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TORREFICATION OF DIPTEROCARP WOOD BY BRICK BEEHIVE KILN

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บทคัดย่อ

ในการทดลองครั้งนี้ใช้เศษไม้ยางจากโรงเลื่อยทั้งหมด 26 ลบ.ม. ผลิตในเตาเผาถ่านอิฐขนาด 2 ลบ.ม. ที่อุณหภูมิสูงสุดระหว่าง 400° ถึง 700° ซ. โดยทดลองทั้งหมด 14 เตา แบ่งการทดลองเป็น 7 การกระทำสรุปได้ดังนี้

ผลผลิตรวมถ่านและหัวถ่านที่อุณหภูมิสูงสุดต่ำกว่า 400° ซ. อยู่ระหว่าง 45–52% ผลผลิตรวมจะลดลงเหลือประมาณ 30% เมื่อเพิ่มอุณหภูมิสูงสุดเกิน 600° ซ. สมบัติของถ่านที่ได้จากอุณหภูมิต่ำเช่น ความร้อนของสันดาป ปริมาณสารระเหยและคาร์บอนคงตัว และประสิทธิภาพในการใช้งาน มีสมบัติต่ำกว่าถ่านไม้ที่จำหน่ายในท้องตลาด อย่างไรก็ตาม ถ่านดังกล่าวสามารถใช้ได้กับเครื่องผลิตแก๊สจากถ่านชนิดเฟอร์โรซีเมนต์ได้เป็นอย่างดี

หัวถ่านจากไม้ที่ได้จากการทดลองไม่เหมาะสมที่จะนำไปใช้กับเครื่องผลิตแก๊สจากถ่าน หัวถ่านที่ได้ยังไม่เหมาะสมที่จะใช้กับเตาหุงต้ม เพราะยังมีปัญหาในการสับให้มีขนาดเหมาะสมในการใช้งาน

ABSTRACT

About 26 cu m of dipterocarp wood from sawmill wastes were carbonized in a 2 cu m brick beehive kiln. 14 kilns representing 7 experiments were tested at maximum temperature (400 to 700 °C).

Charcoal and torrefied wood yield ranged from 45 – 52% when temperature was lower than 400 °C but only about 30% when the temperature was greater than 600 °C. Charcoal produced at low temperature had poor heat of combustion, volatile matter content, fixed carbon content and heat utilization efficiency, but had good properties for the ferrocement gasifier.

Torrefied wood and raw wood are not appropriate to use with a ferrocement gasifier. Torrefied wood is difficult to reduce to proper size for use with a charcoal bucket stove.

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INTRODUCTION

Energy consumption in Thailand totalled the equivalent of almost 23 million tonnes of oil in 1988. Fuelwood and charcoal comprised about 20% of total consumption. Both fuels were main source for the rural energy consumption.

Production of charcoal normally provides low charcoal output, yielding only 10 to 30% by weight, for which the energy conversion efficiency is less than 50% for carbonization temperature above 500°C (RFD, 1984). However, carbonization between 300°-450°C could yield a product greater than 40% by weight (Bailey and Blankenhorn, 1982; Kitirattrakarn and Kiatgrajai, 1986).

The objective of this project was to torrefy dipterocarp wood by 2 cu m brick beehive kiln at carbonization temperature between 350° and 450°C. The product output and its properties were determined.

MATERIALS AND METHOD

Construction of a 2 cu m Beehive Kiln

Two 2-cu m brick beehive kilns were constructed at the Department of Forest Products, Faculty of Forestry, Kasetsart University, following a method suggested by the Royal Forest Department (RFD, 1984). Kiln diameter and height were 1.6 and 1.2 m, respectively. Other dimensions are shown in Figure 1.

Raw Material Preparation

About 26 cu m of dipterocarp wood sawmill waste was carbonized in 14 kilns, representing 7 experiments. Each kiln consumed about 1.8 cu m or 600 kg of air-dry wood. The wood weight for each kiln was measured and 10 to 15 pieces of wood were randomly selected for moisture content determination.

From each piece, a 3-4 cm thick specimen was obtained for moisture content determination. Moisture content (MC) was obtained using the formula:

$$MC\ (\%) = \frac{GW\text{-}ODW}{ODW} \cdot 100$$

where:

GW = Weight of green wood

ODW = Oven dry weight

The weight of oven-dried wood for each kiln was calculated from the values of average moisture content and weight of green wood.

Experimental Design for Carbonization

Seven experiments were set up for this project. Each experiment consisted of two kilns. Data on amount of wood input, wood moisture content, firewood used for heating the kiln, and temperature inside the kiln at 30-, 60-, and 90-cm above the floor at two hour intervals were recorded for each kiln during the process of carbonization. Kilns were operated following a method developed by RFD (1984), except regarding temperature control. The charcoal-producing technique for each experiment is described below.

Experiment 1 was designed to harden the kiln wall. The wood inside each kiln was heated with firewood until thick white smoke was produced. Air inlet at the fire port was controlled. A kiln was manipulated with four chimneys until smoke was clear. The fire port and chimneys were closed once the smoke was clear.

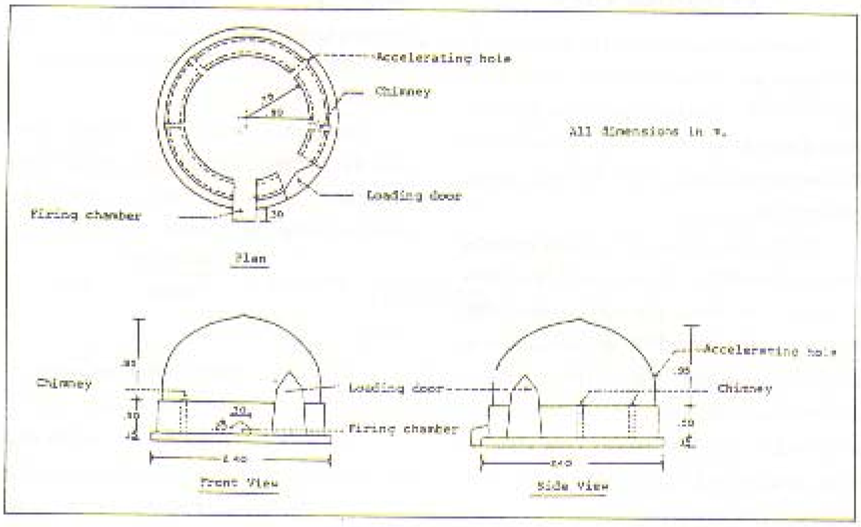

Figure 1. Schematic diagram of a 2 m^3 brick beehive kiln RED – design.

Experiments 2-4 were designed for torrefication. The firing techniques were the same as experiment 1 except that temperature was maintained between 300 and 400°C. Temperature in experiment 2 was controlled by closing the firing port and the chimneys when the temperature exceeded 400°C, and by opening the firing port and the chimneys when the temperature went below 300°C. The kiln was operated until clear smoke was observed.

In experiments 3 and 4, two chimneys in each kiln were alternately closed and opened when temperature was greater than 350°C. This was done every four hours in Experiment 3 and every eight hours in Experiment 4.

Experiments 5-7 were designed to allow hot air from the fire port to enter the kiln from beneath the kiln floor. Firing techniques were similar to Experiments 1, 3, and 4, respectively.

Charcoal and Torrefied Wood Output

Charcoal from the upper part of each kiln was weighed. The lower part was usually partially carbonized or bands of carbonized wood. The weights of both portions were determined and expressed as a percentage of the oven dry weight of the input wood.

Properties of Charcoal

Charcoal samples from Experiments 3-7 were selected at random for determination of charcoal properties. Proximate analysis, determination of heat of combustion, and water boiling tests were conducted for each experiment. The remaining charcoal, partially carbonized wood (torrefied wood), and wood were pooled for ferrocement gasification for water pumping. The sampling techniques and methods of determination are described below.

1. Sampling Techniques

About 10 randomly-selected pieces of charcoal from each kiln were used for proximate analysis, heat of combustion determination, and boiling test. Each piece of charcoal was cut in the middle to obtain a 1-cm thick specimen weighing about 10 g. Specimens from each experiment were pooled and ground with a Wiley mill to pass 1 mm screen for proximate analysis and heat of combustion.

About 2 kg of charcoal obtained at random from the remaining charcoal of each experiment, was chopped to about 2-5 cm size for the water boiling test.

About 312 kg of charcoal and 153 kg of torrefied wood were collected from each experiment (Experiments 3-7) and chopped to about 5 cm size. The chopped charcoal and torrefied wood were separately pooled and delivered to the the Asian Institute of Technology (AIT) for ferrocement gasification test. About 65 kg of raw wood in charcoal size pieces was prepared and sent for a gasification test.

2. Proximate Analysis

About 1 g of charcoal powder from each experiment was weighed to the nearest 0.1 mg in a procelain crucible to determine of moisture, volatile matter and ash contents using the methods described in ASTM D 1762-64. The fixed carbon content is the amount of carbon that is not volatilized in the furnace at a temperature of 950°C for 15 minutes, less the amount of ash remaining after the charcoal is completely combusted in the furnace at a temperature of 750°C for 6 hours. Three replicates were made for each sample. The amount of fixed carbon was calculated from the relation:

% fixed carbon = 100 - % volatile matter - % ash

3. Heat of Combustion

The heat value of each experiment from the combustion of about 1.0 g of charcoal powder in the presence of excess oxygen was determined by using an adiabatic bomb calorimeter, following ASTM D 2015-72 procedure. The heat of combustion of charcoal is the total heat that the charcoal could produce when combusted in an oxygen atmosphere. The charcoal quality can be used to calculate the amount of energy from charcoal weight. The heat of combustion reported for charcoal was based on oven dried weight of the charcoal.

4. Water-boiling Test

The quality of charcoal for household cooking was determined by water-boiling tests. 400 grams of chopped lump charcoal from each experiment were placed in a medium-sized RFD-disigned cooking stove of the following specifications:

Pot hole diameter	23.5 cm
Stove weight	12.8 kg
Exhaust gap	1.5 cm
Grate hole are	112.0 cm^2
Fuel chamber size	2400.0 cm^3

The charcoal was ignited with 30 g of firewood to heat 3.7 liters of water in an aluminum pot (number 24) covered with a lid. The temperature and time required to bring the water to boil were recorded. After this, the lid was removed and the water was allowed to boil for another 30 minutes. The last temperature was recorded and the amount of charcoal and remaining water were measured.

Heat utilization efficiency (HTE) of charcoal from each experiment was calculated according to RFD (1984):

$$\text{HTE} = \frac{\text{Total quantity of heat consumed by water}}{\text{Total quantity of heat given off by fuel combustion}} \times 100$$

5. Ferrocement Gasification

About 312 kg of charcoal, 153 kg each of torrefied wood and wood were separately reduced in size from $2 \times 2 \times 2$ to $5 \times 5 \times 5$ cu cm and delivered to AIT for ferrocement gasification testing.

The gasifier used in the study was of the down daft type with a nominal output of 10 kW shaft power. It has one reactor, two settling tanks and three filtering tanks (see Figure 2). The reactor has an internal diameter of 300 mm and a height of 210 mm. The gas producer is connected to a used 2-liter automotive engine to run a locally-made mixed flow axial pump for irrigation.

Gas yield and composition, pressure drop, and performance of each fuel type were recorded.

RESULTS AND DISCUSSION

Torrefied Wood and Charcoal Output

Typical curves for average time and temperature for the seven charcoaling techniques used in the study are shown in Figures 3 and 4. The wood loaded, moisture content,

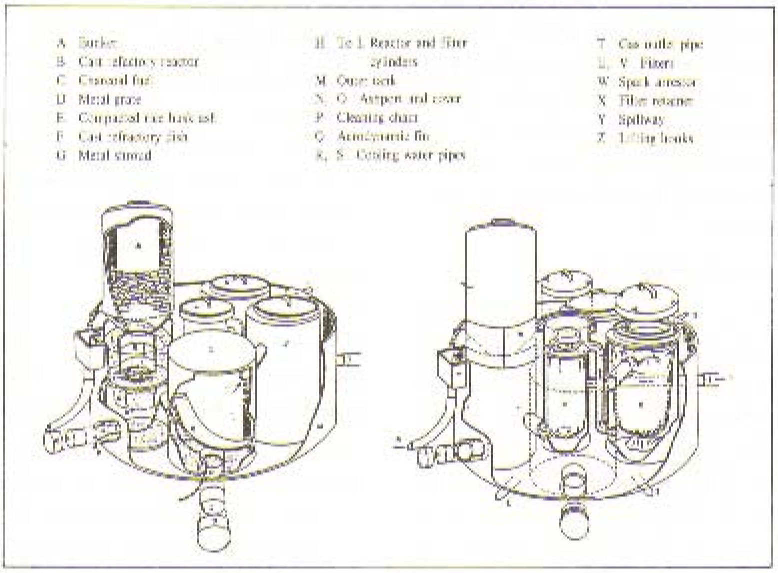

Figure 2. Downdraft ferrocement gasification – Asian Institute of Technology system.

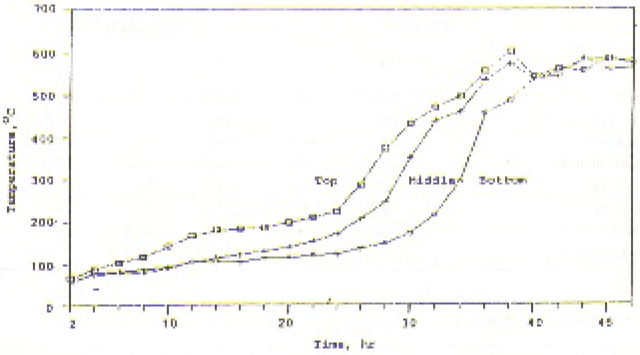

Figure 3. Typical time and temperature relation for experiments 1 and 5.

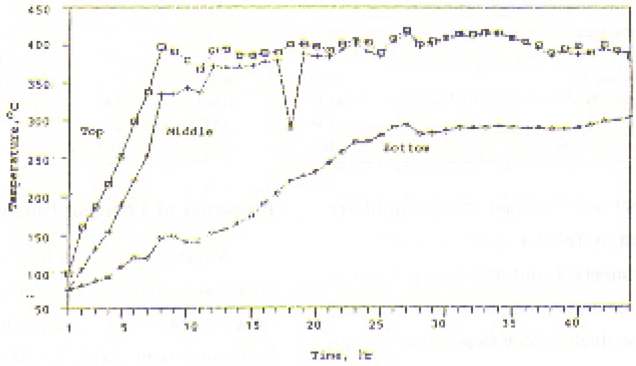

Figure 4. Typical time and temperature relation for experiments 2, 3, 4, 6 and 7.

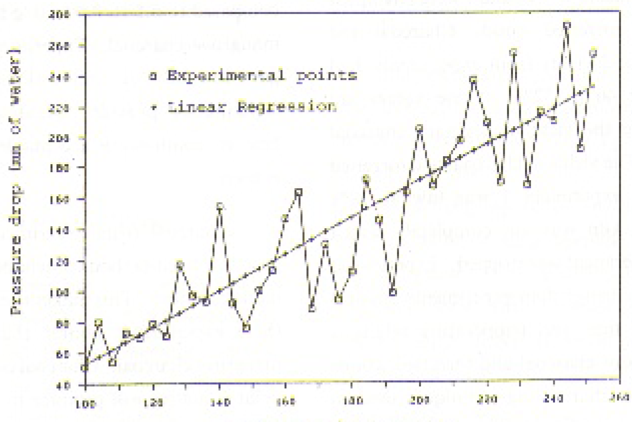

Figure 5. Pressure Drop vs. Operating Time, Torrefied Wood.

Table 1. Torrefied wood and charcoal output of dipterocarp wood from 2 m³ brick beehive kiln.

	Experiment No.						
	1	2	3	4	5	6	7
1. Wood input, kg	646.5	643.7	618.0	595.7	675.9	641.3	625.3
2. Average moisture content, %	32.5	20.3	19.5	17.5	41.5	32.9	30.2
3. Maximum temperature, °C	700.0	400.0	400.0	420.0	600.0	370.0	440.0
4. Time for carbonization, hr	20.0	44.0	42.0	44.0	48.0	52.0	48.0
5. Charcoal output, kg	127.2	166.3	143.8	150.9	132.9	108.7	131.0
Charcoal output, %	20.1	26.1	27.8	25.8	27.7	22.5	27.3
6. Torrefied wood output, kg	24.7	73.0	95.3	115.3	< 1.0	143.4	54.9
Torrefied wood output, %	3.1	11.5	18.4	22.7	–	29.4	11.5

Table 2. Average properties of charcoal.

	Experiment No.				
	3	4	5	6	7
Heat of combustion, kcal/g	6.13	5.80	7.00	5.19	6.47
Moisture content, %	8.02	7.00	7.61	7.41	6.12
Volatile matter content, %	35.10	34.70	19.30	34.80	32.60
Fixed carbon content, %	61.50	61.60	76.90	62.10	65.20
Ash content, %	3.36	3.83	3.41	3.07	1.19
Heat utilization efficiency, %	24.6	24.2	31.5	24.9	26.3

used charcoal and torrefied wood output are also reported in Table 1.

Experiments 1 and 2 were used to test the kilns at maximum temperatures of 700 and 400°C, respectively. Only charcoal and wood outputs were recorded from both experiments.

Experiments 3, 4, 6, and 7 were attempted to produce torrefied wood. Charcoal and torrefied wood yields from experiments 3, 4 and 6 were 46 to 52%. These values are almost twice the yield in ordinary charcoal operation. The yields of charcoal and torrefied wood from experiment 7 was low at 38% because the kiln was not completely sealed after the experiment was stopped. Experiments 6 and 7 were better than experiments 3 and 4 in terms of time and temperature relations and volumes of charcoal and torrefied wood. However, the charcoaling techniques used in experiments 6 and 7 are more difficult than those of experiments 3 and 4.

Properties of Charcoal Output

Values for average heat of combustion, proximate analysis and heat utilization efficiency of charcoal from experiments 3 through 7 are shown in Table 2. The average heat of combustion ranged from 5.6 to 7.0 kcal/g compared to 6.5 to 7.0 kcal/g for commercial mangrove charcoal. Experiments 3, 4 and 6 gave low heat of combustion but the other experiments provided good charcoal with heat of combustion acceptable for the Thai market.

Charcoal from experiments 3, 4 and 6 gave low fixed-carbon content but high volatile matter content. This makes the charcoal from these experiments poorer than commercial mangrove charcoal. Charcoal containing more volatile matter will produce more smoke and will make cooking pots dirty, so it will not be acceptable to users. The ash content for all experiments was less than 4%, which is commercially acceptable.

Charcoal from all experiments gave lower heat utilization efficiency except in the case of experiment 5, which gave efficiency values comparable to those of commercial mangrove charcoal.

Gasification of Charcoal

No significant difference from the Ayuthaya sawmill charcoal has been observed. It must be noted though that the charcoal was more homogeneous, indicating that the system has a greater stability. The gas composition was in the usual range:

CO	20.9 – 28.6%
H_2	4.6 – 9.3%
CH_4	0.8 – 1.4%
CO_2	4.8 – 11.4%
O_2	0.4 – 0.5%
N_2	59.0 – 62.8%

The average gas yield was 4.85 Nm^3/kg. The pressure drop through cloth filter was in the normal range : about 40 mm of water at the beginning and 90 mm of water after about 6 engine hours.

This kind of charcoal is perfectly suited for the existing gasifier.

Gasification of Torrefied Wood

It is well known that the energy efficiency of torrefication must be much higher than that of carbonization in the charcoal – making process. The results of proximate and ultimate analyses however, indicated that torrefied wood is much richer in volatile matter and tar content than charcoal.

The total of 3 runs, consuming 153 kg of torrefied wood, showed that the reactor worked with torrefied wood without any problem. The pressure drop through the filtering system during the first two hours of operation remained the same as an opertion on charcoal. This pressure drop, however, started to increase more quickly afterwards. With such a tendency, the secondary air should be adjusted frequently and the system cannot be expected to run longer that 8 hours. The average graph of the system pressure drop versus the operating time is shown in Figure 5. The cloth filters had to be washed after not more than 50 hours of operation, compared to 300 hours in the case of charcoal. Sticky tar was seen in many places on the cloth and it was difficult to remove by simple washing.

The CO component in the gas was lower, while the H_2 component was higher compared with an operation on charcoal. The CO_2 component was also high :

CO	16.9 – 20.8%
CO_2	8.2 – 13.7%
H_2	5.8 – 12.1%

The average gas yield was 3.3 Nm^3/kg. The average fuel consumption was 10.4 kg/hour compared with 7.9 kg/hour in the case of charcoal.

From the operation point of view, torrefied wood is an acceptable fuel for the existing system. It can give better conversion efficiency from raw biomass (wood) but requires much more attention and care in operation.

Gasification of Raw Wood

Three runs showed that the existing filtering train was not appropriate for the high tar content gas. New, and old washed cloth alike were clogged after 5 to 6 hours of operation, which raised the pressure drop up to 800 mm of water. It was impossible to wash off the tar sticking to the cloth. The filtering train should be completely redesigned if wood is to be used as the main fuel.

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