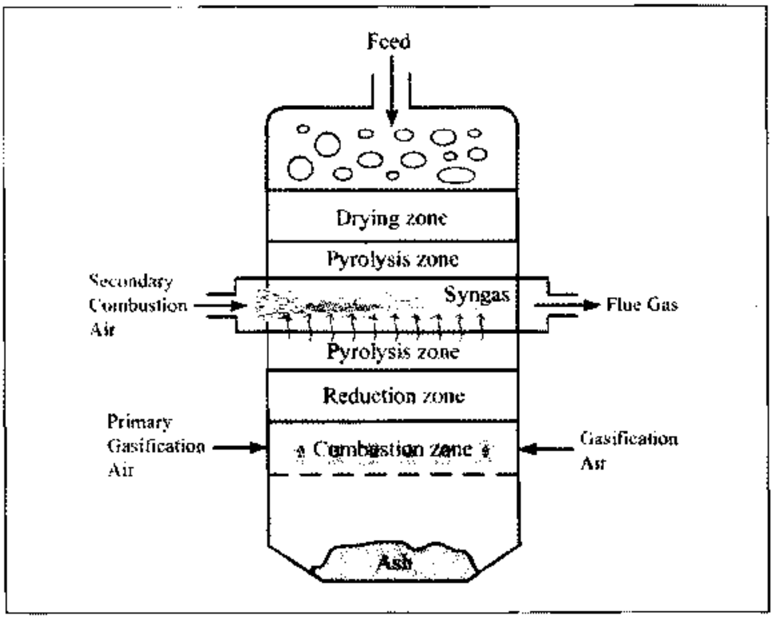

Figure 2. The schematic diagram of the modified fixed bed gasifier.

bottom supports the reacting bed. Gasification air is introduced radially through numerous small holes on a horizontal ring located on top of the grate along the gasifier's inside wall. The syngas produced is forced to squeeze to an embedded tube through many small openings on the lower half of the tube. The embedded tube serves two purposes: as a conduit of the syngas to exit from the reactor and as a syngas combustor by introducing secondary combustion air to fully oxidize the syngas and release clean and hot flue gas for heat and power application.

The biomass feed moves in counter current to the gas flow, and passes through the drying zone, the pyrolysis zone, the reduction zone and the combustion zone. The embedded combustor is a unique feature of the system. The combustor provides a space to directly combust the syngas inside the gasifier. While intensive combustion takes place in the tube, high temperature is attained and maintained in the pyrolysis zone. The creation of a high temperature pyrolysis zone increases the overall gasification intensity, and results in a stable gasification process.

High-pressure air to the tune of 35 m^3/min is a must in this gasifier with embedded combustor for overcoming the high resistance existing throughout the gasifier. When secondary combustion air is introduced through the embedded combustor to mix with the entrained syngas at high temperature (>500 °C) from the gasifier an intensive flame will be established and maintained in the tube. The flue gas temperature can reach 1320 °C and the flue gas contains about 0.05 per cent CO, 5 per cent CO_2 and 0.2 per cent O_2 by volume. The current design therefore is capable of producing clean and very hot flue gas for bamboo carbonisation.

Figure 3. A view of the updraft fixed bed gasifier with an embedded combustor.

Integration strategy

The integration of the biomass gasifier and the earth kiln is schematically shown in Figure 4. Biomass is gasified and burnt in the gasifier to produce high temperature flue gas. The flue gas is adjusted to be slightly reductive by using low air/fuel equivalent ratio. The flue gas is injected into the kiln through a 75 mm fish bone pipe. The flue gas squeezes out of the small openings on the fish bone pipe and is evenly distributed inside the kiln. The numerous jets emerge from the fish bone pipe move upward first and then turn toward the bottom rear of the kiln where the exhaust of the kiln is

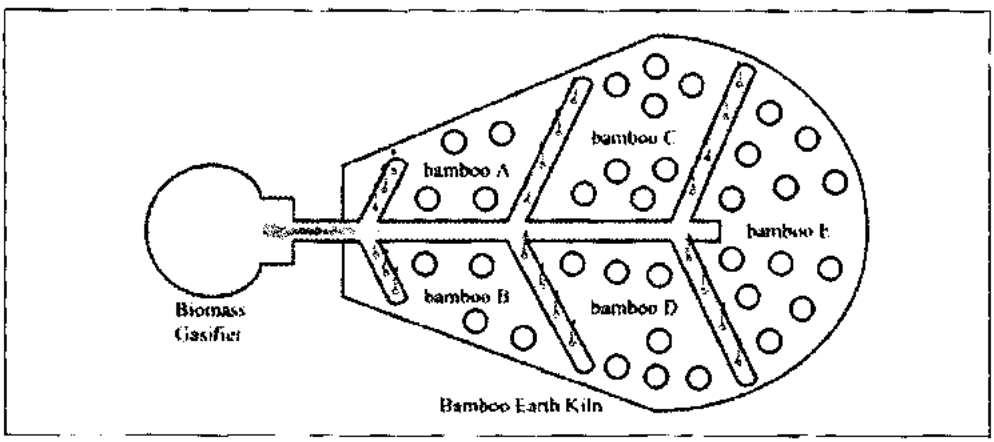

Figure 4. Integration of a bamboo carbonisation kiln with a biomass gasifier.

located. The uniform entry of the high-speed flue gas into the kiln creates uniform temperature distribution in the kiln.

MATERIALS AND EXPERIMENTS

Preparation

Dendrocalamus latiflorus Munro was used to test the performance of the proposed Biomass gasifier/bamboo carbonisation system. The bamboo was cut into strips of 4 cm width and 100 cm length and smoke dried to less than 20 per cent moisture content. About 810 kg dried bamboo was densely packed in the 3 m^3 kiln manually. The gasifier's combustor exit was connected to the entrance of kiln's fish bone pipe. Then the front entrance was hermetically sealed with bricks and clay.

Measurements

An Eurotron Green Line 8000 mobile flue gas analyzer was used to monitor the flue gas that exited from the gasifier to ensure that oxygen free condition was maintained especially in the later stage of the carbonisation process when the charcoal temperature is high. To monitor the transient temperature distribution in the bamboo kiln, 27 K-type thermocouples were placed in the kiln as shown in Figure 5.

Process

After the bamboo kiln was hermetically sealed, biomass was fed into the gasifier and high temperature flue gas generated by the gasifier was forced to enter the bamboo kiln through the fish bone distributor. The bamboo inside the kiln heated by the hot gas goes through drying stage (50-120 °C), primary carbonisation stage (250-500 °C), and secondary carbonisation stage (650-800 °C). It takes around 6 h for the current design to elevate kiln temperature uniform over 750 °C. Further heating of the kiln for about 2 h will reach kiln's insulation limit and peak temperature at about 920 °C.

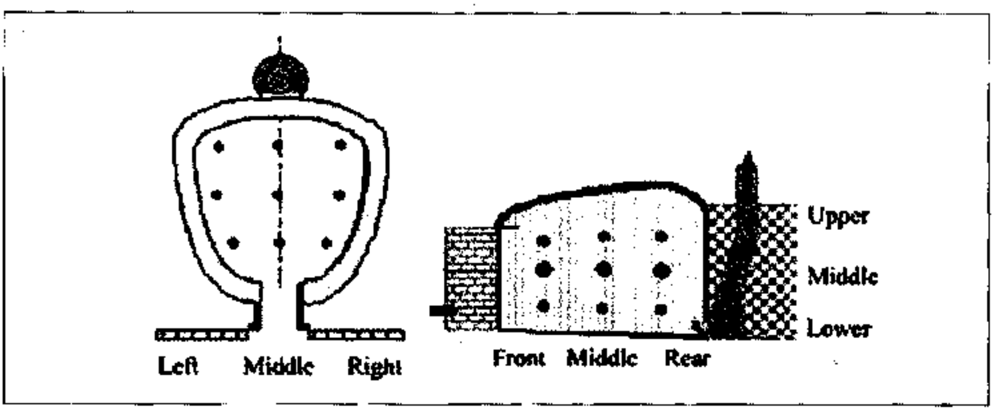

Figure 5. Kiln temperature monitoring layout.

RESULTS AND DISCUSSIONS

Experimental data

Temperature history at the centre of the kiln is shown in Figure 6. Since the heating rate of the gasifier is kept fairly constant, the temperature history curve shows flattening down during endothermic condition like the drying stage (90-120 °C) sloping up during exothermic condition like primary carbonisation (250-450 °C) and secondary carbonisation (600-740 °C). The highest temperature in the kiln was 921 °C while the lowest 835 °C. After the kiln was sealed and naturally cooled for around 40 h, the kiln's temperature dropped below 50 °C. A total of 243 kg bamboo charcoal was produced in the current study. No sign of intensive burning in the kiln was noticed.

Electrical resistance (Ω /cm), fixed carbon rate (%) and BET (m^2/g) values of the bamboo charcoal in the kiln were determined for the bamboo charcoal samples taken at nine positions in the kiln. The results are shown in Table 1. The three attributes measured show a good trend with carbonisation temperature. Electrical resistance of the bamboo charcoals is inversely proportional to the final carbonisation temperature. On the other hand, fixed carbon rate and BET of the bamboo charcoal are proportional to the final carbonisation temperature.

Overall performance

The performance of utilizing an efficient and flexible updraught fixed bed gasifier to carbonize bamboo in a Japanese Schwartz type earth mound kiln is provided in Table 2. The performance of the conventional kiln with external incineration carbonisation method is also given in Table 2. The current approach shortens the bamboo carbonisation time from 240 h to 8 h and cooling time from 72 h to 40 h. Carbonisation cycle is dramatically reduced from 13 days to about 2 days. Bamboo charcoal yield is also significantly increased from 15-20 per cent to 30 per cent. Highest carbonisation temperature achievable without large-scale burn off of the charcoal in the current

Table 1. Bamboo charcoal sample measurements

Location	Final temperature (°C)	Electrical resitivity (Ω/cm)	Fixed carbon rate (%)	BET (m^2/g)
1	851	6.2	92.4	309
2	864	5.8	92.8	320
3	872	5.4	93.0	338
4	879	5.0	93.2	348
5	884	4.1	93.7	354
6	890	3.2	94.1	361
7	895	2.4	94.6	365
8	903	1.2	95.5	370
9	920	0.8	96.1	386

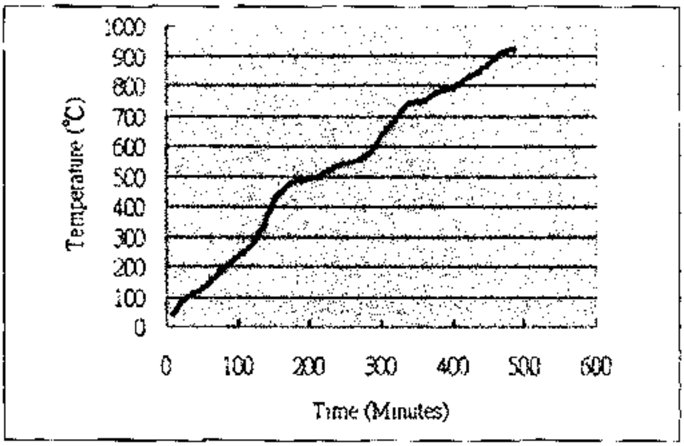

Figure 6. History of temperature at the centre of the kiln.

approach is about 920 °C. Kiln temperature gradient improves from about 300 °C in the conventional method to 90 °C in the current method.

The comparison of overall performance shows the current method is effective in increasing bamboo charcoal yield, shortening carbonisation cycle time, and creating a more uniform temperature distribution in a Japanese Schwartz type earth mound. In other words, the current method significantly lowers the charcoal production cost and provides higher quality bamboo charcoal.

Future improvements

The modified updraught fixed bed gasifier with an embedded combustor is capable of generating reductive high temperature flue gas to enable bamboo carbonisation in the current study. Since, steam as a gasification agent has been proved to be able to increase the hydrogen content in the syngas by the underlying water shift reaction, if partial gasification air used in gasifying the solid biomass is replaced with high temperature steam, without the dilution of air nitrogen, the generated syngas quality and overall gasifier efficiency will be enhanced. In addition, when the added steam in the hot flue

Table 2. Performance of the current method and conventional method

	Conventional method	Current method
Time required to heat the kiln to 800 °C	240 h	8 h
Carbonisation cycle	312 h (13 days)	48 h (2 days)
Charcoal yield	15% ~ 20%	30%
Highest carbonisation temperature achievable without large-scale burn off of the charcoal	800 °C	920 °C
Highest and lowest temperature gradient in the kiln	280 °C ~ 350 °C	90 °C

gas reaches the bamboo charcoal kiln, it would effectively activate the bamboo charcoal into a more porous material with even higher BET values.

The Japanese Schwartz type earth mound used in the current study is originally designed for the conventional external incineration approach. A fish bone distributor is used in the current study for better distribution of hot exhaust generated by an external gasifier into the kiln. However, due to the limitation of the original shape, which is more in length and narrow in width, the flow field in the kiln shows domination in the length-wise direction. Bamboo carbonisation does not occur concurrently everywhere in the kiln. It actually occurs in the upstream direction . The area near the kiln exit will begin to carbonize first; next in the middle part and in the entrance part, the last. The half-orange Argentine kiln or the Brazilian beehive kiln with a ring distributor in the centre of the kiln is believed to be able to bring out the best of the current new approach. The carbonisation time and temperature gradient in the kiln are expected to be further reduced. Even higher carbonisation temperature in the kiln is also very likely to be seen in the proposed modification.

CONCLUSIONS

Conventional Japanese bamboo carbonisation kiln is not able to achieve uniform as well as very high carbonisation temperature. The heating rate of the Japanese kiln is also slow. The Japanese Schwartz type earth mound with a modified updraught fixed bed gasifier with embedded combustor used in the present study demonstrates good performance. The embedded combustor inside the biomass gasifier is shown to produce very clean and hot flue gas for bamboo charcoal production. The results show that the newly adapted biomass gasifier/combustor is capable of producing a higher carbonisation temperature and more uniform temperature distribution inside the kiln. Bamboo carbonisation rate is also much faster than the conventional incineration method. Since, the gasifier exhaust is controlled to be oxygen-free throughout the carbonisation process, no burn off of the bamboo charcoal in the kiln is discernible. The current design therefore significantly improves the bamboo charcoal yield and quality.

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REFERENCES

Abe, I., Fukuhara, T., Maruyama, J. and Tatsumoto, H. 2001. Preparation of carbonaceous adsorbents for removal of chloroform from drinking water. *Carbon* 39: 1069-1073.

Akada, Y., Inoue, Y., Hayashi, S., Namba, T. and Kasaoka, S. 1993. Gas adsorption properties of carbonized chars and activated carbons prepared from bamboo and coconut shell. *Bamboo Journal* 11: 63-70.

FAO. 1987. Simple technologies for charcoal making. http://www.fao.org/docrep/X5328e/x5328e00.html.

Hosokawa, K., Minamide, T. and Kanai, H. 1991. The application of bamboo active carbon for keeping bamboo shoots freshness. *Bamboo Journal* 9: 27-32.

Hung, C., Yang, T. and Wang, S. 2000. Study on basic physical properties of bamboo charcoal, charcoal yield, shrinkage and specific gravity. *J. Exp. For. Nat. Taiwan Univ.* 14(1): 11-20.

Huang, G., Yu, H. and Toba, A. 2004. Effects of carbonisation temperatures in an earthen kiln on the true density and electric resistivity of Makino bamboo charcoal. *Taiwan Journal of Forest Science* 19(3): 237-245.

Minamide, T., Hosokawa, K. and Hada, A. 1992. Effect of bamboo active carbon on quality of cooked rice under warming with electronic rice cooker. *Bamboo Journal* 10: 75-82.

Shenkel, Y., Bertaux, P., Vanwijnbserghe, S. and Carre, J. 1998. An evaluation of the mound kiln carbonization technique. *Biomass and Bioenergy* 14(5/6): 505-516.