Forest Products Research Division
Royal Forest Department
Ministry of Agriculture and Cooperatives

CHARCOAL PRODUCTION IMPROVEMENT FOR RURAL DEVELOPMENT IN THAILAND

Submitted to the
National Energy Administration
Ministry of Science, Technology and Energy

Under the
Renewable Nonconventional Energy Project
Royal Thai Government
U.S. Agency for International Development

So long as the tree is green
Life still goes on
Efficient charcoal making
From plantation grown trees
Is another way of keeping the country green

--charcoal component

ACKNOWLEDGEMENTS

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Mr. Aroon Chomcharn
Component Leader

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EXECUTIVE SUMMARY

Rural development has always been treated as a first priority by all ruling governments of Thailand. Even though progress has been made in solving these socio-economic problems, some of the development, unfortunately, has been at the expense of the environment, particularly soil, watershed, and natural forest.

A nation wide campaign for tree planting in rural communities was hindered by the fact that many people cannot foresee an economic benefit from short rotation forestry activity. At the same time, energy from wood is still essential for the well-being of the community. More than 3 million metric tons of charcoal were used for household cooking (as found in this project survey) with a value of at least 4,500 million baht annually. This kind of high-grade biomass fuel cannot be effectively replaced by any kind of energy within 10-15 years.

The Charcoal Production Improvement for Rural Development Program, therefore, has as its purpose the creation of a market to absorb such forest produce from farmers in large quantities. In order to introduce and implement this concept to rural villagers and farmers, vital information and technical expertise on efficient charcoal production must be first developed. This technical cooperation project was designed with that purpose in mind.

The specific objectives of this project were:

- To establish a country status report on charcoal production, demand and supply, and distribute it throughout the country;
- To investigate all existing charcoal production methods found in Thailand and some methods from abroad;
- To improve charcoal kilns and production techniques so that yield and quality can be optimized with less capital and operating costs;
- To promote and extend such charcoal production technologies to rural charcoal makers and rural government agencies; and
- To increase research facilities and number of personnel for future campaigns on renewable energy from biomass.

This project component was operated by the Forest Products Research Division of the Royal Forest Department. The operation phase was started in April 1982 and ended on June 30, 1984.

Accomplishments of the project can be summarized as follows:

1. A formal report investigating the present status of charcoal production, consumption, and distribution in Thailand was produced.

2. The study evaluated 13 charcoaling methods; three non-permanent techniques, i.e., earth mound, rice husk mound, and saw dust mound; four portable metal kilns, i.e., Tonga, Single Drum, Double Drum, and Mark V; and four permanent installation kilns, i.e., local mud beehive, local brick beehive, Brazilian brick beehive, and the Philippine Hot Tail.

3. Test results indicated that permanent kilns were superior to both metal kilns and nonpermanent mound types in charcoal yield and quality.

4. Improvements in firing techniques and methods of kiln construction (for local mud and brick beehive kilns) resulted in shorter firing time and charcoal quality consistency. The average obtainable yield was 35-40% of oven-dried wood raw material, depending on species and age. The overall energy conversion efficiency was as high as 55%-60%.

5. Nine promotional training programs on improved charcoal production technology employing both mud and brick beehive kilns were completed. The training involved 307 trainees from rural development organizations and rural villagers/ charcoal makers. As many as 34 kilns with a $2m^3$ capacity were built during promotion and training.

6. As a result of research and development activities required during project implementation, the Charcoal Research Center was established. This unique center, as well as the RFD central laboratory, are well-equipped for future research and development and promotion training.

CONCLUSIONS

The implementation of the charcoal improvement component was actually carried out for 26 months between April 1982 - June 1984. The operation can be considered highly successful in terms of the objectives and the scope of work. Conclusions concerning activities and findings can be drawn as follows:

1. The Charcoal Research Center has been successfully established to deal with charcoal improvement for rural development. The Center and the RFD Central Laboratory were well provided with scientific equipment to cope with present and future research, development and promotional training.

2. The nationwide charcoal survey (to determine the status of charcoal production, distribution, and consumption) was completed. A full, separate report was published. This survey revealed that Thailand's charcoal consumption is as high as 3 million metric tons annually with an estimated minimum market value of 4,500 million Baht per year.

3. 18 kilns of various sizes and 13 models (both local and exotic designs) were built and tested to determine their appropriateness for conditions in rural Thailand.

4. Research on various types and sizes of kilns has shown that permanent charcoal kilns provide the highest charcoal yield and conversion efficiency, especially the mud and brick beehive kilns.

5. The 2 to 8 m^3 capacities of both types of beehive kilns are more suitable for rural families and/or communal village practices when such factors as charcoal quality and quantity, ease of operation, firing duration, and capital investment are considered.

6. The moisture content of the wood had very little influence on charcoal yield and conversion efficiency, but the moisture content prolonged the operating time significantly.

7. Continuous firing "until the kiln is closed" versus "until white thick smoke appears" showed that both firing methods did not significantly affect charcoal quality or quantity.

8. Increasing of heating rate of the kiln within the temperature range of 30 - 400° C. significantly enhanced the charcoal output.

9. The extension of chimneys reduced the operating time significantly under carefully controlled conditions; i.e., the chimney should be extended until white thick smoke appears or until carbonization begins.

10. The average charcoal output of wood specimens from eleven species revealed a difference in charcoal quality and quantity. The range of both charcoal yield and conversion efficiency differences was about ten percent. However, a few species provided charcoal yields that deviated from the average.

11. The charcoal outputs within the nonpermanent kilns -- earth mound, rice husk mound and sawdust mound -- were slightly different. The operation must be done carefully to avoid overcombustion. The average charcoal yield and conversion efficiency were better than the mobile kilns.

12. Although the capital investment of the nonpermanent kilns is negligible, the cost of operation was rather high.

13. The mobile kilns such as the Mark V, Tonga, Single Drum and Double Drum are less suitable charcoal kilns for Thailand's rural people because of the high capital investment required and the poor quality of charcoal that was produced.

14. Although the production rate of the mobile kilns was the fastest, the average charcoal yield was the lowest and mobile kilns produced more fine and ash.

15. The promotion training of improved charcoal production technology (employing mostly mud and brick beehive kilns) was launched from January to June 1984. So far, three two-week intensive training courses for government rural development and NGO officials were conducted at the Center and six one-week training courses for village leaders, rural charcoal makers and prospects were conducted at the village level around the country with very close cooperation from the NEA, the Regional Energy Center and Mobile Development Units of the National Security High Command. So far, as many as 34 mud and brick beehive kilns have been built at various places during the promotion campaigns.

16. The results of training (including actual field practices as viewed by most charcoal trainees at the end of the course) indicate that the chance of acceptance of these improved technologies among rural charcoal makers is high, if wood is available. In addition, the introduction of the improved charcoal cooking stove has greatly helped them focus on production, conservation and use of charcoal.

RECOMMENDATIONS

In implementing the Charcoal Improvement Project, a considerable investment was made both in financial and technical support. Even though the operation has attained its objectives and targets of the overall project, there still remains a great deal of future work that should be carried out within a certain time frame. The charcoal technology developed under this Project would be deemed meaningless unless it has found its place in rural areas and becomes widely practiced. In order to achieve this goal, therefore, the following recommendations are proposed:

1. Since the consumption of charcoal for cooking in Thailand is very high and effective replacement by other fuels cannot be foreseen within the next 10-15 years, government efforts should concentrate on a strategy to implement an integrated program on fuel wood production and improved charcoal making technology in rural areas. This program not only will help alleviate the future shortage of charcoal and retard the rate of importation of cooking LPG but will also create more woodlots, a better environment, and more jobs for rural people without having to rely heavily on the natural forest.

2. Information and vital data gathered during charcoal promotional training of village people, even though limited, have indicated that establishing small tree farms to make charcoal for sale can be a very good alternative for those depressed cash crop growers (who are suffering from both low product price and rapid soil depletion). However, the problem still lies with educating farmers to believe in this technology through demonstration and proof. The government, therefore, should not be reluctant to carry out trials. If proven, rural farmers can have another choice for making a living in the immediate future.

3. While keeping the production of more fuel wood from tree farming in mind, the diffusion of improved charcoal technology can be spread throughout the country through:

   a. Training of selected village leaders and rural charcoal makers in methods of making better charcoal (using locally available kilns and/or introducing kilns) with improved firing techniques as well as better fuel wood preparation prior to kilning.

   b. Charcoal Research Center initiated training of officials responsible for rural development and private interest groups on appropriate methods of charcoal making.

c. Exhibition and demonstration of efficient charcoal kilns as a follow-up program in selected villages and at the newly-established Thailand Regional Energy Centers.

d. Public compaigns for improved charcoal production methods, through manuals, pamphlets etc., to be distributed to schools, village libraries, universities and institutions responsible for rural development.

e. Creation of public awareness, particularly among charcoal consumers, on criteria for the selection of good quality charcoal and its more efficient use with better stoves.

4. Research and development activities directed toward even better technology for charcoal conversion from wood should be continued -- particularly with the popular fast growing species. In addition, the recovery of charcoal fines in large-scale commercial mangrove charcoal production and the improvement of inferior physical properties of light-weight charcoal (from rubber wood and from low-medium density fast-growing species) through briquetting techniques should be pursued.

5. Charcoal is an important carbon source for numerous industrial applications such as steel smelting, calcium carbide, activated charcoal, carbon black, etc. At present, its use has been limited because of uncertainty in constant supply, difficulty in procuring charcoal in large quantities, variability in charcoal quality, and lack of appreciation or support to develop such an indigeneous renewable product. To encourage these potential applications, future charcoal research and development should be promoted -- both on various charcoal end-use specifications and standards and on charcoal derived end-products development.

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Chapter 1

Introduction

INTRODUCTION

This report presents the major findings in the testing, development and construction of small to medium-scale permanent, mobile and nonpermanent charcoal kilns currently used by the rural charcoal makers in Thailand and in other developing countries. Kiln performance and efficiency are evaluated in terms of percentage of charcoal output or yield, production rate, energy conversion efficiency and cost of production. Step-by-step procedures in the production of charcoal from these various types of kilns are explained and evaluated. In addition, the properties of charcoal including apparent density, moisture content, fixed carbon and use properties (such as fine percentage during size reduction, fire bursting effect and heat utilization) are also evaluated and discussed.

A. HISTORICAL BACKGROUND

With the uncertainty in the world's oil supply and its rising prices, many nations have been searching for an alternative energy source that is both reliable and economical. Wood fuel harvested from forest plantations is often considered a potential renewable energy source.

For rural people, as well as for many urban people, wood is the dominant domestic fuel in Thailand. Wood fuel in the form of charcoal is usually the preferred fuel because of its efficiency (high heat content, lack of smoke) and its transportability. In addition, charcoal is a commercialized fuel which contributes to employment in the rural areas. However, at present, the major drawback in most developing countries is that charcoal is made by methods which are inefficient and wasteful.

Although there is no official record, it is believed that the production of charcoal has been a significant activity in Thailand for many generations. The scale of charcoal making includes:

1. The operation of large brick beehive kilns in the South to produce charcoal from Mangrove and Rubber wood for domestic use and export;

2. The operation of standard Mark V portable metal kilns in the reforestation villages controlled by the Forest Industries Organization to produce charcoal for urban use; and

3. The small pit kilns, mud beehive kilns, and small brick beehive kilns operated by villagers to produce charcoal for urban use and local consumption.

The total country charcoal consumption is about 3,378 million kilograms, of which 91% is used as household cooking fuel (Chomcharn, 1983). According to the Baseline Survey Report (Meta Systems Inc., 1982), most methods used in the rural areas for charcoal production gave a rather low yield of charcoal per unit of fuel wood used. For example, the average production of charcoal by earth mound yielded only 11% and rice husk mound methods yielded only 22% charcoal (based on oven dry weight of fuelwood input).

B. OBJECTIVES

In Thailand, wood resources are being depleted by land clearing for agricultural purposes and for energy consumption. As a result, wood resources are not sufficient to meet the demand. It is important that information be obtained on this activity and that improved methods of charcoal making be introduced wherever possible. Therefore, the objectives of this study are:

1. To gather information concerning the production, distribution, and consumption of charcoal in Thailand, so that its magnitude can be accurately represented, particularly for use in national energy planning.

2. To improve charcoal production efficiency at the rural level through the use of better kilns and techniques to achieve a better quality charcoal with a higher yield.

3. To promote and extend appropriate charcoal production technologies to rural charcoal makers and rural government mechanisms through public compaigns, seminars, workshops, and field training.

C. SCOPE OF WORK

The scope of work is as follows:

1. To review currently available data on charcoal production and use, including information collected as part of Thailand's Energy Master Plan and the Baseline Survey Report (Meta Systems Inc., 1982).

2. To survey and analyse charcoal production activities, demand/supply and marketing, especially of small and medium-scale industries such as those in the reforestation villages and in rural communities.

3. To prepare a methodology for measuring and procedures for testing the efficiency of charcoal kilns.

4. To collect data on the types of kilns currently used throughout Thailand (including data on their performance characteristics, yield, cost of operation, materials, dimensions and construction, and firing techniques).

5. To establish the Charcoal Research Center. The CRC is to be equipped with test instruments and provide the appropriate facilities to do research, development and promotion training.

6. To conduct tests on the relative efficiency of different kiln designs including indigenous and promising foreign models.

7. To select a series of kilns which have shown higher efficiencies and performance characteristics comparable to units currently used in different parts of Thailand and,

   a. to introduce these designs in demonstration projects; and

   b. to prepare a program for the diffusion of these higher yield kilns to different parts of Thailand.

D. SIGNIFICANCE

In the production of charcoal by rural people, under 25% of the total fuel wood is converted into charcoal. Therefore, the conversion yield is a critical factor in conserving the fuel wood resource. Based on 25% yield produced by the rural charcoal makers, the quantity of fuel wood required to produce 3,000 million kilograms of charcoal would be 12,000 million kilograms of dry wood. If the overall yield of the charcoal could be raised by only 5%, 2,000 million kilograms of dry wood could be saved each year. This is equivalent to 150,000 hectare of high-yield fast growing trees. In addition, the import of cooking fuel such as LPG will not be increased substantially since consumption of domestic fuel--namely charcoal--will be more competitive.

E. PROJECT MANAGEMENT

The Charcoal Improvement Component has been undertaken with technical cooperation between the government of Thailand and the United States of America under the Renewable Nonconventional Energy Project (#493-0304). The Project is coordinated by the National Energy Administration, Department of Technical and Economic Cooperation and the U.S. Agency for International Development (USAID). The Charcoal Improvement Component is operated by the Forest Products Research Division of the Royal Forest Department.

The Charcoal Improvement Component is one of 14 separate components involved in the Renewable Nonconventional Energy Project. Projects carried out include:

Industrial Biogas
Biomass Casification
Charcoal Improvement
Energy Master Plan Support
Micro-Hydro Project
National Energy Information Center
Pyrolysis of Rice Husks
Regional Energy Centers
Solar Thermal Processes
Solar/Wind Assessment
Stove Improvement
Village Survey
Village Woodlots
Water Lifting Technology

Chapter 2

Review of the Literature

REVIEW OF THE LITERATURE

This chapter reviews the literature on charcoal production from pilot charcoal kilns. The laboratory study of heat treatment of wood specimens, factors of carbonization temperature, wood moisture content in production of charcoal, and charcoal properties will also be discussed.

A. TYPES OF CHARCOAL KILNS

The types of charcoal kilns according to their characteristics can be divided into three categories (Earl, 1975):

1. Fixed or permanent kilns such as brick beehives, masonry kilns, mud beehives, furnaces and retorts,

2. Nonpermanent kilns such as pits and mounds, and

3. Portable or mobile steel kilns such as Mark V, Tropical Product Institute (TPI) design, Single drum, Double drum and Tonga.

These kilns differ in capital investment and charcoal production yields, as well as ease of operation. According to a FAO report (Booth, 1983), the estimated capital investment per annual ton of charcoal production from such kilns were:

- Earth mounds and pits	฿ 800 - 1,200
- Brick kilns	฿ 7,000 - 14,000
- Portable steel kilns	฿ 25,000 - 56,000
- Small steel retorts	฿ 24,000 - 66,000

Research has confirmed that the charcoal production yield from a fixed kiln is the highest (Lejneune, 1983; Srivastava, 1982; Publishing U.S. Forest Products Laboratory, 1961; Earl, 1975). The average lowest charcoal production yield from fixed kilns could be as high as 35%, whereas the lowest charcoal production yield from an earth mound kiln could be as low as 10% (Meta Systems Inc., 1982).

According to the Baseline Survey (Meta Systems Inc., 1982) and the project report (Chomcharn, 1983), charcoal in Thailand is mainly produced from both fixed and nonpermanent kilns such as mud beehive, brick beehive, earth mound, rice husk mound and sawdust mound. The average charcoal yields and kiln size in Thailand with respect to each kiln type were reported as follows:

	Yield	Kiln Size/Load Range	Average
Brick beehives	36%	70 - 369 m^3	150 m^3
Mud beehives	30%	75 - 34,000 kg	730 kg
Rice husk mounds	22%	23.5 - 700 kg	83.5 kg
Sawdust mounds	20%	5 - 30 m^3	22.7 m^3
Earth mounds	19%	42 - 914 kg	323 kg

However, the comparison of charcoal yields from these kilns is quite rough because factors that can influence the yield (such as wood quality, kiln operators, kiln size, etc.) are variable.

B. THE EFFECTS OF CARBONIZATION TEMPERATURE AND WOOD MOISTURE CONTENT UPON CHARCOAL QUALITY AND QUANTITY

Although there are many publications on the laboratory studies of wood carbonization, there are few reports that discuss the operating factors which affect charcoal quality and quantity in actual production. The main factors reported that affect charcoal quality and quantity in a kiln were carbonization temperature and wood moisture content (Florestal Acesita S.A., 1982; U.S. Forest Products Laboratory, 1961). As charcoal yield is reduced, the carbon content will increase as a function of temperature. The experimental results of a 37 m^3 brick beehive kiln using *Eucalyptus grandis* revealed the following:

Carbonization Temperature, °C	Fixed Carbon, %	Volatile Matter, %	Charcoal Yield, %
300	68	31	42
500	86	13	33
700	92	7	30
900	94	5	29

Wood moisture content can play a role in charcoal yield and properties also. Several studies reported only a slight effect of wood moisture content to charcoal yield, charcoal fine content (on the thumbling test) and compressive strength when the moisture content was below 35%. However, the wood moisture content influences the charcoal quality and quantity when it is greater than 35%.

C. THEORY OF CARBONIZATION PROCESS

Anatomical Property of Wood After Carbonization

Several efforts have been made to study the minute structure and cell wall structures of porous and coniferous woods after heat treatment (Kollmann and Sach, 1967). Although the chemistry and physics of wood degradation are changed in the carbonization process, the structure of wood cells remains basically intact when the temperature is below 277°C. Blankenhorn, Jenkins and Kline (1972) observed the anatomical change of Black Cherry, Birch, White Oak and White Ash while these wood specimens were heated at the rate of 3°C per minute in a nitrogen atmosphere. The specimens were held for two hours at 600°C and the average fractional weight loss of Black Cherry specimens was 72%. However, the atmosphere of heat treatment (either in nitrogen or in air to 277°C) did not produce any anatomical change (Kollmann and Sachs, 1967).

Although the heat treatment was conducted at carbonization temperatures higher than 300°C, the structure of certain xylem wood cells remained basically intact (Beall 1972; Beall, Blankenhorn and Moore, 1974; Blankenhorn, Jenkins and Kline, 1972; Elder, et al., 1979 and Zichermann and Williamson, 1981 and 1982). Several microstructures of the cell wall such as helical thickening, simple perforation plates, bordered pit pair and vessel pits were revealed in carbonized wood at temperatures below 600°C. The vessel pits of Black Cherry disappeared after the temperature of 900°C but the helical thickening, simple perforation plates, intervessel pits and bordered pit pairs still clearly remained in the specimens.

Chemical and Physical Properties of Carbonized Specimens

The chemical and physical properties of carbonized specimens have been studied in laboratories for more than thirty years. This section will discuss the research on charcoal properties before and after 1970.

Research on charcoal properties before 1970

Several efforts have been made in the study of the properties of charcoal. The research confirms that charcoal properties depend mainly on carbonization temperature. Two important reports of charcoal properties were summarized by Wenzl in 1970. The reports of Bergstrom in 1954 dealt with several physical properties as a function of temperature and of Pohl in 1957, revealed the relationship of charcoal yield and its elementary composition with respect to carbonization temperature.

As can be seen from Fig. 2.1, at carbonization temperature above 600°C, water absorption and electrical conductivity properties of charcoal depend on the temperature, while charcoal yield, specific gravity, moisture content and carbon content were less dependent on the temperature.

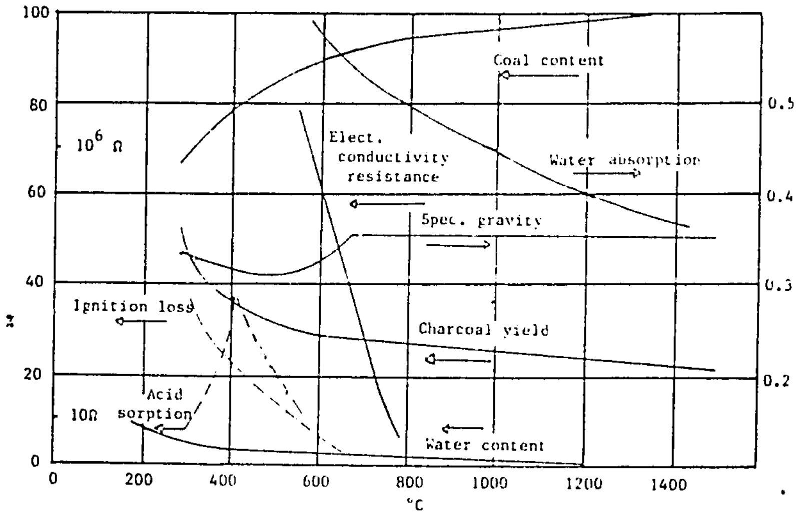


Figure 2.1 Effect of temperature on coaling and charcoal quality (Bergstrom, 1954). (Yield of charcoal, coal content in percent on dry wood; water content and ignition loss; acid sorption in milliliters per gram charcoal; electric conductivity resistance in ohms; water sorption in grams per 100 grams oven-dry charcoal; all figures approximate.)

The relationship of charcoal yield and elementary composition to carbonization temperature is shown in Fig. 2.2 (Pohl, 1957). The carbon fraction of charcoal increases but the hydrogen and oxygen fractions decrease with respect to carbonization temperature. The greatest change in the elementary composition was between 200 to 500°C.

Although Bergstrom's and Pohl's reports provide very important information concerning charcoal properties, relationship of wood chemical composition, heat content, conversion efficiency, heating rates, dimensional and volumetric shrinkages, changes of real density, apparent density and porosity with respect to carbonization temperature had not been widely studied before 1970.

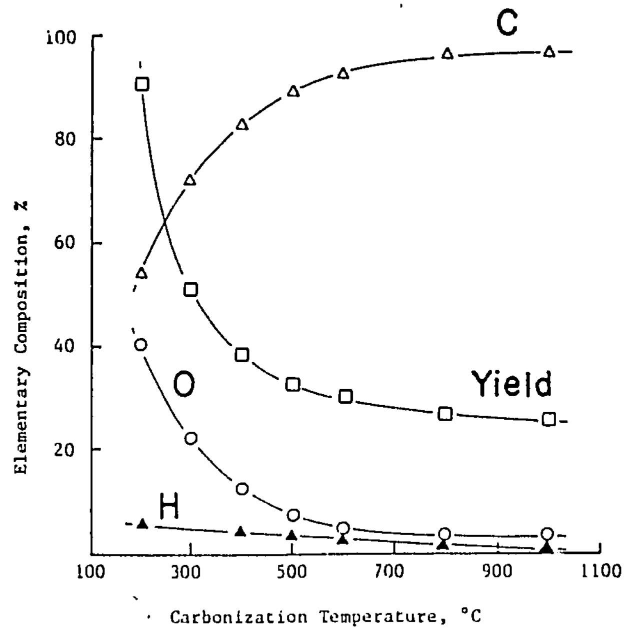


Fig. 2.2 Elementary composition and yield of charcoal in relation to the carbonization temperature.

Research work after 1970

a. Wood chemical composition and mass loss in carbonization.

It is commonly known that the organic chemical composition of wood consists of cellulose, hemicelluloses, lignin and extractives. This composition varies from species to species, for example, hardwoods grown on southern pine sites consist of 33.8 - 48.7% cellulose, 23.2 - 37.7% hemicelluloses, 19.1 - 30.3% lignin and 1.1 - 9.6% extractives (Karchey and Koch, 1979). These organic chemicals could yield various charcoal amounts at carbonization temperatures below 400°C but there would be slightly different yields above 400°C as shown in Fig. 2.3 (Beall, Blankenhorn and Moore, 1974; Slocum, McGinnes and Beall, 1978). The differences of mass loss from cell wall components at temperatures below 400°C might be due to variation in elementary composition and chemical structure. Mass loss of cellulose was found greater than lignin and hemicelluloses (Shafizadeh and Chin, 1977). Above 400°C, however, the chemical nature of cell wall components were somewhat altered, while the slopes of mass losses for the charred components were about the same. The typical fractional mass losses of a hardwood and its cell wall constituents indicated that some hardwood species could provide higher charcoal yields if their cell wall components consisted of larger portions of lignin and hemicelluloses.

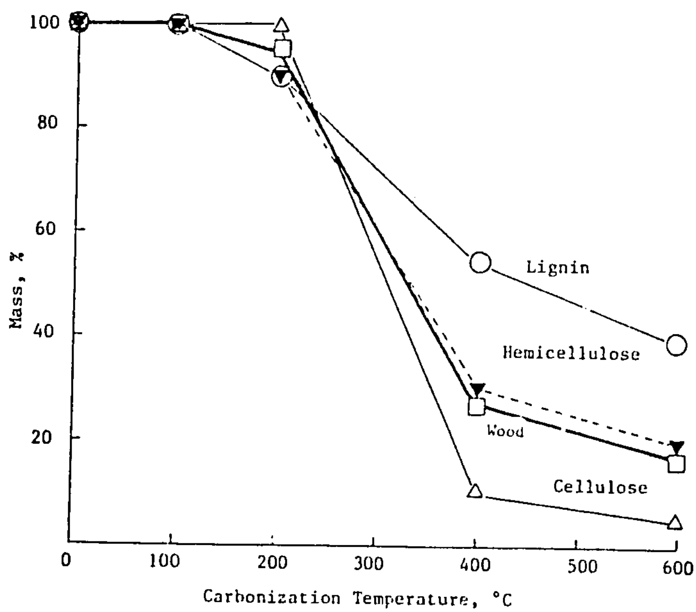


Fig. 2.3 Typical fractional mass loss of hardwood and its constituents as a function carbonization temperature.

It is still difficult to draw a conclusion on the effect of wood extractives on charcoal yield. The quantity and quality of wood extractives vary greatly but the amounts add up to only a small percentage of total cell wall components. However, Kryla (1980) revealed that extracted wood specimens from several angiosperms and gymnosperms provided slightly less charcoal yield than the unextracted one at a carbonization temperature of 600°C.

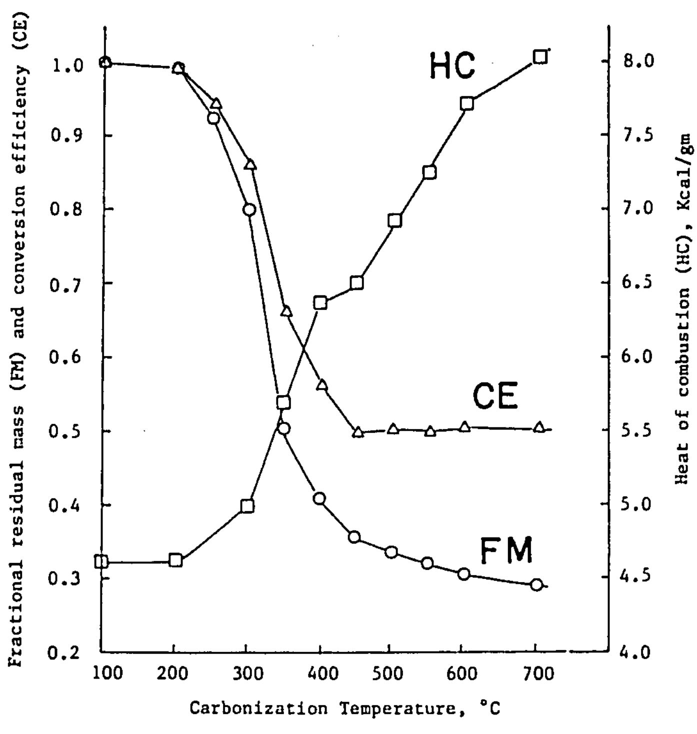


Fig. 2.4 Relationships of average charcoal residual mass, their respective heat of combustion and conversion efficiency versus carbonization temperatures of specimens from red oak, southern yellow pine, black cherry and hybrid poplar (Data from Bailey and Blankenhorn, 1982).

b. Mass loss, charcoal heat content and conversion efficiency in carbonization.

A number of studies have been reported concerning mass loss of wood specimens during carbonization. They concluded that the wood greatly deteriorated at temperatures between 200° and 400°C. However, as shown in Fig. 2.4, Bailey and Blankenhorn (1981) reported the relationship between mass loss and heat of combustion of three hardwoods and a softwood with carbonization temperatures up to 700°C. They confirmed that the average charcoal residual mass and calculated conversion efficiency were greatly affected at temperature ranges of 200°C - 450°C and the heat of combustion of charcoal greatly increased above 300°C. These laboratory results implied that the production of charcoal between the temperatures of 350° and 450°C would provide better yield and conversion efficiency along with moderate heat of combustion. The result of these studies was, however, based on small size specimens.

In addition, Bailey and Blankenhorn formulated an equation for gross heat of combustion of each species at a heating rate of 3°C/min from carbonization temperatures of 200°C to 700°C as follows:

$$HC = A + BT$$

in which, HC is gross heat of combustion in cal/g, T is carbonization temperature in degree Celsius, and A and B are constants specific to each species. A was 3111, 2999, 3023 and 3253 cal/g and B was 7.45, 7.14, 7.98, and 7.38 cal/g°C for Red Oak, Southern Yellow Pine, Black Cherry, and Hybrid Poplar, respectively. The coefficients of determination were greater than 95% for the first-three species but 89% for the Hybrid Poplar.

c. Heating rates and mass loss

There were only a few studies that reported the effect of heating rate to mass loss. Beall, 1977 and Slocum, McGinnes and Beall, 1978 reported that the mass loss of Redwood specimens at the heating rate of 1°C/min was greater than 50°C/min when the carbonization temperature was below 400°C. However, as shown in Fig. 2.5, the mass losses of both heating rates were slightly different at higher carbonization temperatures. It was noted that the higher the heating rate the greater the charcoal yield. However, the study of heating rates, heat transfer coefficients of wood and charcoal, and mass loss still need more, future investigation in order to confirm Beall's work.

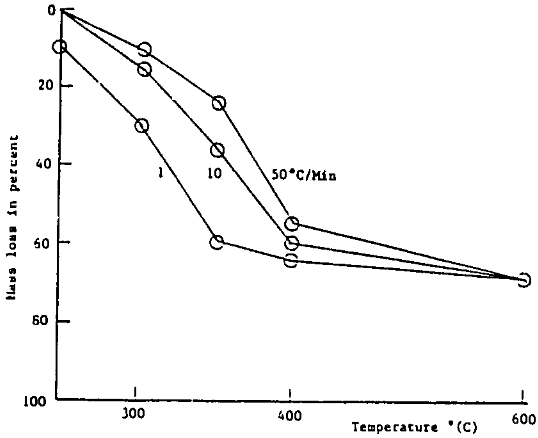


Figure 2.5 Mass loss of redwood at three heating rates to end temperatures of 250°, 300°, 350°, 400°, and 600° C, (Beall 1977).

d. Dimensional shrinkages, density and porosity changes during carbonization.

The dimensional shrinkages of charcoal can be divided into two categories: dimensional changes by losses of absorbed water and the water from carbonization of cell wall components (mass). The shrinkage during absorbed water loss normally takes place at wood moisture content below the fiber saturation point or at approximately 25-30% moisture content (Panshin and de Zeeuw, 1970). The shrinkage curves from Fig. 2.6 are typical for wood in general. The tangential shrinkage for air-dried wood was about twice as large as the radial at the same moisture content. The longitudinal shrinkage from the green to oven dried condition for normal wood was very small, only 0.1-0.5%.

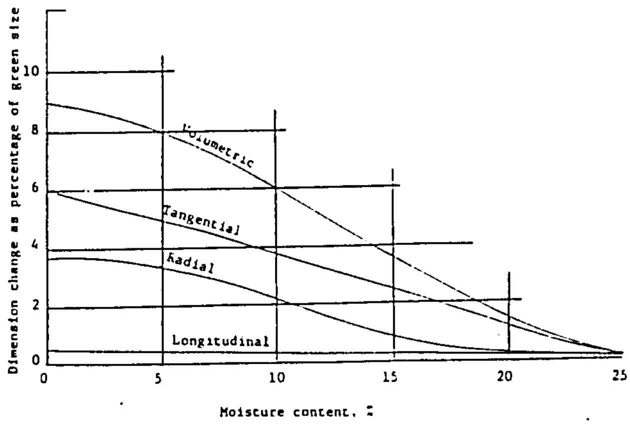


Fig. 2.6 Shrinkage curves for wood from green to oven dried condition (Pashin and de Zeeuw, 1970).

The dimensional change due to loss of water from the carbonization of the cell wall components could be observed at temperatures higher than 200°C (Moore, et al., 1974; Beall, 1977; Slocum, McGinnes and Beall, 1978; Kryla, 1980). Shrinkage curves of White Oak and Shagbark Hickory specimens as a function of temperature are shown in Fig. 2.7 (Slocum, McGinnes and Beall, 1978). Each heat treatment was conducted by different heating rates from 1.5 to 130°C/hr. (These heating rates were similar to those of 7 cord, commercial, masonry block kilns). The longitudinal shrinkage of green wood was many times greater than that of the oven dried wood. The significant change in the longitudinal dimension might be due to the loss of oxygen between anhydroglucose monomers of cellulose. Radial and tangential shrinkages also increased several times over shrinkage of normal oven-dried wood. These observed dimensional shrinkages were similar to those from birch and redwood (Moore, et al., 1974 and Beall, 1977). There was evidence indicating that slopes of mass loss and volumetric shrinkage concerning carbonization temperatures were also similar (Slocum, McGinnes, and Beall, 1978, and Kryla, 1980).

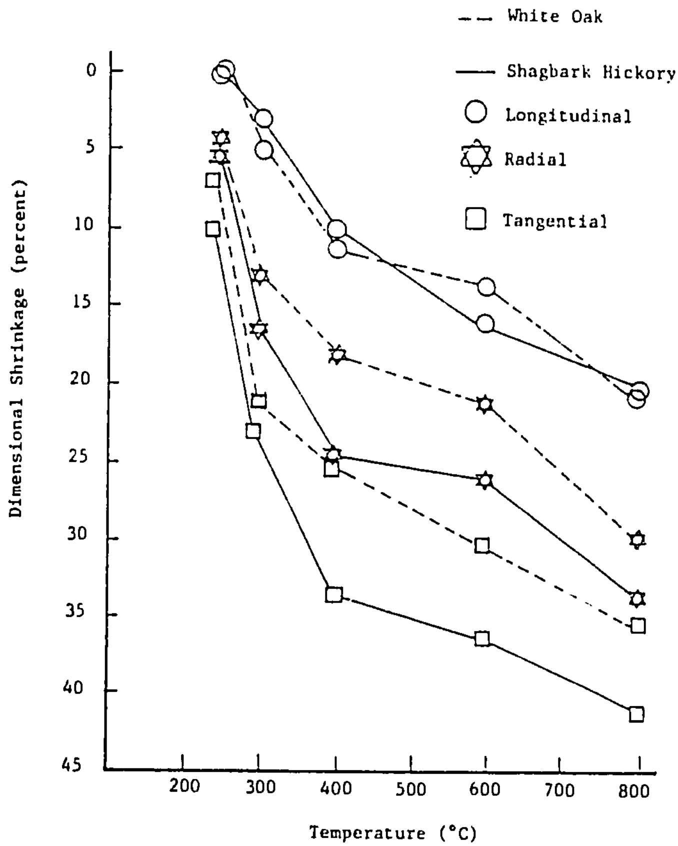


Figure 2.7 Dimensional shrinkage of White Oak and Shagbark Hickory as a function of heat treatment temperature (Slocum, McGinnes and Beall, 1978).

There are three criteria used when dealing with mass loss and volumetric shrinkage in wood carbonization: apparent density, real density and total porosity. The apparent density and total porosity of charcoal was reported to depend on carbonization temperature, but the real density was somewhat ambiguous. Results from the carbonization of Red Oak, Southern Yellow Pine, Black Cherry and Hybrid Poplar specimens that were heated in an electric furnance at 3°C/min under a nitrogen atmosphere, indicated that apparent density decreased, total porosity increased, but the real density remained fairly constant with respect to temperature (Bailey and Blankenhorn, 1982). The decrease in apparent density of charcoal with the increase in carbonization temperature was confirmed by several studies (Blankenhorn, Jenkins and Kline, 1972; Beall, 1977; Kryla, 1980 and Cutter and McGinnes, 1981). However, studies of the latter group contradicted the results of real density constancy. The carbonization of seven hardwood and softwood specimens, namely, Southern Pine, Western Red Cedar, Douglas-fir, Redwood, White Oak, Basswood and Hard Maple, at a heating rate of 1°C/min under a nitrogen atmosphere, revealed that the real density of charcoal, combining all species, slightly decreased with temperatures up to 600°C.

D. CHARCOAL PROPERTIES

When discussing charcoal properties, proximate analyses normally reported the quality of the charcoal as well as the heat content. These analyses reveal the fixed carbon, volatile matter and ash content, which are accepted in the charcoal market. However, other charcoal physical properties were rarely reported, especially those from actual charcoal kiln experiments. The quality of the charcoal is of major concern to experienced consumers. Such qualities as the presence of smoke (if volatile matter content is very high), the fire bursting effect when the charcoal is ignited, the hardness of charcoal bulk (tested by its sound when dropped on a hard surface or cracked with a rod), the amount of charcoal fines that are left when the charcoal is crushed or broken during size reduction, and the weight of the charcoal should be made known to charcoal users and makers.

It should be noted, in addition, that charcoal properties from kiln production are not uniform even within a kiln, due to the temperature gradient inside which varies from the top to the bottom of the kiln. The following paragraphs will discuss the average charcoal properties from various kiln types in relation to charcoal yield and its applications.

The Relationship of Charcoal Yield and Properties in Commercial Kilns

The charcoal production from 10.4 and 24.2 m^3 pilot masonry block kilns could yield 27 to 32% charcoal with the final carbonization temperature between 450° and 510°C (U.S. Forest Products Laboratory, 1961).

The proximate analyses of the charcoal produced were as follows:

moisture	2- 4%
ash	1- 4%
volatile matter	18-23%
fixed carbon	74-81%

However, the fixed carbon content of Southern Red Oak charcoal produced from the 24.2 m^3 kiln, vary within the kiln as follows:

top zone	85%
center zone	80%
floor zone	75-79%

The charcoal production from a brick kiln is more efficient. A 5 m diameter of brick beehive Brazilian designed kiln, could yield 33% charcoal produced from five year old *Eucalyptus grandis* at 76% to 81% fixed carbon content (Florestal Acesita S. A., 1982). The average fixed carbon content of each kiln zone was recorded as follows:

top zone	81%
middle zone	80%
bottom zone	76%

The average carbonization temperature at the final stage varied from 450° to 500°C.

Average charcoal yield and properties from nonpermanent and portable kilns were rather poor (Maslekar, 1982 and Majumdar, 1982). The average charcoal yields of country kilns (pits and mounds) and 6.64 m^3 portable kilns (the TPI designed steel kilns) were only 20%. The proximate analyses of charcoal from both kiln types, however, were different. The average percentages of fixed carbon, volatile matter, ash, and moisture content for the charcoal from the country kilns and from the portable kilns are shown below:

	country kilns	portable kilns
fixed carbon	60%	70%
volatile matter	29%	24%
ash	6%	4%
moisture content	4%	2%

From the previous paragraphs, it is apparent that both charcoal properties and yields from portable steel kilns and from pits and mounds were far less efficient than those from fixed kilns.

Relationship Between Charcoal Properties and End Use Application

The applications of charcoal can be categorized as industrial and non-industrial. Generally, charcoal compositions are 80 to 90% fixed carbon, 7 to 30% volatile matter, and 0.5 to 10% ash (Meyers and Jennings, 1979). Charcoal yield is closely related to charcoal composition, especially fixed carbon content, as previously discussed. Therefore, charcoal production must be done carefully, according to the market requirement. The following paragraphs will discuss the general charcoal properties and characteristics for industrial and non-industrial applications, although most charcoal production in Thailand is destined for non-industrial applications, particularly for cooking.

The industrial applications of charcoal can be divided into two classes: metallurgical and chemical charcoal (U.S. Forest Production Laboratory, 1961). Both types of charcoal should contain high fixed carbon, low volatile matter and low ash contents. However, the requirements of some industrial charcoal extend to the amount of surface area. The properties of industrial charcoal may be identical to white charcoal specifications (as in Japan where carbonization temperature ranged from 750 to 1000°C). The volatile matter content of oak white charcoal was about 5%, while that of black charcoal was about 30% (Krishimoto and Sugiura, 1982).

In summary, the charcoal making experience reveals that a fixed charcoal kiln provides better charcoal yield and energy conversion efficiency than a nonpermanent kiln. The carbonization temperature is the most important factor affecting the quality and the quantity of charcoal output. The raw wood material (such as species and wood moisture content) can also influence the charcoal output, but to a lesser degree.

Chapter 3

Project Design

PROJECT DESIGN

A. DETERMINING STATUS OF CHARCOAL IN THAILAND

A nationwide charcoal survey was to be conducted to determine charcoal production, distribution and consumption.

The aim of this study was to determine Thailand's charcoal production status and to research, develop, and choose appropriate small-scale charcoal production technology, and then extend and promote this technology to the rural people. This chapter will discuss the operational plan that was used.

B. ESTABLISHMENT OF THE CHARCOAL RESEARCH CENTER

The Charcoal Research Center was established in April 1982 and is located in the Central Forest Experimental Station of the Royal Forest Department, Pukae, Saraburi. It is 125 km from Bangkok along Paholyothin Road (Rt. No. 1) toward Lopburi. This Center provides facilities for research as well as for training. The facilities on one hectare of land include: a semi-permanent shed for certain types of charcoal kilns and test equipment, a semi-permanent shed for temporary storage of charcoal, lodgings for Project personnel and trainees, a meeting room, and an office. In addition, a 3 hectare intensive fuel wood plantation is being raised for future research and development.

C. CONSTRUCTION OF CHARCOAL KILNS

Various types of charcoal kilns were to be constructed and fabricated at the Charcoal Research Center. These kilns were to be of small size, feasible for small scale production of charcoal by the rural people. The kilns to be constructed were: brick beehives, mud beehives, Brazilian, and Brazilian modified (brick), hot tails (brick), Mark V's (metal), Tongas (metal), Single drums and Double drums (metal), and pit or mound (i.e. earth mound, sawdust mound, and rice husk mound). The shapes of these kilns were to be simulated from those used elsewhere. The purpose of the research was to redesign, modify and refine these kilns in order to improve performance and to accommodate certain practical requirements.

D. EVALUATION OF CHARCOAL KILNS

In order to evaluate the efficiency as well as advantages and disadvantages of each kiln model, several criteria for testing were established.

Test for Kiln Performance and Efficiency

The kiln performance and efficiency were to be evaluated in terms of: percentage charcoal output or yield, production rate, energy conversion efficiency and cost of production. In addition, a trial recovery of by-products during the carbonization process was to be studied.

Test for Charcoal Properties

As the primary purpose of charcoal produced is its use as a household cooking fuel, the following properties of the charcoal were to be tested: apparent density, moisture content, fixed carbon, and use properties (such as fine percentage during size reduction, fire bursting effect and work done or heat utilization efficiency). In addition, the heat content of the charcoal was to be determined for use in the calculation of conversion efficiency.

Analysis of the Results

The overall performance of the kilns tested was to be evaluated in terms of the parameters just mentioned. The analysis was to single out the charcoal kilns suitable for the rural population.

E. EVALUATION OF FIRING TECHNIQUES

Several firing techniques* are employed by charcoal makers in Thailand. To keep the variable factors narrow, only 2 m^3 brick and mud beehive kilns were to be used in the testing of firing techniques.

*"Continuous firing" is a technique practiced in Mangrove charcoal production employing large brick beehive kilns. The firing is maintained from the start until kiln closing.

"Initial firing" is a technique practiced in upland charcoal production employing small mud beehive kilns. The firing is maintained until the carbonization begins (as indicated by the appearance of thick white pungent smoke).

"Chimney extension" is a technique employed to increase the heating rate by temporarily connecting steel pipes to kiln chimneys until the carbonization begins.

In this study, the firing techniques to be used are listed below together with wood moisture content.

Dry wood, continuous firing
Dry wood, initial firing
Dry wood, continuous firing and extension of chimneys
Semidry wood, continuous firing
Green wood, continuous firing
Green wood, initial firing
Green wood, continuous firing and extension of chimneys

During each firing technique, kiln temperature, smoke temperature, smoke odor and color were to be observed or monitored and data was to be recorded for analyses.

F. PROMOTION AND TRAINING

During the last six months of the final year of the Project, extension and promotion were to be the main activities. Three workshop/training programs were scheduled at the Charcoal Research Center, Saraburi. The trainees of these workshops were to be composed of village leaders and government officials. In addition to these workshops, six field training courses were to be scheduled to follow up the trainees as well as to demonstrate the techniques and to train village people.

The purpose of the workshops and training programs was to transfer the improved charcoal production technology to rural charcoal makers. During the course of the training, the trainees were to become involved in the construction of brick beehive and mud beehive kilns. Then, they were to learn to make charcoal from the kilns they constructed. The brick and other construction materials including fuel wood, were to be provided to the trainees. The knowledge of small-scale charcoal production that the trainee will learn begins with wood preparation, wood loading into the kiln, firing the kiln, controlling the kiln during carbonization, closing the kiln, and finally, opening the kiln and unloading the charcoal. Evaluating the performance of the kiln was to be done in terms of charcoal output yield and production rate.

Along with training in charcoal production technology, the introduction of efficient household biomass cooking stoves was to be included. In addition, for promotion efforts, several publications were to be made available to the public, (such as promotion brochures, training manuals, seminar and workshop papers, as well as documented results of the charcoal survey and technical development).

Chapter 4

Experimental Techniques and Procedures

EXPERIMENTAL TECHNIQUES AND PROCEDURES

This chapter will discuss the species of wood used as raw materials, features of the charcoal kilns that were tested, and the step-by-step procedures in the production of charcoal from each type of kiln. In addition, a method to recover charcoal by-products and methods to evaluate charcoal quantity and quality are discussed.

A. RAW MATERIAL

This section will discuss the physical and chemical properties of the wood species used.

Wood Species

Acacia catechu Willd was the main species used as raw material in the experiment because of its availability. The acacia wood was obtained from a 15-year-old growth at the Chaibadal forest plantation in Lopburi and from a 20-year-old Pang-Asoke forest plantation in Nakhon Rachasima (Korat). The trees were planted using 4 x 4 m spacing and had been thinned several times.

The diameter of the wood used ranged from 4 to 15 cm. Wood with a diameter larger than 15 cm was split to a smaller size. The length of the wood used was 1 m for the smaller logs (diameter <10 cm) and 0.5 m for the larger logs.

Ten other wood species were also used as testing specimens in limited amounts. These included:

1. *Acacia auriculiformis*
2. *Casuarina equisetifolia*
3. *Casuarina junghuniana*
4. *Combretum quadrangulare*
5. *Eucalyptus camaldulensis*
6. *Leuceana leucocephala*
7. *Melia azedarach*
8. *Peltophorum dasyrachis*
9. *Rhizophora apiculata*
10. *Spondias pinnata*

The materials used were classified according to their condition after periods of air drying:

Type of wood	% Moisture Content
Green wood	>35
Semidry wood	25 - 35
Dry wood	<25

Physical Properties

The following were physical properties of the acacia wood used in the experiment based on oven-dried wood.

a. Density of different wood sizes

Diameter, mm (excluding bark)	Density, kg/m^3 solid
40 - 65	668
80 - 105	680
110 - 140	682
40 - 140 average	677

b. Sapwood-to-heartwood ratio of different wood sizes.

Diameter, mm (excluding bark)	Sapwood/Heart wood (radius length)
50 - 79	1.430 : 1
80 - 109	0.784 : 1
110 - 139	0.565 : 1
140 - 199	0.296 : 1
200 - 240	0.204 : 1
average	0.597 : 1

c. One stere of oven dried wood weighed approximately 400 kg.

Chemical Properties

The following were average values of some chemical properties of the acacia wood--diameter range 40-170 mm (excluding bark).

		Sapwood	Heartwood
a.	Proximate analysis		
	Volatile matter %	84.72	79.85
	Ash %	0.95	0.70
	Fixed carbon %	14.33	19.45
b.	Heat of Combustion		
	cal/g	4,680	4,820
c.	Heat of combustion of whole wood		
	Excluding bark	4,770 cal/g	
	Including bark	4,721 cal/g	

In the experiment, whole wood was used except for sample specimens where bark was excluded. Decayed and heavily blue-stained woods were rejected.

B. CHARCOAL KILNS

In this research, several types and sizes of kilns were tested. The kilns can be grouped into three types: permanent, nonpermanent and mobile kilns. Table 4.1 tabulates all of the kilns used in this experiment together with their size, cost of construction and symbol. The symbols of the kilns will be used throughout this report. The features of each kiln will be discussed in this section.

Brick Beehive Kilns

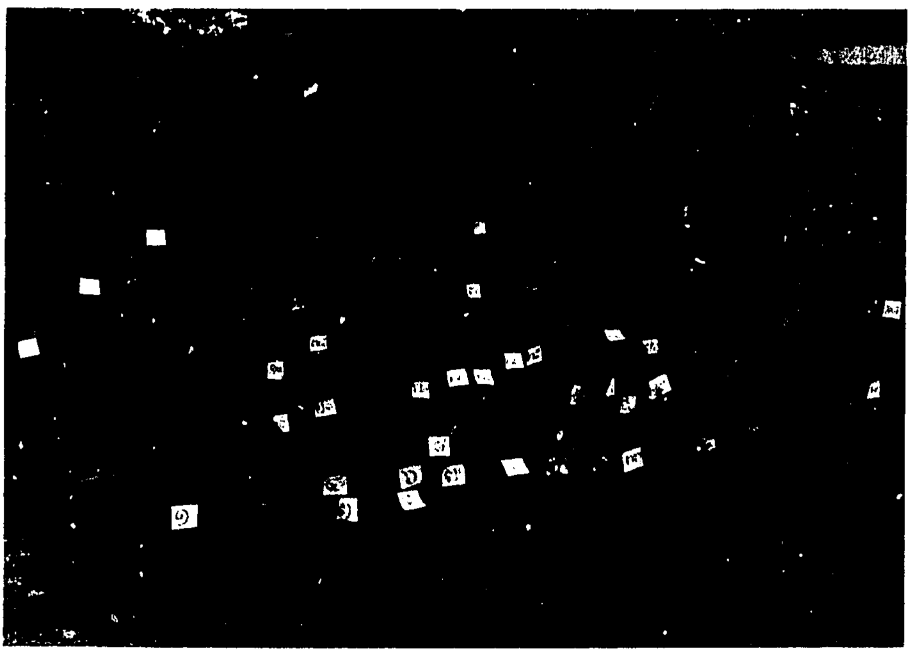
The brick beehive kilns that were used were typical commercial charcoal kilns, but smaller in size. Three sizes of brick beehive kilns were constructed:

Table 4.1 Types of sizes of kilns tested

Kiln types	Symbol	Volume M^3	Cost of Construction*	
			Baht	US Dollar
Permanent				
Brick beehive 1	BB1	8.3	฿ 5,019	$ 218
Brick beehive 2, 3	BB2, 3	2.0	2,405	105
Brazilian modified	BM	8.3	3,153	137
Hot tail	HT	0.5	507	22
Hot tail modified	HM	0.5	507	22
Mud beehive 1	MB1	7.2	882	38
Mud beehive 2, 4	MB2, 4	3.7	540	23
Mud beehive 3, 5	MB3, 5	2.2	504	22
Mobile				
Mark V 1	MV1	4.8	15,000	652
Mark V 2	MV2	2.6	12,000	522
Tonga	TG	0.2	300	13
Single drum	SD	0.2	400	17
Double drum	DD	0.4	700	30
Nonpermanent				
Rice husk mound	RM	0.7	-	
Saw dust mound	SM	0.7	-	
Earth mound	EM	0.7	-	

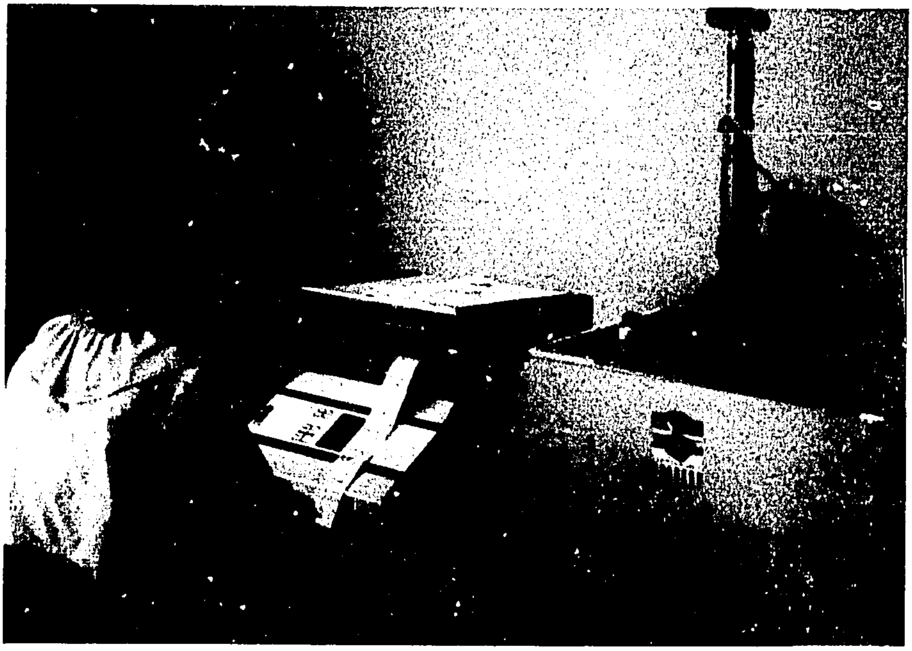
* including labor

Leucaena wood raw material



Tools for kiln construction, wood preparation, and charcoal retrieval

Trial recovery of charcoal by-products



Determination of charcoal heat content

Brick beehive kiln	Size Constructed
Brick beehive 1 and Brazilian modified	8.3 m^3
Brick beehive 2 and Brick beehive 3	2.0 m^3
Hot tail and Hot tail modified	0.5 m^3

The schematic diagrams of 2 m^3 brick beehive, Brazilian modified, and hot tail kilns are shown in Fig. 4.1, 4.2 and 4.3, respectively. The shape of the 8.3 m^3 brick beehive kiln is similar to that of the 2 m^3 brick beehive kiln. The hot tail kiln has the same shape and size as that of the hot tail modified kiln. The difference is that the hot tail modified kiln has three chimneys similar to those of 2 m^3 brick beehive kiln. Table 4.2 tabulates characteristics of each kiln in detail.

The raw materials for constructing a brick beehive kiln were bricks, clay and sand. Some simple instruments such as a shovel, spade, trowel, aluminum can and levelers were used in construction. There were 3 steps involved in the construction: preparation of land, preparation of cementing materials and constructing the kiln.

The location for a kiln must be away from a flooding area. A land area of 4 x 4 m was cleared and leveled. An O-shaped ring for the kiln foundation was made by using a straight bamboo rod and nails at the specified diameter for the kiln size (see Table 4.2). The foundation was dug out to about the depth of three layers of bricks.

The preparation of the cementing materials for the bricks was made with soft clay and sand. The softening of clay was done by soaking it in water for a few days. The mixture of clay to sand was 1:2 for cementing bricks and 1:3 for the exterior coating of the kiln.

The arrangement of the bricks from the foundation to the top of the kiln was in the same manner as normal brick construction. For a brick beehive of local design, the construction procedure is as follows: When three brick layers of the foundation have been constructed, spaces for four chimneys and a loading port and firing port are left before the base wall is begun. The sizes of these characteristics are listed in Table 4.2. Each layer of brick must be vertically and horizontally leveled. At 0.8 m above the kiln floor, a space for an accelerating hole must be left in the wall, opposite that of the fireport. The kiln shape is similar to Fig. 4.1. Four chimneys are constructed after finishing the kiln wall. The original design placed the firing port at the loading port, but in the later design they were separated so that the tunnel could be neatly and permanently built.

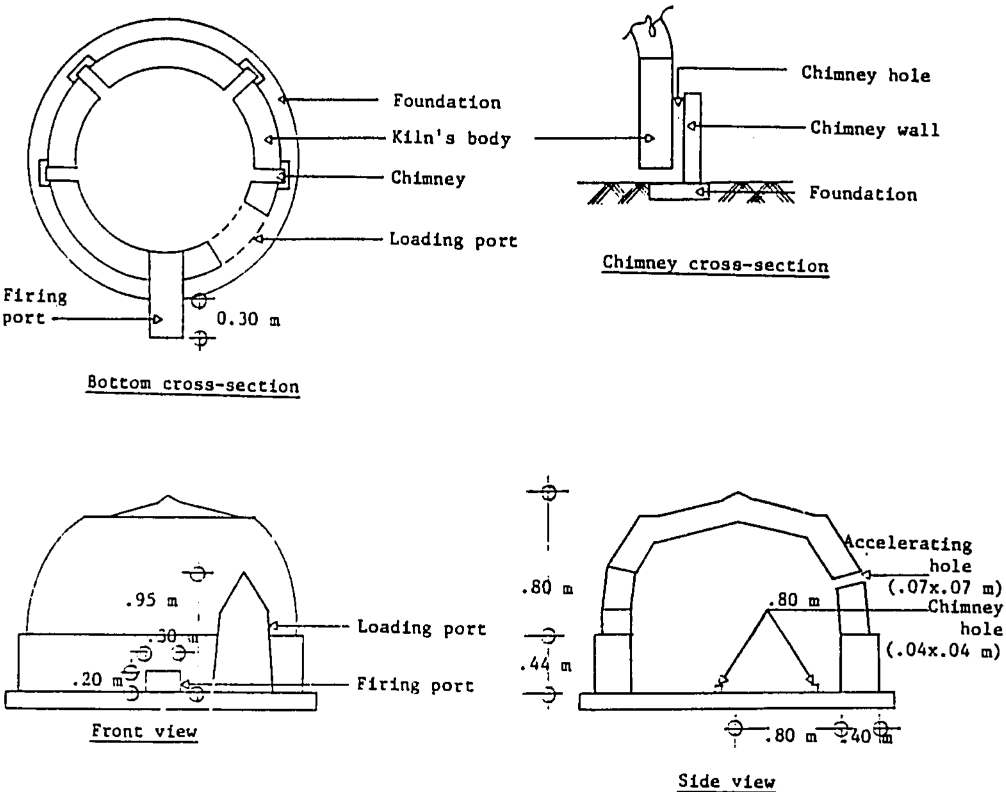


Fig. 4.1 Schematic diagram of Brick Beehive Kiln (2 m^3)

Table 4.2 Characteristics of brick beehive kilns

Description	BB1	BB2, 3	BM	HT	HM
Volume m^3	8.3	2.0	8.3	0.5	0.5
Number of brick used (3.5x6.5x15 cm)	8,690	4,025	5,440	880	880
Height, m	1.9	1.2	1.9	1.0	1.0
Inside diameter, m	2.6	1.6	2.6	1.0	1.0
Foundation thickness, cm	46	31	46	22	22
Wall thickness, cm					
Base	31	24	31	16	16
Middle	23	16	7	7	7
Top	16	16	7	7	7
Loading port area, m^2	0.9x1.2	0.7x1.0	1.3x0.7	0.4x0.7	0.4x0.7
Firing port area, m^2	0.4x0.2	0.3x0.2	0.1x0.3	0.05*	0.05*
Chimney					
Number	4	4	3	-	3
Height, m	0.64	0.51	1.4	-	0.34
Area, cm^2	6x10	4x6	10x10	-	4x4
Accelerating hole					
Number	1	1	37	24	20
Height, m	1.2	0.8	varied	varied	varied
Area, cm^2	9x10	7x7	5x9	5x9	5x9

*Circular hole at top

Drying and curing of the binding materials were carried out by burning 1-2 armfuls of firewood for 3-4 hours inside the kiln. The cost of the kiln construction was evaluated based upon the material costs and labor which are shown in Table 4.3.

Table 4.3 Construction cost of brick beehive kilns

Kilns	Capacity m^3	Number of bricks	Amount of sand, m^3	Labor man-hr.	Total Construction	
BB 1	8.3	8,690	2	208	฿ 5,019	$ 218
BB 2 & 3	2.0	4,025	1	103	2,405	105
BM	8.3	5,440	1.3	130	3,153	137
HT & HM	0.5	880	0.2	21	501	22

Brick 0.30 baht/piece
Sand 270 baht/m^3
Labor 9 baht/man-hr.

Mud Beehive Kilns

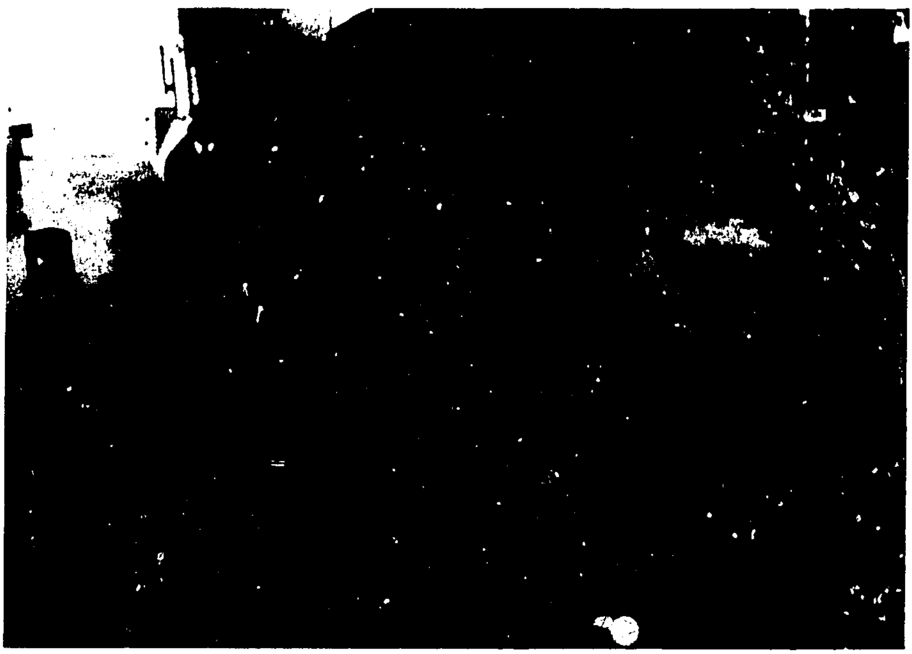
The mud beehive kilns used in the experiment are typical charcoal kilns used by the rural people. Three sizes of mud beehive kilns were constructed:

Mud Beehive Kiln	Size Constructed
Mud beehive 1	7.2 m^3
Mud beehive 2 & 4	3.7 m^3
Mud beehive 3 & 5	2.2 m^3

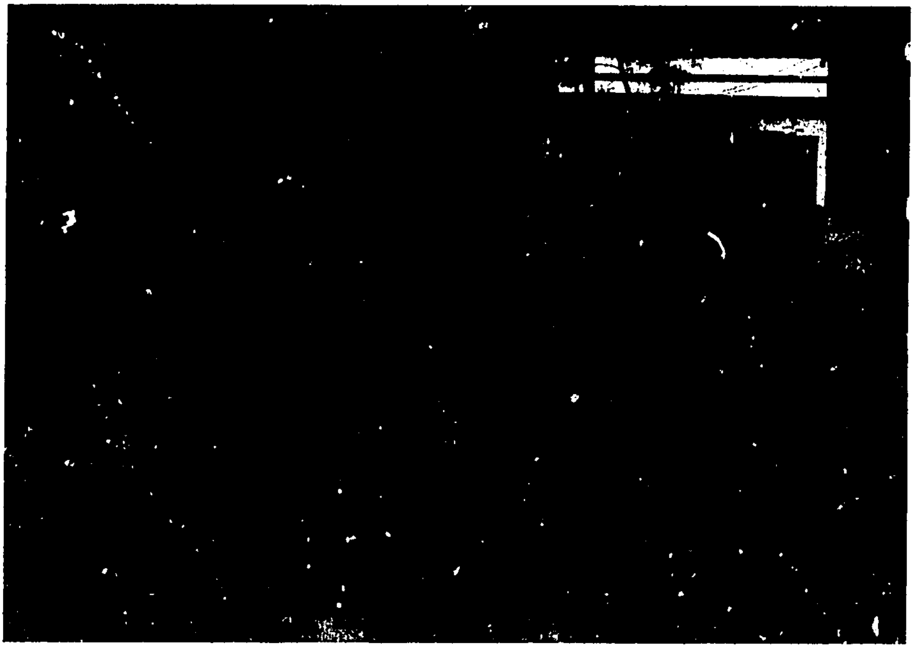
The schematic diagram of the mud beehive kiln is shown in Fig. 4.4. Table 4.4 tabulates characteristic specifications of the mud beehive kilns that were constructed.

The location of the mud beehive kiln is even more important than that of the brick beehive kiln. Since the kiln's floor is usually dug below ground level (even a high ground mud beehive can be built on the ground like a brick beehive, but it is not common), the kiln has to be located on high ground above the water table in order to avoid a wet floor during operation and flooding in the rainy season.

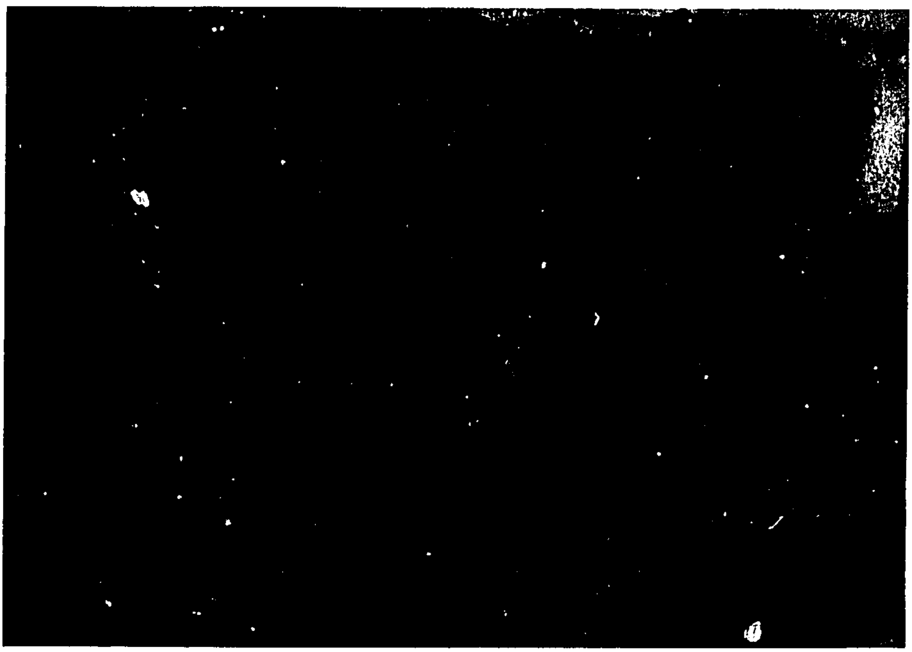
Brick beehive kilns



Mud beehive kiln



Brazilian modified kiln



Hot tail kiln

The material used in the construction of the wall of the mud beehive kiln was a soft lateritic mud or sandy clay. After digging in the ground to the specified floor level and inside diameter, a bundle of wood (to be covered later) was stacked up on the kiln floor to support the soft mud until it was solidified. The shape of the bundle of wood was made in accordance to the shape of the kiln. The small pieces of wood and grass/leaves were used on the top of the bundle so that the interior of the kiln would be smooth. Then the whole stack of wood was covered with 10-15 cm of mud. The kiln wall was made compact by beating it with a piece of flat wood.

After completion of construction, the first run of the kiln to produce charcoal could not be made until the soft mud was hardened or dry enough to be self-supporting. This usually takes a few days. The mud wall can be tested for hardness by touch. The first kiln operation must be fired slowly in the firing port.

As the mud starts to dry during the carbonization process, small cracks in the kiln's wall will appear. To seal these cracks, a slurry of mud in water was applied until all of the cracks were gone.

The labor costs of the construction of the mud beehive kiln are tabulated in Table 4.5. These included kiln drying, shaping and preliminary fire curing.

Mark V Kilns

The body of the Mark V kiln was made from 3.2 mm steel sheets. The kiln was cylindrical in shape with a funnel-shaped cover as shown in Fig. 4.5. The body of the kiln could be separated into three parts for ease of transportation, wood loading and charcoal unloading. The interface between each part was made so that a small track was available for sand filling. This will prevent air from leaking into the kiln at the end of the charcoaling process.

Two sizes of Mark V kilns were made--4.8 m^3 (the MV1) and 2.6 m^3 (the MV2). The characteristics and specifications of both sizes are tabulated in Table 4.6. As shown in Fig. 4.5, the lower part of the kiln is set on the kiln's supporters. These supporters also function as chimneys and the air inlet ports.

The cost of construction of Mark V kilns are ฿ 15,000 (652 US$) for Mark V1 and ฿ 12,000 (523 US$) for Mark V2, excluding the transportation cost. These prices include material and labor. In comparing these kilns to other types of kilns, even with larger capacities, the Mark V is unfortunately, the most expensive.

Table 4.4 Characteristics of mud beehive kilns

Description	MB1	MB2, 4	MB3, 5
Volume, m^3	7.2	3.7	2.2
Height, m	2.1	1.8	1.7
Inside diameter, m	2.4	2.0	1.4
Floor level (below ground), m	0.9	0.8, 0.5	0.7, 0.0
Wall thickness, cm	10	10	10
Loading port area, m^2	0.6 x 0.8	0.6 x 0.6	0.7 x 0.8
Firing port area, m^2	0.3 x 0.3	0.3 x 0.3	0.2 x 0.3
Chimney			
Number	3	2	2
Height, m	1.2	1.1	0.75
Diameter cm	9	9	6
Distance from kiln wall, cm			
Top	50	50,20	70,30
Bottom	40	50,35	70,37
Accelerating hole			
Height, m	1.5	1.1	1.2
Diameter, cm	8	8	8

Table 4.5 Construction costs of mud beehive kilns

Kilns	Labor man-hr.	Total cost	
MB 1	98	฿ 882	$ 38
MB 2 & 4	60	540	23
MB 3 & 5	56	504	22

Labor: 9 baht/man-hr.

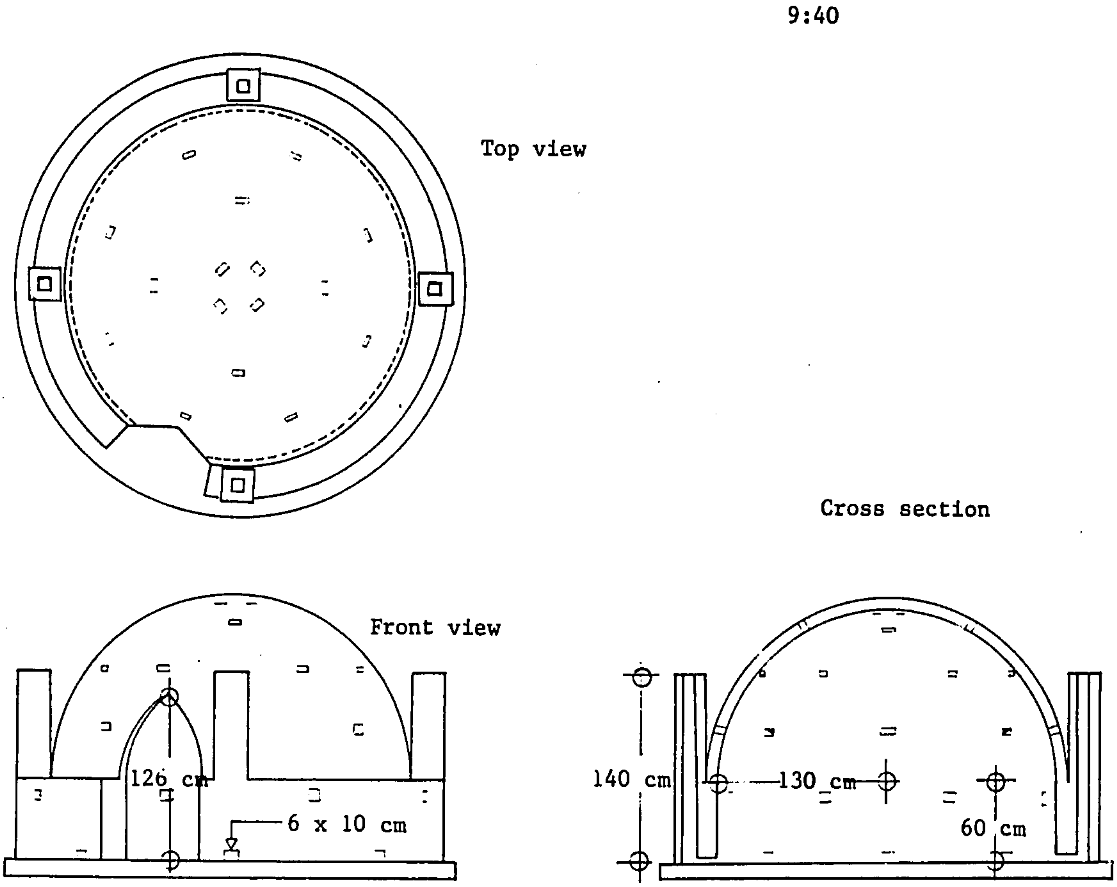


Figure 4.2 Schematic diagram of Brazilian Modified Kiln (8.3 m^3)

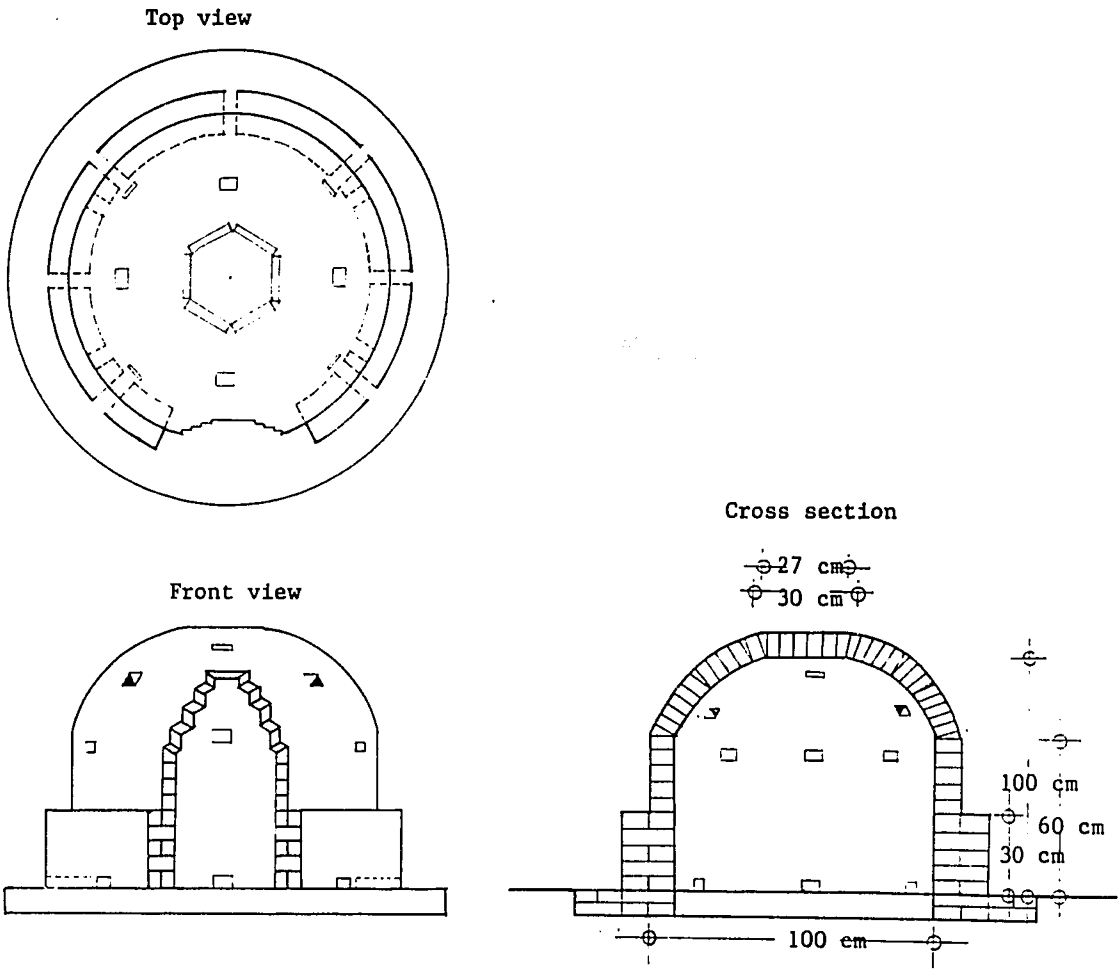


Figure 4.3 Schematic diagram of Hot Tail Kiln (0.5 m³)

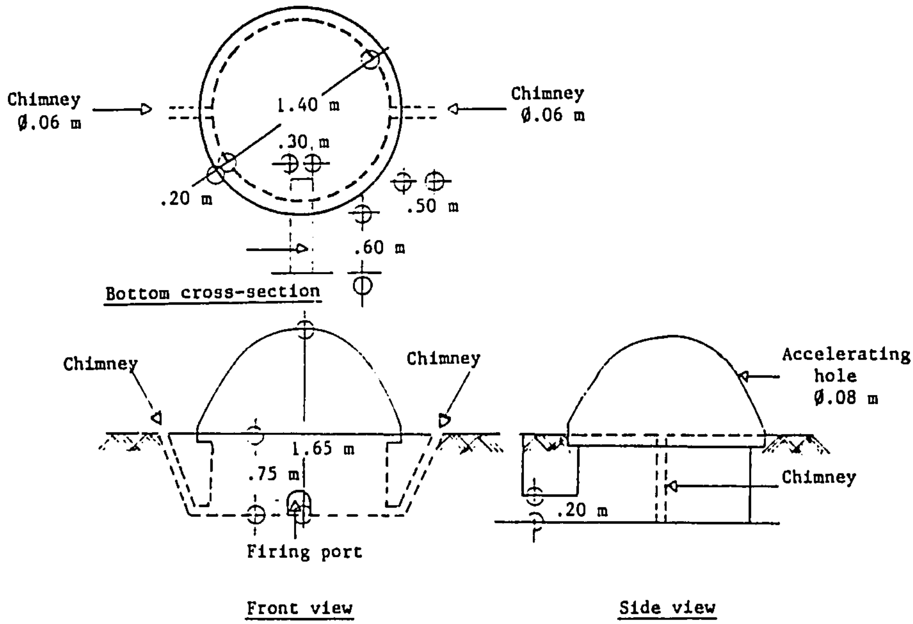


Figure 4.4 Schematic Diagram of a Mud Beehive Kiln ($2m^3$)

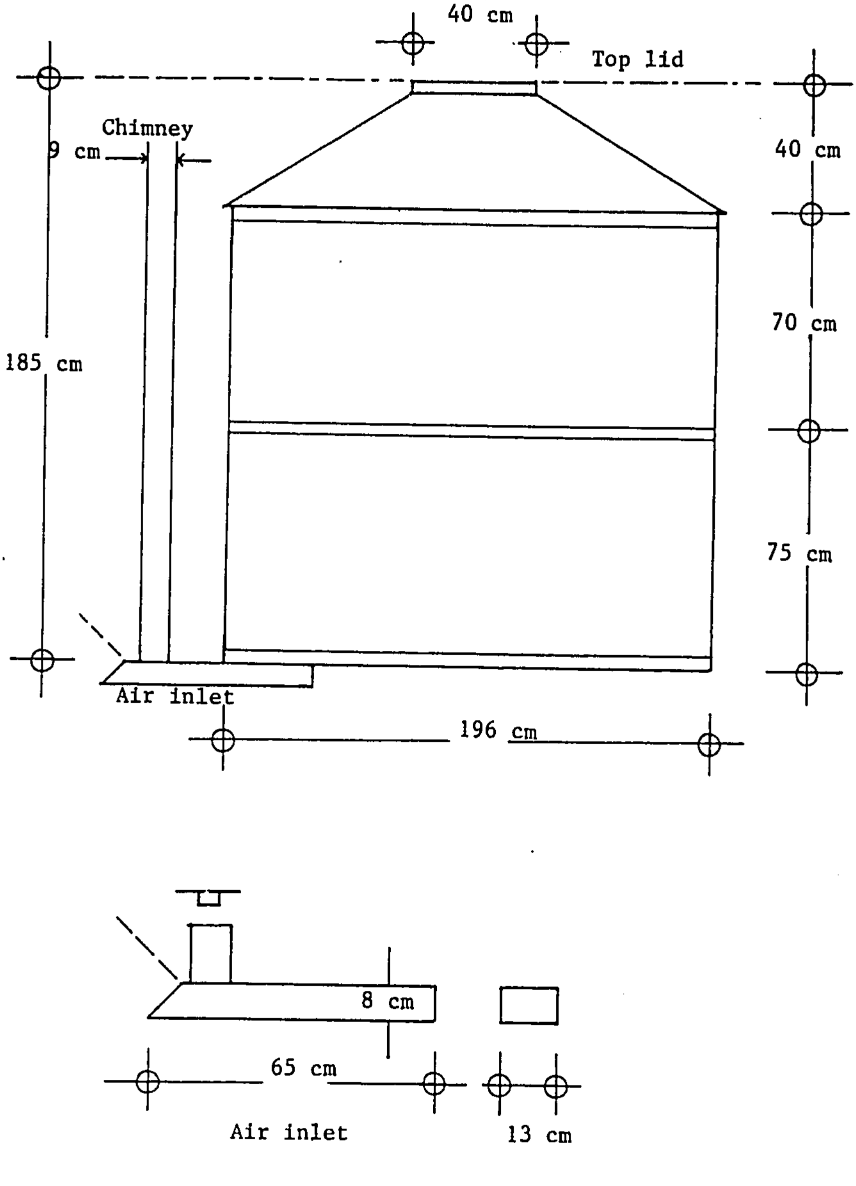


Figure 4.5 Schematic Diagram of Mark V Kiln (5 m³)

Table 4.6 Characteristics of Mark V Kilns

Description	MV 1	MV 2
Volume, m^3	4.8	2.6
Kiln's dimension, m		
Height of lower portion	0.9	0.7
Height of upper portion	0.6	0.5
Height of lid	0.5	0.5
Total height	2.0	1.7
Diameter	1.9	1.6
Kiln's supporter		
Number	8	6
Width, cm	13	11
Height, cm	8	8
Length, cm	60	45
Chimney		
Number	4	3
Height, m	2.7	1.5
Diameter, cm	9	7
Accelerating hole's diameter, cm	36	30

Metal Drum Kilns

Three types of metal drum kilns were used in this study: The tonga (TG), single drum (SD), and double drum (DD). The schematic diagrams of the three kilns are shown in Figs. 4.6 - 4.8.

The tonga kiln originated in Fiji and was used for production of charcoal from coconut trees. The kiln was made from a 200 liter oil drum. The cost to make this kiln was about ₿ 300 (13 US$), drum included.

The single drum kiln originated in the Republic of the Philippines and was primarily used to produce charcoal from coconut shells. The kiln was made from a typical 200 liter oil drum. The cost to make this kiln was about ₿ 400 (17 US$), drum included.

The double drum kiln is actually two-200 liter oil drums joined together to double the inside volume. The cost to make this kiln was about ₿ 700 (30 US$), drums included. The diagrams of the metal drum kilns can be found in Figs. 4.6, 4.7 and 4.8.

Nonpermanent Kilns

Three types of nonpermanent kilns were selected to be used in this study: rice husk mound (RM), sawdust mound (SM), and earth mound (EM). These are typical kilns used by the rural people to produce charcoal. The sizes of these kilns range from small sizes for household use, to large sizes for commercial charcoal production. In this study, only small size kilns were simulated, similar to those us by the rural population.

There is no cost for the construction of these kilns, since the kiln can be made by digging a shallow pit in the ground. The shape of the pit is not defined since the purpose of the well is only to contain the rice husk, sawdust, or earth used in covering the wood. The size and shape of the three nonpermanent kilns used in this work are shown in Fig. 4.9. The differences among the three types are that the SM and EM have chimneys and require several layers of leaves to cover the top of the wood to prevent sawdust or earth from falling inside the pile of wood. The rice husk mound, on the contrary, requires no chimney nor layers of leaves to cover the top.

C. TEST PROCEDURES

This section will discuss test procedures in wood preparation, wood loading, operation of each type of kiln, and in-trial recovery of by-products.

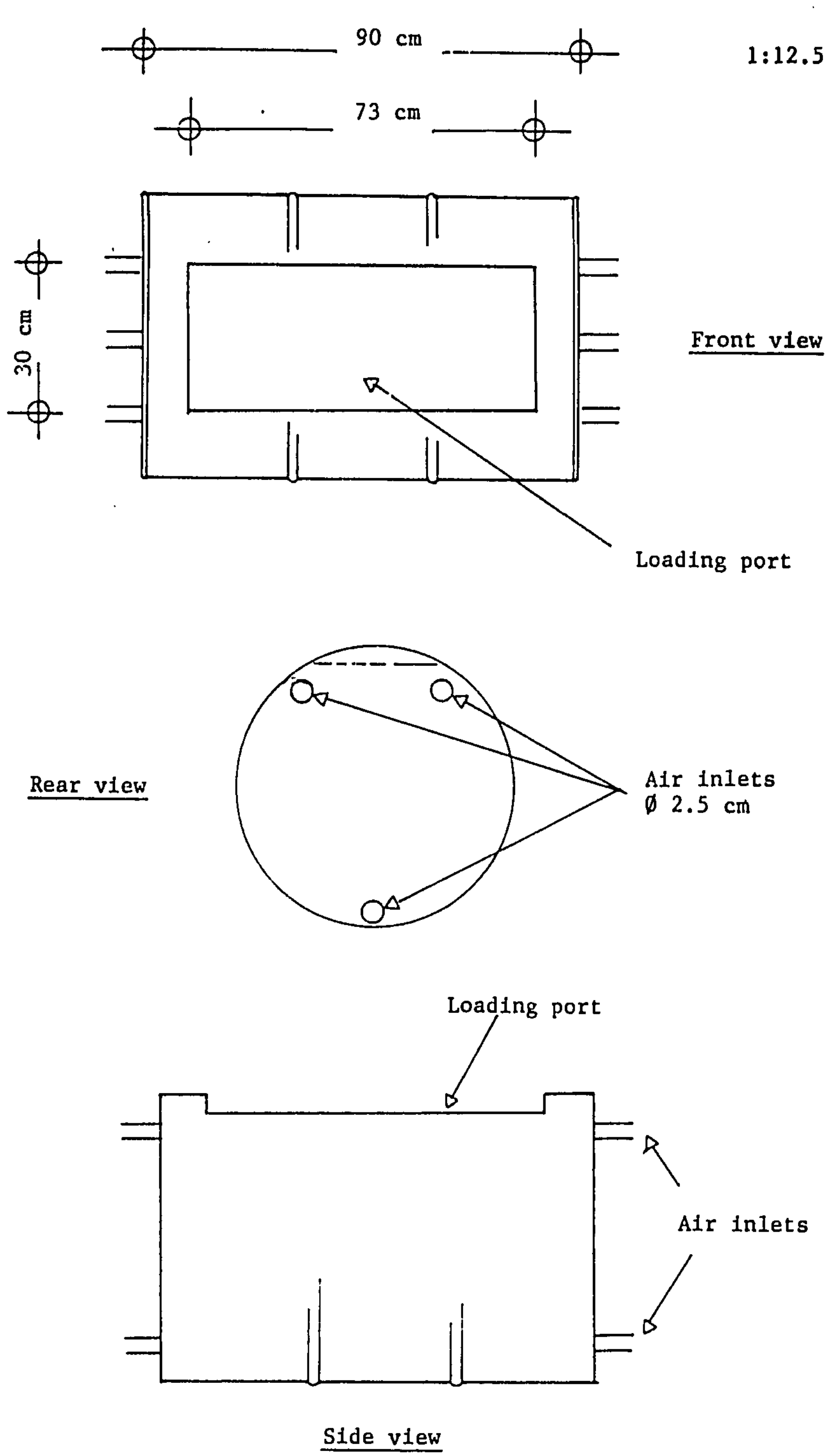


Figure 4.6 Schematic Diagram of a Tonga Kiln

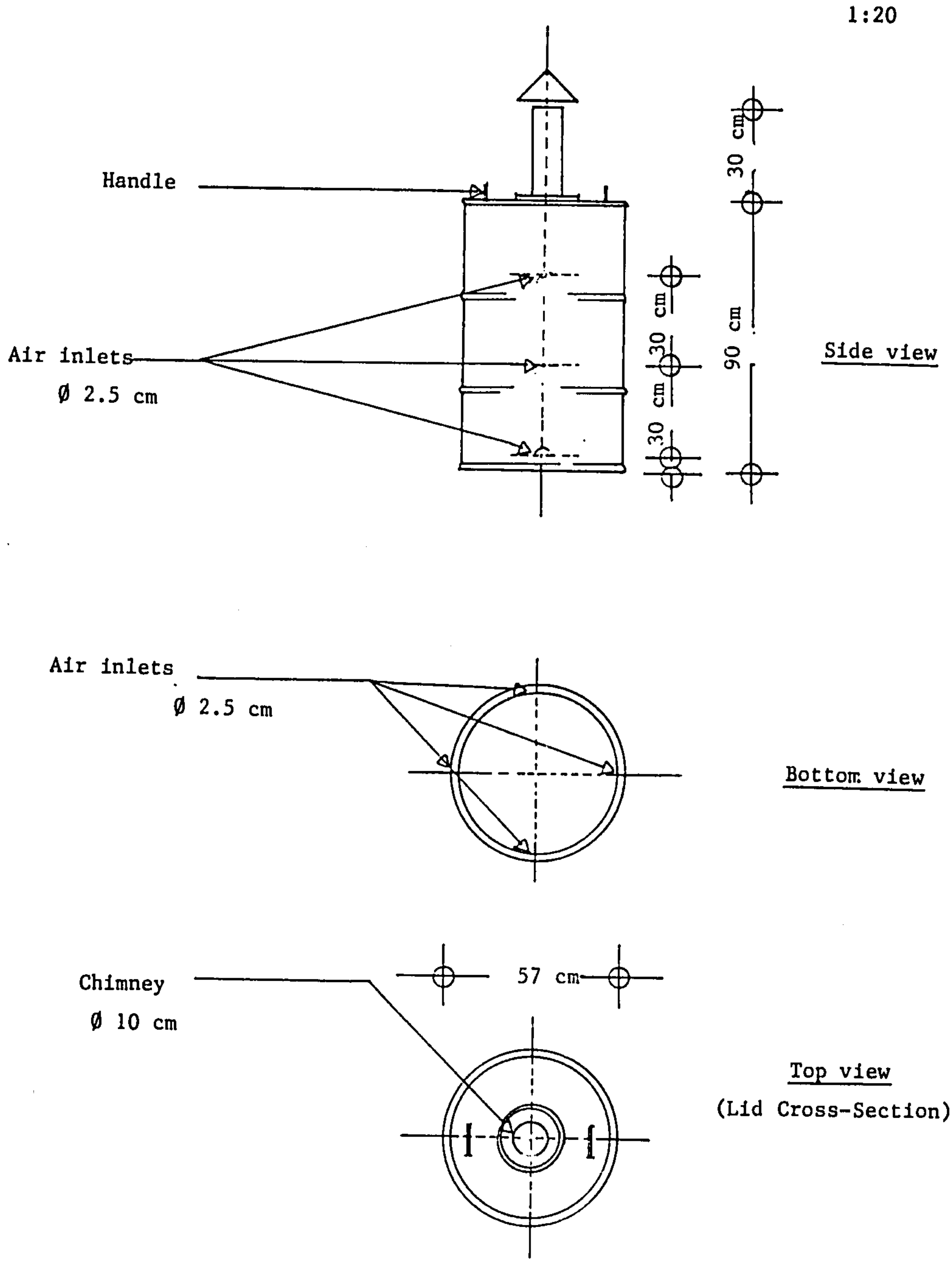


Figure 4.7 Schematic diagram of a single drum kiln

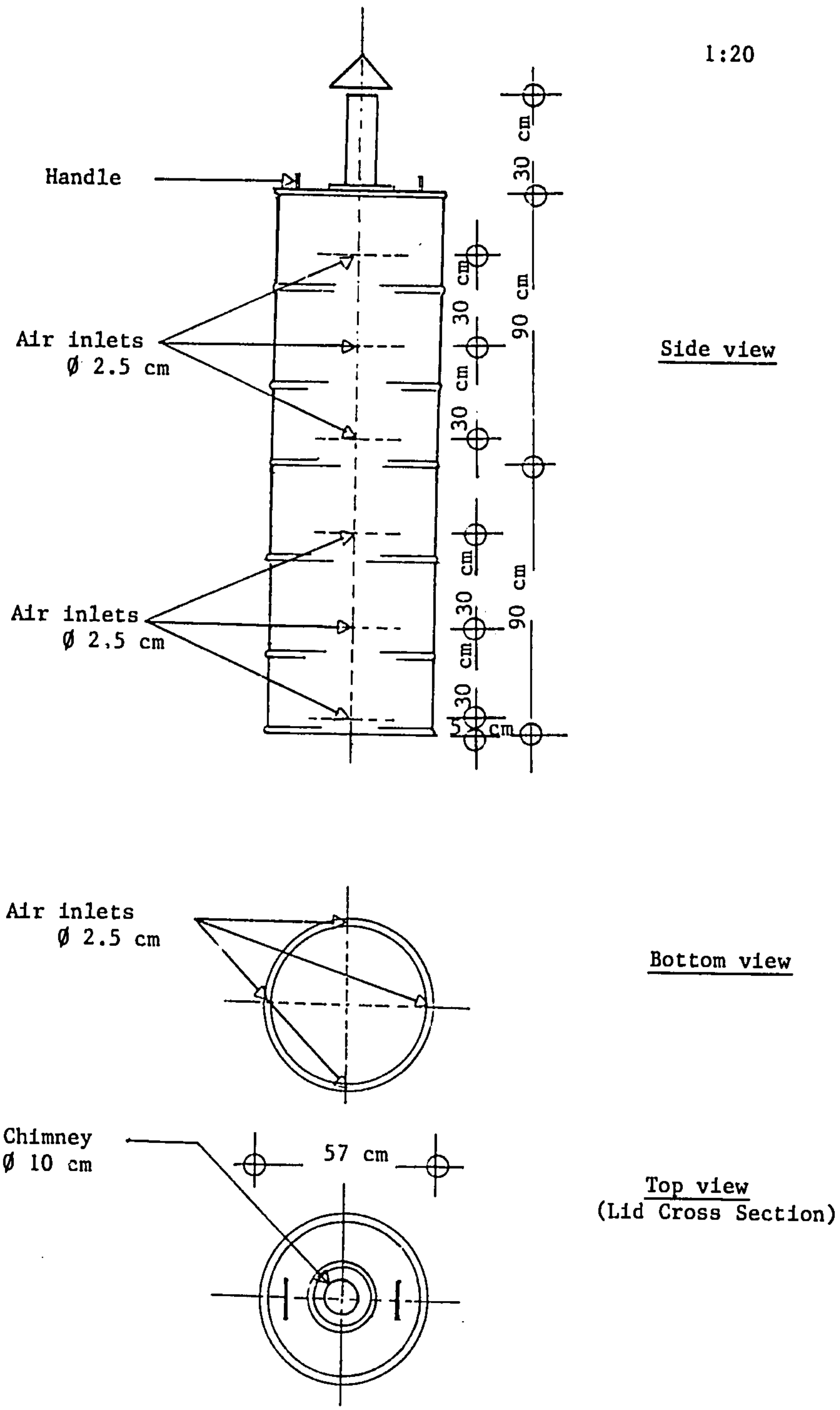


Figure 4.8 Schematic Diagram of a double drum kiln

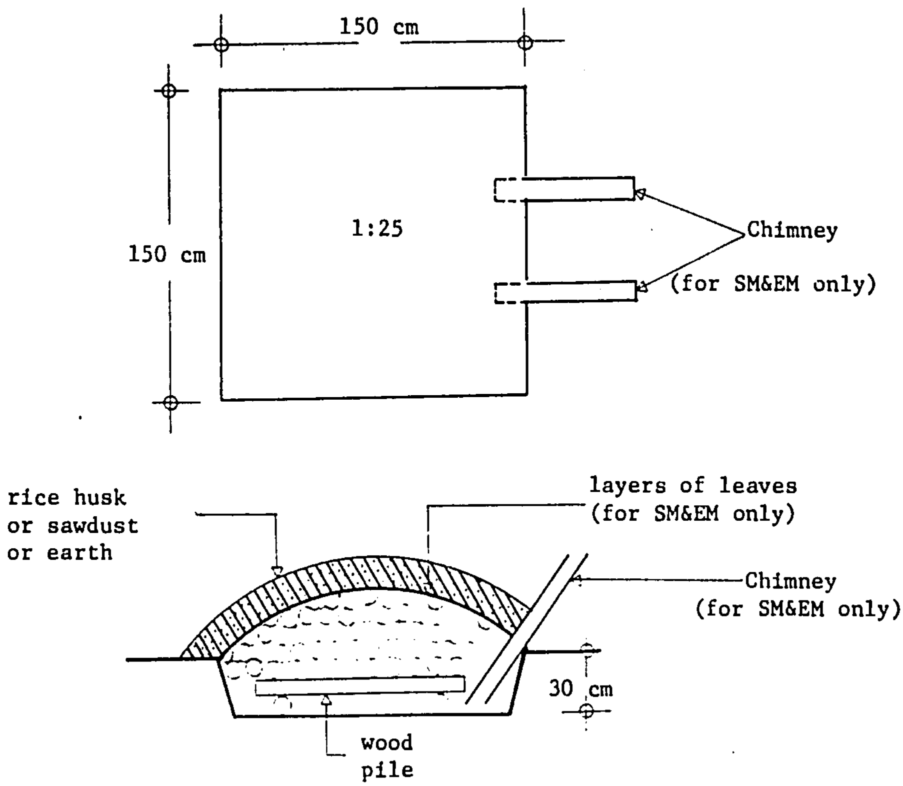


Fig. 4.9 Diagram of non-permanent kilns

Wood Preparation

The acacia wood from both Chaibadal and Pang-Asoke forest plantations was cut down to 2 m logs for seasoning (the diameters of wood from both sources were between 15 to 40 cm) and was then left in the forest plantation to dry. The moisture content of wood from Chaibadal was below 25%. This wood contained very little fungi or insects.

The amount of acacia wood used from Chaibadal was approximately 100 steres. All wood was air dried for all MV2, SD, DD, TG experiments, several experiments of BB2, MB3 and EM and a few experiments for BB1 and MB1 & 2.

The acacia wood from Pang-Asoke--approximately 150 steres--was stacked in three piles of 2 x 2 x 10 m. The wood moisture content was over 70% before stacking and then decreased as follows:

Percent wood moisture decreased	day piled
65%	30
50	60
40	90
35	120
30	150

The seasoning was done from January to May 1983 (mid-winter to mid-summer). This amount of wood was used for all experiments of firing techniques for BB2 & 3 and MB 3 & 5, and for kiln testing of BB1, BM, HT, RM, MV1 and MB 2 & 4.

The diameter of the wood used ranged from 4 to 15 cm for all brick and mud beehives, Brazilian modified and Mark V kilns. Wood with a diameter larger than 15 cm was split to a smaller size. The longest length of wood used was 1 m for the small size (diameter <10 cm) and 0.5 m for the larger size pieces. The wood for all other kilns was 3-8 cm in diameter and 0.5 m in length.

Almost all of the wood in the experiment included bark except a few samples that had been debarked. Six debarked samples were used in the small kilns <5 m^3 and nine samples were used in the larger kilns >5 m^3.

Wood Loading

In the loading of the permanent kiln, small pieces of wood were vertically piled from the kiln floor and larger pieces were piled randomly above the smaller wood and near the firing port. The wood was stacked as close as possible in order to produce more charcoal per kiln. Areas adjacent to smoke outlet holes (e.g., chimneys and accelerating holes) were left for at least a 10 x 10 cm area. The wood was loosely packed near the firing port.

Piling of wood for Mark V kilns was done horizontally as described by Earl, 1975. At the base of kiln, some space was left for air inlet and smoke outlet and for firewood to start up the kiln. The remaining wood was randomly piled--small wood was arranged near the kiln wall and the larger pieces were stacked near the center.

The loading method for other kilns was simple: additional details will be discussed in the following section.

Kiln Operation

The charcoal kilns at the Charcoal Research Center (CRC) were operated by two methods: increasing the temperature quickly and slowly at the initial (start up) period and for the remaining operation either the reverse or the direct draft was used. The quick temperature increase at the initial period was applied to all mobile and nonpermanent kilns and some permanent kilns such as hot tail, hot tail modified and Brazilian modified kilns in which the wood was fired at the beginning without controlling the air. Therefore, the moisture content of the loaded wood for such kilns must be low.

The slow, increasing temperature of the initial period was applied to the Thai classical mud and brick beehive kilns. This operation required additional firewood for heating. The firewood was combusted in the fire port and the amount of air was controlled by the accelerating hole and chimneys. The moisture content of the loaded wood could be high or low. The following paragraphs give the details of operation for such kilns.

Brick and mud beehive kilns

The operation of these kilns was slow at the beginning because the loaded wood was not combusted. The kiln temperature was initially slowly increased by the hot air from the combusting firewood in the firing port. The hot air will get into the kiln by way of the accelerating hole and chimneys replacing the cold air inside. The accelerating hole was closed when the smoke temperature was approximately 120°C so that the chimneys could fully perform their normal function thereafter.

The kiln and smoke temperatures were raised slowly until the kiln temperature reached 180-200°C. The smoke became thicker, white and smelled of acid and methanol. This phenomena revealed that the spontaneous carbonization started to take place from the front and top of the kiln. The hot air from the firing port must be terminated. The firing port was reduced to 6 x 6 cm and adjusted for proper cold air inlet by smoke observation until complete carbonization took place. This operation is called "initial firing technique" and it is generally applied to mud beehive kilns by local charcoal makers. If the hot gas from firing is continued throughout complete carbonization, the operation is called "continuous firing technique". This technique is generally applied to large, commercial brick beehive kilns by local Mangrove charcoal makers.

With both firing techniques, the kiln and smoke temperatures slowly increased.

Kiln Temp.°C	Smoke Temp.°C	Smoke Color
200-300	70	white, thick
350-400	80-90	gray
450-500	140-160	blue
>500	>160	clear

Near the end of carbonization, the smoke turned to blue indicating that the kiln temperature was greater than 450°C, and clear when the temperature was higher than 500°C. The kiln was closed after the tar was dry and hardened at the chimney outlet (tested by using a wood stick or finger to see if it would be tainted with the tar). The hardened tar might take place by polymerization of phenolics with formaldehyde that was later produced by carbonization at 400-500°C (U.S. Forest Laboratory Report, 1961).

Each chimney was closed one after another whenever the tar inside was hardened (except for the last one). The last chimney was then closed after closing the firing port for two hours in order to avoid the back pressure of hot gases which could spontaneously set fire or explode. The kiln was left for 10-12 hours and any cracking walls were sealed with slurry mud. The mud suspension (10-30% solid content) was used to bathe the kiln in order to completely seal any leaking wall and to speed up cooling the kiln. The charcoal was unloaded when the kiln temperature decreased to 70°C or less (which was approximately two days after kiln bathing). Precaution was taken when opening the kiln while charcoal was hot (near 60-70°C) by providing 2-3 buckets full of water in case the charcoal caught fire due to spontaneous combustion. The weights of lump charcoal, brands, fine (<1 cm charcoal) and ash were recorded.

Tonga

The operation of the Tonga kiln began with combustion until the combusted firewood volume was reduced to 50-70%. The drum was then turned over for carbonization. The reaction was completed when the smoke coming out of the smoke holes was clear. For additional details of operation see Agrix Publishing Corp., 1976.

Single drum and double drum kilns

The operation of single and double drum kilns began with combustion and was gradually followed by carbonization with direct draft. The fire was set at the bottom of the kiln and then the wood was loaded at the top. The kiln air inlet holes were plugged when the wood transformation into charcoal was observed at each level. The carbonization was terminated when the smoke from the chimney was clear. The cooling period of the single drum and double drum kilns were approximately six hours. More details of single and double drum kiln operation can be obtained from Agrix Publishing Corp., 1976.

Mark V kilns

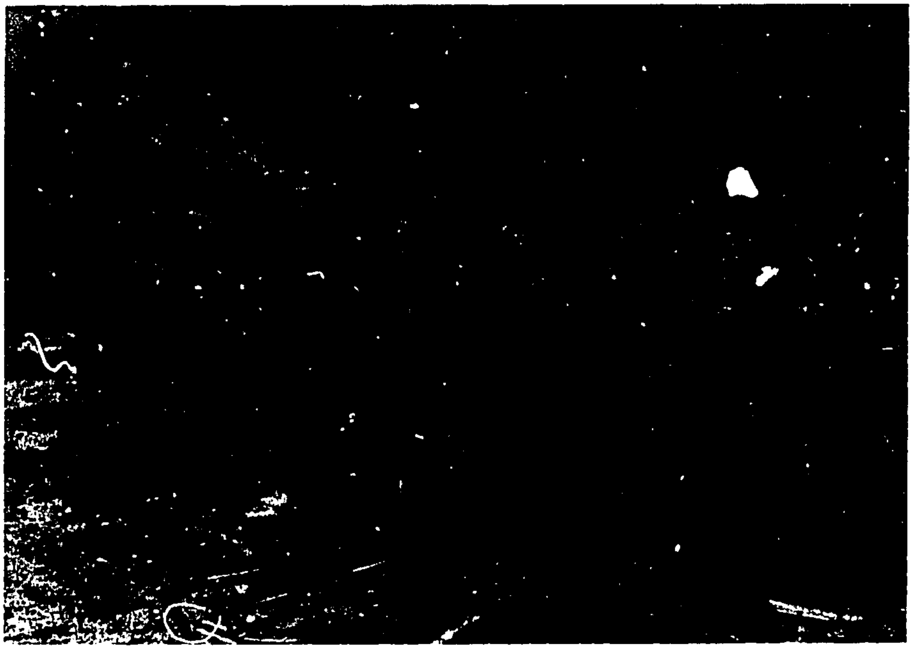
The operation of the Mark V kilns followed according to methods described by Earl, 1974, and Earl and Earl, 1975. The operation began from combusting the wood for 30 to 60 minutes. The remaining time for dehydration and carbonization was done by reversed drafts through air inlet-chimney alternations. The temperature and smoke characteristics were similar to the brick and mud beehive kiln except that the temperature was higher. The closing of the Mark V kiln was done when hardened tar appeared at the chimney ends and clear smoke was observed. The cooling period of the Mark V was normally overnight.

Rice husk mound

The fire was lit at the bottom of the wood horizontally piled by placing a small amount of firewood and dry grasses or leaves underneath the pile between the cross stickers. The whole pile of wood was allowed to burn with a completely free access of air until all of the bark was in flames. This stage took about ½ an hour. Then the whole wood pile was covered with about 6 inches of rice husk. The supply of air to the carbonization reaction was achieved through the porous nature of the rice husk. The smoke from the carbonization process also escapes through these pores. At the initial stage the rice husk pile looked wet because of wood moisture and later turned into a tarry product that was combustible. As the wood turned to charcoal, the volume of the pile decreased and the color of the smoke changed from white to blue. Finally, at the end of the carbonization process, the smoke became colorless. At this stage, the kiln was closed with a covering of soft sandy soil or a metal sheet and sealed with clay. The mound will cool in two or three days or it can be left long enough to fully cool down before opening. If the mound needs to be opened before cooling, water must be used to extinguish the fire. However, using water for retrieval causes cracking of the hot charcoal into fines and dirt which are unable to be separated from the charcoal.

During the carbonization process, care was taken not to let any opening appear in the rice husk layer. If this should happen, additional rice husk must be added to refill the hole. Also, near the end of the

Mark V kiln



Tonga kilns

Single Drum kilns

Operation of Double Drum kiln

carbonization process, tars and oils from wood and rice husk may start fires on the rice husk layer. This fire will last only few minutes, but care should be taken to keep other flammable materials away from the flame.

When the mound was opened, the lump charcoal was separated from the fines and burned rice husk by using a sieve tray. The lump charcoal was then separated from the brands before separately weighing each to determine the charcoal output yield.

Sawdust mound and earth mound

The operation of the sawdust mound and earth mound kilns was similar to the rice husk mound. After covering the whole wood pile (except one end opposite the chimney) with grass or leaves plus sawdust or earth, the fire was lit at this open end with a small amount of firewood. The layer of grass or leaves must be thick enough for preventing sawdust or earth from directly touching the pile of wood. (If this happens, a variety of brands will be produced). The pile was then allowed to burn with a completely free access of air until the bark was in flame. At this stage the flaming end was covered with grass or leaves and sawdust or earth. The reverse draft and control of the supply of air to the kiln was achieved through the chimney.

Near the end of the carbonization process, the chimney through which the red hot charcoal was observed, was removed and the hole covered with sawdust or earth. When all of the chimneys were removed, the kiln was closed in the same manner as that used in the rice husk mound method.

During the carbonization process, one could observe the color of the smoke in the same manner as was observed with the brick or mud beehive kilns. However, one of the mound's chimneys was always an air inlet port; therefore, no smoke could be observed.

The opening of the mound to collect the charcoal is done in the same manner as the rice husk method.

Trial Recovery of Charcoal Organic Chemical By-Products*

A stainless steel condenser was made downflown, about 13 feet tall (see Fig. 4.10). The vertical condenser was composed of four small tubes of ½ inch norminal inside diameter shelled by a large tube of 2½ inch norminal inside diameter. The condenser can store 11 liters of water

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* The design of the recovery system and the analysis of charcoal by-products in this report was conducted by the research team from the Department of Chemical Engineering King Mongkut Institute of Technology, Thonburi. Key persons were: Mr. George Thompson, Dr. Sakarint Phumiratana, Dr. Morakot Tantichareon and Ms. Pojanee Jongjitrat.

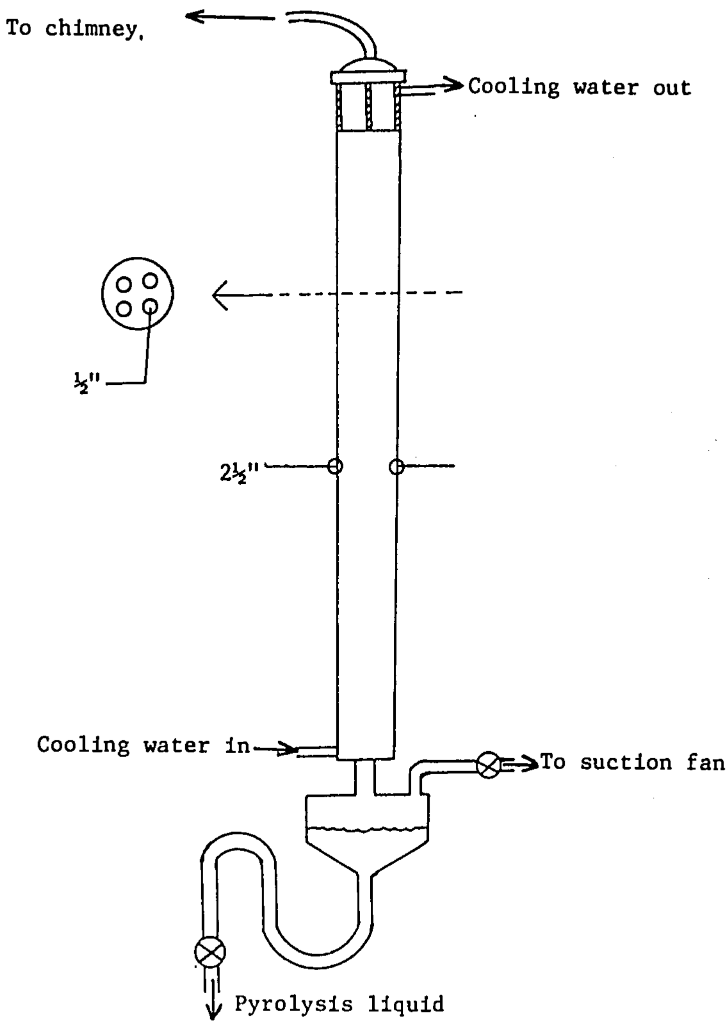


Fig. 4.10 Pyrolysis liquor collector from 2 m^2 mud and brick beehive kilns.

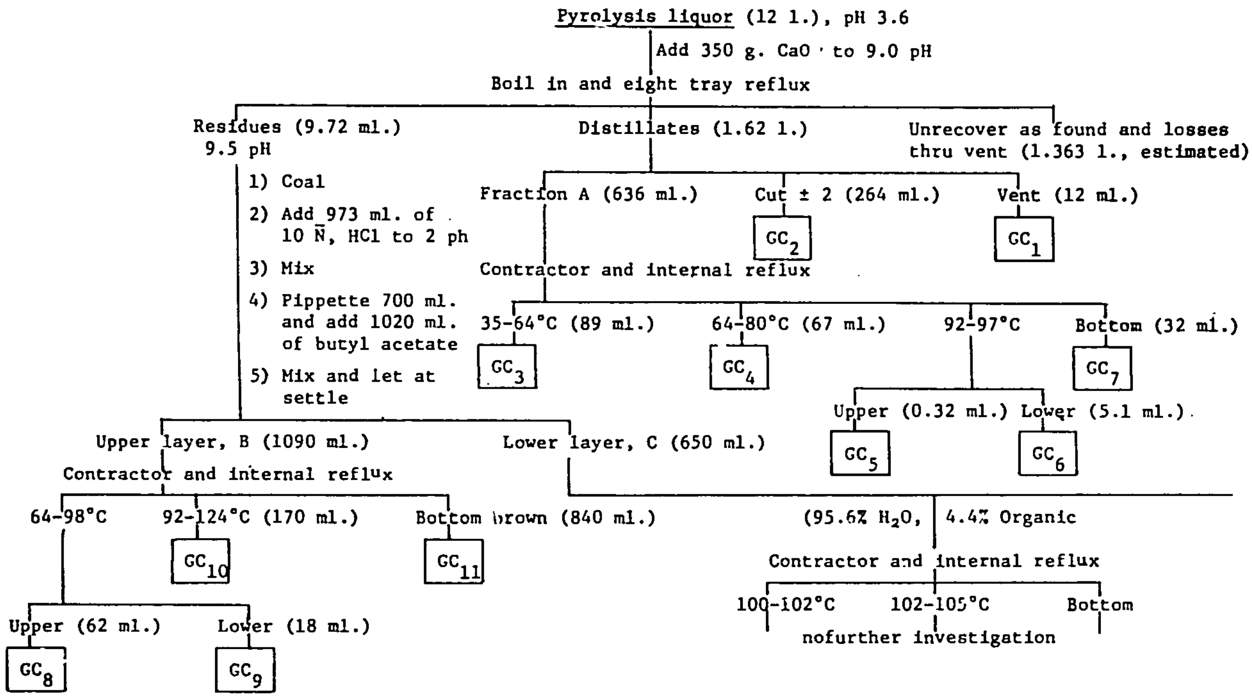


Fig. 4.11 Fractionation of pyrolysis liquor using on eight tray reflux and contractor and internal reflux (GC results, see Appendix A).

for cooling the pyrolysis vapor which was able to condense the pyrolysis liquor at the rate of 1 liter per hour from the vapor temperature of 100° to 180°C without circulating water inside the shell. At the entry end of the condenser a flexible hose was attached to the kiln'r chimney, while at the exit end a high speed suction fan and the reservoir for collecting the condensed liquid were provided.

The pyrolysis liquor had been taken from a chimney of 2 m^2 brick and mud beehive kilns. The mixed wood species of *Acacia catechu*, *Samanea saman*, *Melia azadirach* and *Leuceana Leucocephala* were loaded and the initial firing technique was applied. The pyrolysis liquor was collected after the kiln temperature was 180°C, equivalent to stack temperature of 68°C. The liquor was brought back to the KMIT laboratory for analysis.

The fractionation of pyrolysis liquor had been made by light tray reflux and a contractor and internal reflux. The method of fractionation is described in Fig. 4.11. There were eleven fractionated pyrolysis liquor samples for analyses by gas chromatography.

The gas chromatography conditions for analysis of fractionated pyrolysis liquor samples were as follows:

Column length:	2 meters
Packaging:	15% DEGS on chromasorb W
Gas carrier:	Helium
Column temperature:	Temperature program at 5°C/min from 60° to 200°C
Detector:	TCD and FID
Attenuation:	32 or 64 x 5

The identification of each gas chromatogram was made by comparative retention time with known chemicals. The peak area was measured for an amount of identified chemical.

D. CHARCOAL OUTPUT EVALUATION

The charcoal output was evaluated in terms of yield, production rate and production efficiency. This section will discuss the methods used to determine these factors.

Yield

The charcoal output yield can be evaluated either by volume or by weight of charcoal output/wood input. For large scale kilns, it is more convenient to evaluate the output yield based on volume. In this study, the evaluation was based on weight since only small and medium scale kilns were used. In addition, for scientific purposes, the only sure measurement is weight as weight accurately reflects the conversion loss through the process. The charcoal output yield can be calculated from the relation:

$$\% \text{ yield} = \frac{\text{Weight of lump charcoal output (freshly recovered)}}{\text{Oven dried weight of wood input - weight of brands}} \times 100$$

The weight of wood input (including firewood used at the firing port) is based on oven-dried weight which can be calculated from the actual weight of wood input.

$$\text{Ovendried weight of wood} = \frac{\text{weight of green wood}}{(\text{moisture content}/100) + 1}$$

In the experiment, the moisture content of green wood was determined by averaging the moisture content of at least 10 pieces of green wood selected randomly from the wood loaded.

$$\% \text{ moisture content} = \frac{\text{green wood weight - oven dried wood weight}}{\text{oven dried wood weight}} \times 100$$

Output from charcoal kilns included lump charcoal, fine and ash, and brands. The brands resulted from the incomplete conversion of wood to charcoal. Most of the brands were at the bottom end of wood standing on the kiln floor. It is assumed that the lump charcoal immediately taken from the charcoal kiln has no moisture content.

Production Rate

The charcoal output production rate can be calculated from the relation:

$$\text{Production rate, kg/hr} = \frac{\text{lump charcoal weight, kg}}{\text{total operating hour}}$$

(Note: total operating time counts from start firing until kiln closing).

Conversion Efficiency

The conversion efficiency in the production of charcoal can be calculated from the relation:

$$\% \text{ efficiency} = \frac{\text{Heat content of charcoal x weight of lump charcoal x 100}}{\text{Heat content of wood input x (weight of wood input - brands)}}$$

The determination of heat content of wood and charcoal was discussed previously.

E. CHARCOAL QUALITY EVALUATION

This section will discuss the methods by which the charcoal quality was evaluated. Sampling methods for specimens to be used in the determination of moisture content and density, proximate analyses, heat of combustion and the water boiling test will be discussed.

Sampling

In the evaluation of charcoal qualities produced from various techniques and kilns, a number of sample specimens were loaded into the kilns. Depending on the types and sizes of the kiln, the position and number of samples in each kiln are shown in Fig. 4.12. Each sample was 50 cm long and wrapped in metal screens to prevent breakage. In some cases marking of the kiln sample was made through the use of steel rings or washer tied to the sample with a steel wire. Before loading the wood samples into the kilns, a number of measurements were made which include: weight, length, and diameter.

The charcoal from each wood sample was divided into several portions for quality testing as shown in Fig. 4.13. The qualities of charcoal to be tested included moisture content, apparent density, percent fixed carbon, heat value, and charcoal use properties observed in the water boiling test.

Moisture Content and Density

The moisture content of the lump charcoal was determined by drying it in an oven at 105 ± 2°C until constant weight was obtained. Then the moisture content was calculated as follows:

$$\% \text{ moisture content} = \frac{\text{Charcoal weight - oven dried weight of charcoal}}{\text{Oven dried weight of charcoal}} \times 100$$

The density of the lump charcoal was calculated from the relation:

$$\text{Density} = \frac{\text{Charcoal oven dried weight, g}}{\text{Volume of oven dried lump charcoal, cm}^3}$$

The volume of the lump charcoal was measured by the water immersion method. To prevent water from being absorbed into the lump charcoal, it was dipped in melted paraffin. This produced a thin film coating on the lump charcoal.

Proximate Analysis

The lump charcoal was ground into powder for the determination of moisture, volatile matter, and ash content according to the method described

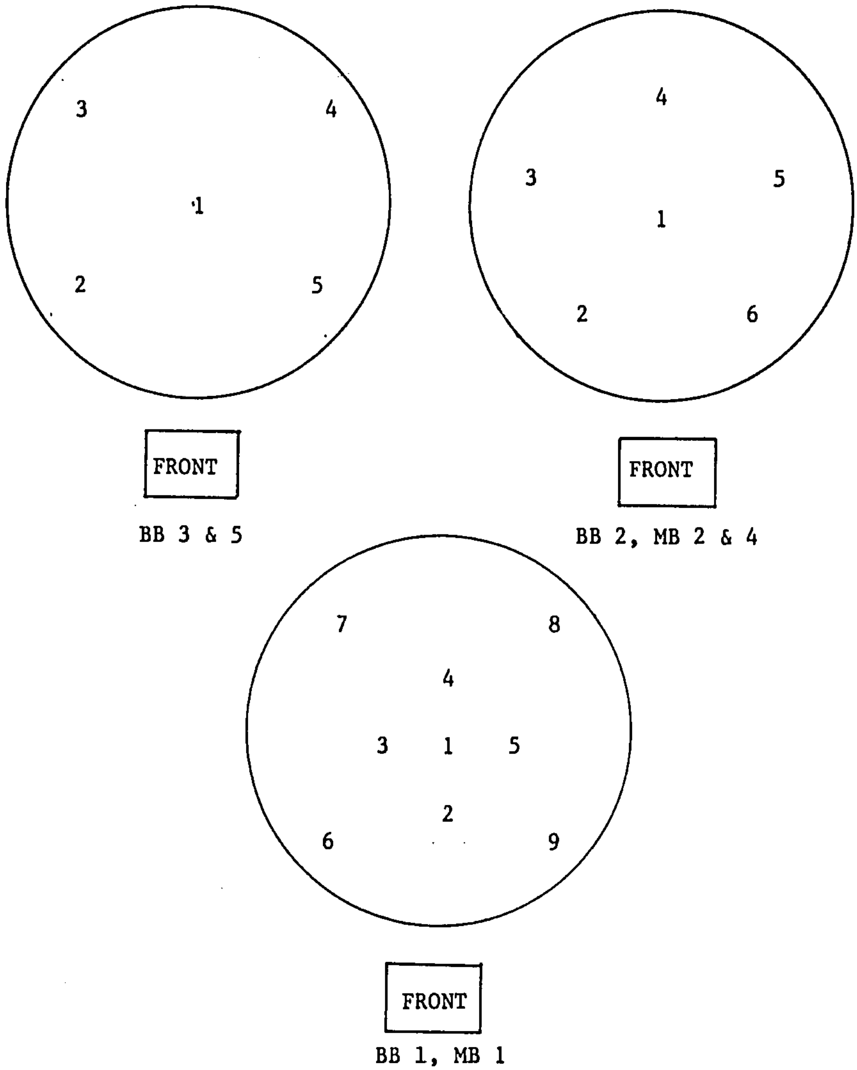


Figure 4.12 Numbers and positions of wood samples in charcoal kilns

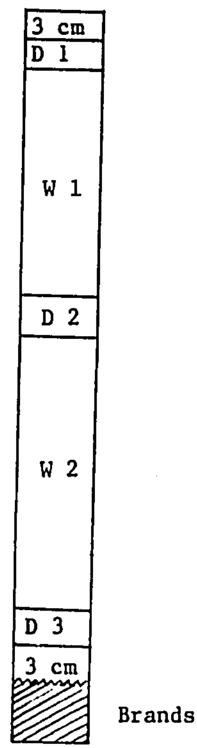
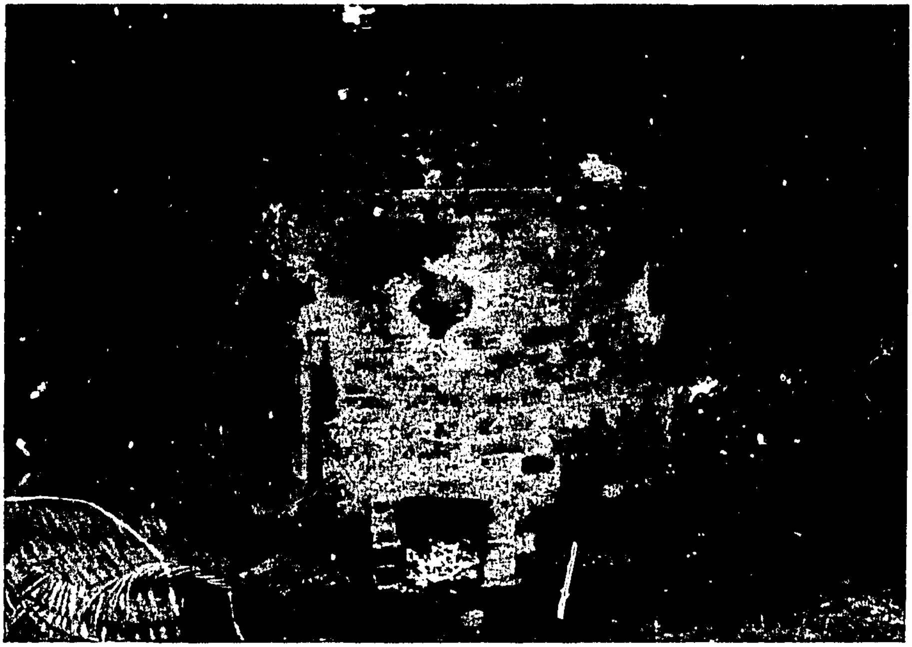


Figure 4.13 Portions of charcoal sample for quality evaluation

W 1, 2 = water boiling test

D 1, 2, 3 = moisture content, density, heat content and proximate analysis



Hot tail modified kiln

Experimenting on rice husk mound

in ASTM D 1762-64. The fixed carbon content was the amount of carbon that is not volatiled in the furnace at a temperature of 950°C for 15 minutes, less the amount of ash remaining after the charcoal was completely combusted in the furnace at a temperature of 750°C for 6 hours. Three replicates were done for each sample. The amount of fixed carbon was then calculated from the relation:

$$\% \text{ fixed carbon} = 100 - \% \text{ volatile matter} - \% \text{ ash}$$

Heat of Combustion

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

Water Boiling Test

The quality of charcoal for household cooking application was determined by water boiling tests in the same manner as reported by the Improved Stove Component under this same Project.

The lump charcoal was chopped into pieces (2-3 cm by 5-6 cm by 7-8 cm) for the water boiling test. The fines resulting from this chopping process were measured and recorded as percent fine.

Then, 400 grams of chopped lump charcoal were placed in a cooking stove of medium size with the following specifications:

Pot hole diameter	23.5	cm
Stove weight	12.8	kg
Exhaust gap	1.5	cm
Grate hole area	112	cm^2
Fuel chamber size	2,400	cm^3

The performance of this stove when operated with premium grade Mangrove charcoal is 28% heat conversion efficiency; time to boil was 19 minutes.

The charcoal was ignited with 30 grams of firewood to heat 3.7 liters of water which was contained in an aluminum pot (number 24) covered by a lid. The temperature and time were recorded until the water started to boil. Then the lid was removed and the water continued to boil for another 30 minutes. The last temperature was recorded and the amount of charcoal and water remaining were measured.

During the water boil. ıg test, fire cracking was also observed and recorded as follows:

	Score
No fire cracking	4
Minimum fire cracking (lasts only 1 minute)	3
Fire cracking lasting 2 to 3 minutes	2
Severe fire cracking longer than 5 minutes	1

Chapter 5

Results and Discussion

RESULTS AND DISCUSSION

This chapter will present the results of the charcoal survey, and discuss and analyze the results obtained from the research on charcoal output, charcoal quality, conversion efficiency, firing techniques, effect of heating rate, relationship between smoke temperature and kiln temperature, properties of the acacia wood in pyrolysis, production cost analysis and recovery of charcoal by-products.

A. CHARCOAL SURVEY

The charcoal field survey was completed in 6 months. It covered all 72 Provinces in Thailand. Information collected from each geographical region was as follows:

Central	30	samples
Eastern	15	"
Northeastern	48	"
Northern	90	"
Southern	36	"
Total	219	samples

The detailed results from this study were published in a separate report ("A Survey on Charcoal Production, Distribution, and Consumption", Royal Forest Department, August 1983) and will not be repeated here. However, the results can be summarized as follows:

On Charcoal Production

It was found out that the types of charcoal kilns used were ranked as follows: small mud beehive 37%; earth mound 36%; large brick beehive 17%; sawdust mound 8%; and Mark V 2%. The norm capacity for each type of kiln was 7-8 m^3, 3-4 m^3, 50-100 m^3, 30-35 m^3 and 3-6.5 m^3, respectively.

Wood species used included premium mangrove wood (only 10.5%), upland high density hardwoods (87.3%) and rubber wood (approximately 2%). The cost of charcoal production (including the cost of raw timber material) varied greatly and depended on the type and size of kiln and method of operation. The cost of Mangrove production was the highest at 1.71 baht/kg charcoal while the cost of upland and rubber woods were respectively 0.71 and 0.75 baht/kg -- the lowest from large brick beehive operations. All charcoal producers sampled stated that their main problem was that acquiring wood was getting more difficult and expensive.

On Charcoal Distribution

219 producers and 605 sale agents were sampled. They revealed that distribution outlets for charcoal were well established in all provinces through wholesalers, retailers, and vendors. In many cases charcoal producers also distributed the product themselves. The producer selling price at the kiln site varied depending on raw materials and charcoal quality. For example, average mangrove and upland hardwood charcoals were priced at 2.67 and 1.40 baht/kg, respectively. At the end-user side, average country retail prices of such charcoals were found to be approximately 3.26 and 2.21 baht/kg, respectively. The distribution problem most reported was the seasonal fluctuation of charcoal supply -- scarcity in the rainy season and sometimes oversupply in the dry season. Charcoal competition with government-subsidized commercial fuels, particularly LPG and electricity, was the concern of charcoal distributors.

On Charcoal Consumption

Results of the study indicated that, at present, charcoal still plays an important role. Charcoal is essential for people in rural areas and many urban suburban areas. Total charcoal consumption amounted to 3.5 million metric tons. It can be divided into three sectors: namely, household, industrial and social services. The percentage share for each sector was 91, 0.2, and 8.8, respectively.

B. CHARCOAL OUTPUT

Average experimental results of nonpermanent, mobile and permanent charcoal kilns are reported in Table 5.1, 5.2 and 5.3, respectively. *Acacia catechu* wood was used as raw material for the most of the kilns except the 7.2 m^3 mud beehive kiln and the *surveyed local charcoal* kilns (K 1-3). The selected wood species were loaded in mud beehive kiln (MB 1). One experiment was done using the acacia wood, two experiments using *Casuarina junghuniana* and three using *Leuceana leucocephala*. The mixed wood species from a dry dipterocarp forest were used for the K 1-3 kilns. The observations were made on green weight of wood load and firewood used, moisture content of wood load and firewood, operating time, kiln and smoke temperatures, weights of lump charcoal (< 2 cm size), fine, ash and brands.

According to the charcoal properties reported in the following paragraphs, lump charcoal yield is the most desirable property. However, lump charcoal production rate is also of concern because it is a factor effecting the cost of charcoal production. Therefore, both lump charcoal yield and production rate will be discussed in the following paragraphs, as well as the types and sizes of charcoal kilns.

Effect of Kiln Types

The charcoal kilns at the Charcoal Research Center could be grouped into three types, according to kiln characteristics and firing methods. These types were nonpermanent, permanent and mobile. The wood moisture content for the nonpermanent and mobile kilns was less than 25% but the permanent kilns could use wood with any moisture content with the exception of the Brazilian modified, hot tail and hot tail modified kilns. These later kilns favored rather dry wood similar to those of the nonpermanent and mobile kilns. The charcoal yield and production rate of each kiln type are discussed in the following paragraphs.

Nonpermanent kilns

The average results of lump charcoal yield from rice husk mound (RM), sawdust mound (SM) and earth mound (EM) kilns were as follows:

Kilns	Number of Test	Lump Charcoal Yield	Coefficients of Variations
Rice husk mound	7	31.6%	4.5%
Sawdust mound	5	32.8%	2.4%
Earth mound	5	31.1%	9.7%

Table 5.1 Average results of charcoal output of nonpermanent kilns

Item	Kiln Types		
	RM	SM	EM
Number of tests	7	5	5
Wood weight, kg	205.7	214.3	200
Moisture content, %	18.5	23.4	15.7
Calculated oven dried weight, kg	173.7	173.9	172.8
Operating time, hr	10.4	22.1	11.4
Max. kiln temp., °C	427.5	478.5	-
Charcoal output - lump, kg	52.9	50.6	52.9
- % yield, mean	31.6	32.8	31.1
max	33.6	33.8	35.5
min	29.3	31.9	27.3
CV, %	4.5	2.4	9.7
- % brands	3.5	11.4	1.5
Production rate, kg/hr - mean	5.1	2.3	4.6
- max	8.9	3.3	6.1
- min	3.7	1.6	4.1
- CV, %	30.9	25.8	17.6

Table 5.2 Average results of charcoal output of mobile kilns

Item	Kiln Types				
	MV1	MV2	DD	SD	TG
Number of test	2	7	3	7	6
Wood weight, kg	1,983	1,016	248.5	100	50
Moisture content, %	24.5	24.5	17.6	17.8	17.8
Calculated oven dried weight, kg	1,594	816.7	211.3	85	42.5
Operating time, hr	42	23	4	3.3	4.2
Max. kiln temp., °C	800	-	-	-	-
Max. smoke temp., °C	119	-	-	-	-
Charcoal output - lump, kg	452.3	232.6	50.1	20.4	9.4
- % yield, mean	30.4	30.6	23.9	24.2	22.7
max	31.8	33.0	25.5	29.3	25.6
min	29.1	29.0	22.8	20.0	20.5
CV, %	-	5.0	5.9	12.9	8.4
- % fine & ash	1.0	0.69	0.2	0.87	3.1
- % brands	4.7	7.0	0.8	0.86	2.4
Production rate, kg/hr - mean	10.8	10.1	12.5	5.9	2.2
- max	11.1	15.5	14.3	8.7	2.9
- min	10.5	5.9	10.7	4.2	1.7
- CV, %	-	31.1	14.4	26.2	19.3

Table 5.3 Average results of charcoal output of permanent kilns (mud beehives)

Items	Kiln types			
	MB1	MB2&4	MB3&5	K1-3*
Number of tests	6	9	27	3
Wood weight, kg	2,719	1,472	956	1,174
Moisture content, %	40.6	40.3	31.9	48.9
Calculated O.D. weight, kg	1,935	1,049	725	788
Firewood used, kg	106	100	75.8	43.8
Operating time, hr	72.3	69.8	55.0	51.0
Max kiln temp., °C	492	437	457	528
Max smoke temp., °C	138	129	163	221
Charcoal output				
- lump, kg	596.4	370.2	276.7	262.0
- % mean	32.0	37.8	37.2	31.5
- max - min	36.1-27.5	42.9-35.5	45.9-28.4	37.2-27.1
- CV, %	9.77	12.96	10.10	16.43
- % fine & ash	0.55	0.67	0.63	-
- % brands	9.35	14.7	6.58	-
Production rate, kg/hr				
- mean	7.66	5.30	5.08	5.28
- max - min	8.68-6.44	6.47-4.36	6.8-3.2	6.07-3.90
- CV, %	10.97	15.66	17.94	22.68

* local charcoal kilns - Koke Slung, Saraburi

Table 5.3 (continue) Average results of charcoal output of permanent kilns (brick beehives)

Items	Kiln types				
	BB1	BB2&3	BM	HT	MH
Number of test	3	35	2	6	3
Wood weight, kg	3,049	872.5	3,230	220.4	235.2
Moisture content, %	23.9	31.5	25.1	18.9	19.9
Calculated O.D. weight, kg	2,460	663.7	2,655	185.7	196.1
Firewood used, kg	169.4	74.5	-	-	-
Operating time, hr	88.7	49.4	85.5	8.6	21.3
Max. kiln temp., °C	442	462	423.5	-	-
Max. smoke temp., °C	173	187	176.5	-	-
Charcoal output					
- lump, kg	976.3	263.0	913.7	55.7	60.1
- % yield, mean	39.6	37.5	34.5	33.3	30.7
- max - min	41.8-35.7	43.6-32.2	35.4-33.6	35.5-31.3	32.8-29.6
- CV, %	9.64	7.16	-	5.71	5.92
- % fine & ash	1.2	0.60	2.09	1.3	1.4
- % brand	8.2	5.0	5.95	9.7	0.3
Production rate, kg/hr					
- mean	11.1	5.6	10.7	6.5	2.9
- max - min	13.3-8.2	9.2-3.0	11.5-10.0	7.96-5.64	3.51-2.33
- CV, %	23.39	27.45	-	13.94	20.42

The T-test of charcoal yield from each kiln was not significant at the 95% level of confidence. However, the maximum and minimum yield of the earth mound kiln is rather high, the coefficient of variation is 9.7%.

The lump charcoal production rates for the nonpermanent kilns are 1.6 to 8.9 kg/hr. The rice husk mound (RM) and earth mound (EM) kilns produced lump charcoal faster than the sawdust mounds (SM) but there is no difference in the production rate of the RM and EM. The maximum and minimum charcoal production rates and the coefficients of variation for the nonpermanent kilns were:

Kilns	Maximum & Minimum Charcoal Production Rate	Coefficients of Variation
Earth mound	4.1 - 6.1 kg/hr	17.6%
Sawdust mound	1.6 - 3.1 kg/hr	25.8%
Rice husk mound	3.7 - 8.9 kg/hr	30.7%

Mobile kilns

The average results of charcoal output from the big Mark V (MV 1), small Mark V (MV 2), double drum (DD), single drum (SD) and Tonga (TG) kilns are reported in Table 5.2. The average wood moisture content in all experiments of these kilns was less than 25%. The operating times ranged from 3.3 to 42 hours depending on the amount of loaded wood. Most kiln temperatures were not recorded because the experiments were completed before a pyrometer was obtained. The average percent fine and ash was one or less except the TG which was greater than 3%. The average amount of brands from all experiments was less than 5% except the MV 2 kiln which was 7%. The normal brand weight from a local charcoal maker should be less than 5% of wood load.

The average lump charcoal yields ranged from 22.7 to 30.6%. The average lump charcoal yields and the calculated coefficients of variation of the mobile kilns are summarized as follows:

Kilns	Number of Test	% Yield		Coefficients of Variation
		Average	Min - Max	
TG	6	22.7	20.5-25.6	8.4%
DD	3	23.9	20.0-29.3	5.9%
SD	7	24.2	22.8-22.5	12.9%
MV 1	2	30.4	21.9-31.8	-
MV 2	7	30.6	29.0-33.0	5.0%

The lower yields obtained from the DD, SD and TG might have been effected by wood quality. The wood quality for the TG and SD kilns was poorer than that used in the other kilns. Most of wood quality in the TG and SD kilns tested previously were obtained from the acacia limbs (branches) which contained more sapwood than heartwood; however, the loaded wood of the other kilns was taken from the stems which contained more heartwood. Another possible reason for lower productivity in the SD, DD and TG kilns is that most of the firing methods for these kilns were combustion and carbonization by direct draft process, while the firing method for the Mark V kilns started with a short period of combustion and was followed by a reversed draft process until the operation was completed. It has been confirmed that the reversed draft process is more efficient than the direct draft process.

The lump charcoal production rates from the mobile kilns were higher than the other kiln types. The average charcoal production rates and the coefficients of variation were as follows:

Kilns	Production Rate, kg/hr		Coefficients of Variation
	Average	Min - Max	
TG	4.5	1.7- 9.3	19.3%
SD	5.9	4.2- 8.7	26.2%
MV 2	10.1	5.9-15.5	31.1%
MV 1	10.8	10.5-11.1	-
DD	12.5	10.7-14.0	14.4%

The average charcoal production rates from both Mark V kilns and DD kilns were not significant, but they could produce lump charcoal faster than the SD and TG. There was no difference in charcoal production rates for the SD and TG kilns.

Permanent kilns

There were three permanent kiln groups: mud beehive (MB 1, MB 2 & 4 and MB 3 & 5), brick beehive (BB 1, BB 2 & 3) and fast pyrolysis brick beehives (BM, HT, MH) that had been constructed at the Saraburi Charcoal Research Center. The first two groups were constructed the same size or smaller than the rural charcoal kilns and the others were modified from Brazilian and Philippine designs. The wood moisture content for the mud beehive and brick beehives could vary, but in the exotic kilns, only dry wood could be used in pyrolysis. Numerous tests of the 2 m^3 mud and brick beehive kilns (MB 3 & 5 and BB 2 & 3) were done, because firing techniques and wood moisture condition effecting the charcoal yield and production rate needed to be known for promotion, extension and training. These two factors will be discussed in the following section.

The average maximum kiln temperatures from mud and brick beehive kilns were from 400° to 500°C. These carbonization temperatures provided the best charcoal yield and conversion efficiency (Bailey and Blankenhorn, 1982). The hot tail and modified hot tail kiln temperatures were not recorded.

Most permanent kilns provided appropriate amounts of fine, ash and brands. The amount of fine and ash from the mud and brick beehive kilns was less than 2%. Unfortunately, the amount of fine and ash from several experiments of the mud beehive kilns was not recorded as some ground water flooded the kiln's floor. It was noted that most of the ash taken from the fireport that was produced by combusting firewood, and the amount of fines, were mostly produced from crushed bark charcoal during the charcoal unloading.

The amount of brands from the permanent kilns was exceptable. The average percent of brands from the MB 1 and MB 2 & 4, BB 1 and HT kilns was not much greater than 5%. The usual percent of brands from local charcoal makers is less than 5%. The high percentage of brands from the mud beehive kilns of some experiments might come from the interference of ground water flooding the kiln's floor during the experiment in the rainy season.

Mud beehive kilns

The average lump charcoal yields were:

Kilns	Number of Test	Average Lump Charcoal Yield	Coefficients of Variation
MB 1	6	32.0%	9.8
MB 2 & 4	9	37.8%	13.0
MB 3 & 5	27	37.2%	10.1

Both MB 2 & 4 and MB 3 & 5 gave similar charcoal yields and they produced more charcoal than the MB 1.

The average charcoal yield from the MB 1 was low because of three important reasons:

a. High carbonization temperature caused by the unproportional design of chimneys;

b. The appearance of ground water on the kiln floor during carbonization of some experiments; and

c. Wood species.

The carbonization temperature of MB 1 in some experiments was greater than 500°C. Charcoal specimens in the laboratory could yield only 32% (Bailey and Blankenhorn, 1982). Another important factor that lowered the charcoal yield came from the interference of ground water on the kiln floor. The floor of the kiln was dug too deep and ground water dispersed on the floor during the rainy season. The flooding over the kiln floor led to over-consumption of firewood and uncertainty in determining the closing time of the kiln. These two factors could have lowered the charcoal yield. The last factor that lowered the charcoal yield was wood species. Only one-sixth of the experiments of the MB 1 were loaded with the acacia wood and the remaining experiments were loaded with *Leuceana leucocephala* and *Casuarina junghuniana*. These species provided less charcoal yield than the acacia specimens as shown in Table 5.20.

The average charcoal production rates, minimum and maximum values kg/hr and the coefficients of variation for the mud beehive kilns are listed below.

Kilns	Average Charcoal Production Rate	Minimum and Maximum Values	Coefficients of Variation
MB 3 & 5	5.03 kg/hr	3.2 - 6.8 kg/hr	17.9%
MB 2 & 4	5.30 kg/hr	4.4 - 6.5 kg/hr	15.7%
MB 1	7.66 kg/hr	6.4 - 8.7 kg/hr	11.0%

It was clear that the charcoal production rates depended on kiln size. The larger kiln produced charcoal faster than the smaller ones.

The results of lump charcoal yields and production rates from the mud beehive kilns at the Charcoal Research Center (CRC) were better than those from the local mud beehive kilns (K 1-3) nearby the Center. However, it is difficult to conclude that the CRC kiln designs are better than the local charcoal kilns because there are many variables that control the lump charcoal yields and production rates other than the kiln design, such as wood quality and operation factors. The kiln design and chimney dimension are still untested. These characteristics are very important. They can control kiln temperature that affects the lump charcoal yield and production rate.

Brick beehive kilns

There are two groups of brick beehive kilns--locally designed (slow pyrolysis) brick beehive and exotic designed (fast pyrolysis) brick beehive kilns that have been constructed at the CRC. The locally designed brick beehive kilns were constructed in two sizes, 8 m^3 (BB 1) and 2 m^3 beehive (BB 2 & 3) kilns. The exotic designed brick beehives were also constructed in two sizes, 8 m^3 for the Brazilian modified (BM), and 0.5 m^3 for the hot tail (HT) and hot tail modified (MH) kilns.

The average lump charcoal yields and coefficients of variation were summarized as follows:

Kilns	Number of Test	% Yield		Coefficients of Variation
		Average	Min - Max	
MH	3	30.7	29.6-32.8%	5.9
HT	6	33.3	31.3-35.5%	5.7
BM	2	34.5	33.6-35.4%	-
BB 2 & 3	35	37.5	32.2-43.6%	7.2
BB 1	3	39.6	35.7-41.8%	9.6

The charcoal yields of the HT and MH were less than the local brick beehive kilns for three reasons; kiln size, wall thickness and firing techniques. Both exotic kilns are at least 4 times smaller and their wall thickness was also thinner than both local brick beehive kilns. These two factors might lower the charcoal yield. The other factor that could reduce yield is the method of operation. Most of the operating time from both MH and HT was done by the direct draft process (ignition firing starts from the top) which is less efficient.

The lump charcoal production rates were:

Kilns	% Yield		Coefficients of Variation
	Average	Min - Max	
MH	2.9	2.3- 3.5	20.4
BB 2 & 3	5.6	3.0- 9.2	27.5
HT	6.5	5.6- 8.0	13.9
BM	10.7	10.0-11.5	-
BB 1	11.1	8.2-13.3	23.4

The t-test indicated that the production rate of MH was lower than that for HT, BM, and BB 1. However, the production rate of BB 2 & 3 was not significantly different from other brick beehive kilns.

The results of charcoal yield from the acacia wood in previous discussions were higher than the common wood species because the acacia heartwood consisted of an abnormal amount of condensed tannin. For example, 15% of condensed tannin was reported in the heartwood of *Acacia catachu* (Hathway, 1962). The condensed tannin provided high charcoal yields because its elementary composition consists of high carbon content as in lignin.

Effect of Kiln Size

The charcoal kilns at the Charcoal Research Center (CRC) could be divided into three sizes; a small size, 1 m^3 or less; a medium size, 1-4 m^3;and a large size, 4-10 m^3. The lump charcoal yield and production rates from each kiln size are discussed in the following paragraph.

Small charcoal kilns

The kilns that have a volume of 1 m^3 or less were RM, SM, EM, TG, SD, DD, HT and MH. The average lump charcoal yields were as follows:

Kiln	Average Lump Charcoal Yield
TG	22.7%
DD	23.0%
SD	24.2%
MH	30.7%
EM	31.1%
RM	31.6%
SM	32.8%
HT	33.3%

The t-test at the 95% confidence level revealed that the MH, EM, RM, SM and HT did not produce a different charcoal yield but they produced a higher charcoal yield than the TG, SD and DD.

The average production rates were as follows:

Kiln	Average Production Rate
TG	2.3 kg/hr
SM	2.3 kg/hr
MH	2.9 kg/hr
EM	4.6 kg/hr
RM	5.1 kg/hr
SD	5.9 kg/hr
HT	6.5 kg/hr
DD	12.5 kg/hr

Most mobile kilns produced charcoal faster than the others except the TG. The production rate of the DD was the highest, those of the RM, EM, SD and HT were intermediate, and those of the MH, TG and SM were the lowest.

Medium charcoal kilns

The medium charcoal kilns at the CRC were BB 2 & 3, MB 3 & 5, MB 2 & 4 and MV 2. The average lump charcoal yields were as follows:

Kiln	Average Lump Charcoal Yield
MV 2	30.6%
MB 3 & 5	37.2%
BB 2 & 3	37.5%
MB 2 & 4	37.8%

The t-test at the 95% confidence level revealed that the yield from the MV 2 which was the lowest was significantly different from the others.

The average production rates were as follows:

Kiln	Average Production Rate
MB 3 & 5	5.0 kg/hr
MB 2 & 4	5.3 kg/hr
BB 2 & 3	5.6 kg/hr
MV 2	10.7 kg/hr

The t-test revealed that the rate of the MV 2 was the fastest but the others were not significantly different. The MV 2 produced charcoal faster than the others because of drier wood and longer chimneys.

Large charcoal kilns

The large charcoal kilns at the CRC were MV 1, MB 1, BB 1 and BM. The BB 1 and BM provided better yield than the others. The average yields and production rates are listed below.

Kiln	Average Yield	Production Rate
MV 1	30.4%	10.8 kg/hr
MB 1	32.0%	7.7 kg/hr
BM	34.5%	10.7 kg/hr
BB 1	39.6%	11.1 kg/hr

It is very difficult to draw a conclusion from the results because of the limited number of experiments and because of some uncontrolled variables in the MB 1 experiment, such as, the wet condition of the kiln floor and use of different wood species.

C. CHARCOAL QUALITY

Chemical properties, physical properties, and use quality in water boiling tests of charcoal produced from various kilns and various firing techniques are tabulated in Table 5.4 through 5.8.

The moisture content of the lump charcoal was between 3-5%, which is acceptable for industrial usage. The apparent density of the lump charcoal from various kilns can be grouped as follows:

1. Density 0.45 g/cc (BB, MB, BM, MV 1).

2. Density between 0.40 and 0.44 g/cc (SM, EM).

3. Density between 0.35 and 0.39 g/cc (MV 2, RM, HT, MH).

4. Density 0.35 g/cc (SD, TG).

The variation of the density corresponds to the kiln type and consequently the controlling of the kiln temperature. The low densities of the charcoal from groups 3 and 4 are mainly due to high temperatures inside the kilns during operation. For these types of kilns, the controlling of the temperature was rather difficult. In addition, these types of kilns exhibited more direct process than reverse draft process during operation. The density of the charcoal from DD kiln was not measured, but it is expected that the density would have also been low. For the first two groups, the density of the charcoal was rather high. This is reasonable, since the maximum temperature of these kilns (group 1 and 2) were controlled well below 500°C. Furthermore, these kilns exhibited more reverse draft process than direct draft process during the operation. The difference in the charcoal densities of the Mark V kilns need further explanation.

The experiments on MV 2 were done early when the project started. Measuring of the kiln temperature of MV 2 was not done, and the direct draft process took place most of the operating time. As a result, the temperature might have been be too high which was reflected in the low density of the charcoal produced. Unlike MV 2, the experiments on MV 1 were done near the end of the project, where the controlling of the kiln's temperature was done carefully. For MV 1 the reverse draft process took place more than direct draft during operation.

The densities of the lump charcoal from various firing techniques conducted on the mud and brick beehives kilns were high -- as expected. The explanation is the same as that for group 1 and 2.

The average values of the results from proximate analysis and from the determination of heat content of charcoal produced from various type of kilns and firing techniques are as follows:

% Ash	2.82 ± 0.77
% Volatile matter	20.92 ± 4.21
% Fixed carbon	76.65 ± 4.61
Heat content	7439 ± 2.8 cal/g

Table 5.4 Average results of charcoal quality of large kilns

Items	Kiln types			
	MV1	BB1	MB1	BM
Chemical & physical properties:				
lump moisture content, %	3.92	3.03	3.74	4.91
lump density, g/cc	0.53	0.47	0.45	0.56
ash, %	3.80	2.50	1.94	1.62
volatile matter, %	22.96	22.61	15.59	20.35
fixed carbon, %	73.24	74.88	82.47	78.03
heat content, cal/g	7672	7365	7583	7183
Water boiling test:				
fine, %	9.26	13.05	7.52	11.40
fire cracking [1]	1.0	1.0	1.0	1.0
time to boil, min	17.1	14.1	13.2	15.6
boiling time, min [2]	21.0	21.7	19.6	16.6
last temp., °C	95	94.7	93.4	93.6
burning rate, g/min	7.85	8.92	10.14	9.97
fuel used, g	324	352	367	347
fuel remaining, g	76	48	33	53
water evaporated, g	763	862	868	706
work done, g. H_2O/g. fuel [3]	2.36	2.45	2.36	2.03
heat utilization, %	25.91	27.23	26.03	24.63

1 Fire cracking rating; 1 worst, 2 poor, 3 little, 4 none.

2 Boiling time means the time in which the water in the pot remained boiling prior to the heat energy becoming exhausted.

3 Work done means grams of water evaporated per grams of charcoal used.

Table 5.5 Average results of charcoal quality of medium kilns

Items	Kiln types			
	MV2	BB2 & 3	MB 2 & 4	MB 3 & 5
Chemical & physical properties:				
lump moisture content, %	2.34	4.02	4.40	4.35
lump density, g/cc	0.38	0.47	0.50	0.47
ash, %	2.19	2.84	1.86	2.82
volatile matter, %	27.60	23.27	30.07	20.26
fixed carbon, %	70.20	3.89	69.07	76.92
heat content, cal/g	7,250	7,519	7,545	7,340
Water boiling test:				
fine, %	9.58	10.77	10.2	10.10
fire cracking	3.0	1.0	1.0	1.0
time to boil, min	13.6	16.68	15.9	15.8
boiling time, min	26.04	24.88	24.00	22.04
last temp., °C	93.9	95.4	93.8	94.6
burning rate, g/min	8.39	7.52	7.84	8.46
fuel used, g	366	334	339	345
fuel remaining, g	34.0	64.6	61.5	54.6
water evaporated, g	900	722	676	714
work done, g.H_2O/g. fuel	2.41	2.16	2.00	2.06
heat utilization, %	27.05	24.46	27.84	24.67

Table 5.6 Average results of charcoal quality of small kilns

Items	Kiln types							
	DD	SD	TG	RM	SM	EM	HT	MH
Chemical & physical properties:								
lump moisture content, %	6.15	6.24	5.42	4.45	6.00	7.48	2.27	2.27
lump density, g/cc	-	0.29	0.30	0.39	0.40	0.43	0.35	0.37
ash, %	2.50	3.17	3.79	3.67	3.25	3.65	3.82	4.04
volatile matter, %	16.06	19.51	8.81	29.86	19.06	22.99	18.10	12.58
fixed carbon, %	81.44	77.32	87.4	66.47	77.69	73.36	78.08	83.38
heat content, cal/g	7,780	7,560	7,760	7,600	7,592	7,819	7,562	7,828
Water boiling test:								
fine, %	7.54	15.53	15.93	12.35	1.0	2.0	2.0	2.0
fire cracking	3.0	4.0	4.0	1.0	7.92	10.58	10.47	8.78
time to boil, min	14.0	14.6	15.4	14.4	1.0	2.0	2.0	2.0
boiling time, min	22.20	25.87	24.45	24.3	21.75	23.2	21.8	22.8
last temp., °C	93.3	92.4	90.8	95.1	94.0	94.0	93.9	93.8
burning rate, g/min	8.16	8.35	8.49	8.07	8.97	8.84	9.43	8.95
fuel used, g	365	375	385	340	350	350	362	358
fuel remaining, g	35.0	25.5	15.0	60.0	50	50	38	42
water evaporated, g	999	1,002	986	851	803	1,020	960	1,000
work done, g. H_2O/g. fuel	2.74	2.69	2.56	2.51	2.30	2.92	2.65	2.79
heat utilization, %	27.56	27.68	25.75	26.59	25.40	27.35	27.35	27.54

Table 5.7 Average results of charcoal quality of 2 m^3 mud beehive kiln for different firing techniques

Items	Firing techniques *					
	A	B	D	E	F	G
Chemical & physical properties:						
lump moisture content, %	3.81	5.65	3.21	4.04	4.23	4.86
lump density, g/ml	0.39	0.40	0.47	0.51	0.51	0.54
ash, %	2.36	2.20	2.49	1.29	2.93	3.16
volatile matter, %	17.96	26.58	18.04	18.52	22.58	22.48
fixed carbon, %	79.68	71.22	79.47	80.19	74.49	74.36
heat content, cal/g	7,012	7,396	7,258	7,273	7,326	7,447
Water boiling test:						
fine, %	9.78	7.91	10.90	9.58	9.17	10.16
fire cracking	1.0	3.0	1.0	1.0	2.0	1.0
time to boil, min	15.9	13.8	15.1	14.2	17.0	16.2
boiling time, min	21.2	26.5	20.7	22.6	26.4	23.4
last temp., °C	94.0	93.7	94.4	93.6	96.0	94.8
burning rate, g/min	8.69	8.19	8.89	9.12	8.66	8.17
fuel used, g	350	359	348	361	333	348
fuel remaining, g	50.5	36.3	52.5	39	67	52
water evaporated, g	731	848	744	700	618	640
work done, g.H_2O/g.fuel	2.08	2.37	2.15	1.94	1.86	1.84
heat utilization, %	28.30	26.37	28.77	26.77	26.93	26.10

* A - Dry wood, continuous firing
B - Dry wood, initial firing
C - Dry wood, continuous firing and extension of chimneys
D - Semidry wood, continuous firing
E - Green wood, continuous firing
F - Green wood, initial firing
G - Green wood, continuous firing and extension of chimneys

Table 5.8 Average results of charcoal quality of 2 m^3 brick beehive kilns for different firing techniques

Items	Firing techniques						
	A	B	C	D	E	F	G
Chemical & physical properties:							
lump moisture content, %	5.05	2.58	3.78	4.05	3.20	4.24	5.17
lump density, g/cc	0.40	0.42	0.47	0.49	0.54	0.49	0.49
ash, %	2.12	2.32	2.35	4.01	2.29	3.04	3.68
volatile matter, %	24.69	21.27	14.70	20.80	22.36	17.05	19.87
fixed carbon, %	73.20	76.41	82.95	75.19	75.35	79.91	76.45
heat content, cal/g	7,437	7,471	7,775	7,237	7,269	7,789	7,653
Water boiling test:							
fine, %	7.52	12.47	10.74	10.42	-	9.09	8.94
fire cracking	2.0	1.0	1.0	1.0	-	1.0	1.0
time to boil, min	14.2	15.2	16.8	15.4	-	16.2	18.2
boiling time, min	25.99	26.6	24.7	23.4	-	28.4	25.8
last temp., °C	89.8	95.8	95.6	95.6	-	96.4	95.2
burning rate, g/min	7.97	7.76	7.31	8.0	-	7.0	7.05
fuel used, g	351	354	326	336	-	333	334
fuel remaining, g	49.2	46.0	74.0	64.0	-	67.0	66.0
water evaporated, g	805	792	738	736	-	692	582
work done, g.H_2O/g. fuel	2.29	2.24	2.00	2.19	-	2.07	1.74
heat utilization, %	25.98	29.32	-	29.52	-	28.74	25.88

These results indicate that the qualities of charcoal produced are suitable not only for use as a household cooking fuel, but also for some industrial use. The low percentage of ash and volatile matter means that, when used, it will leave less residue and produce less smoke. The high percentage of fixed carbon content is related somewhat to the high heat content of the charcoal, which make it suitable for industrial applications. The small variation of the results among various kilns and firing techniques is rather difficult to interpret. However, this may account for the fact that the charcoal samples are rather nonhomogeneous in nature.

The results from the water boiling test of charcoal produced from various kilns and firing techniques are shown in Table 5.4 through 5.8. The results indicate that the quality of charcoal for household cooking are independent of type of kilns and firing techniques used. The average of some of the parameters are listed below:

Parameters	Average value	Standard deviation
Fine, %	10.27	2.12
Fire cracking	1.61	0.96
Time to boil, min	15.11	1.34
Burning rate, g/min	8.40	0.77
Heat utilization, %	26.81	1.39

D. CONVERSION EFFICIENCY

The lump charcoal yields and charcoal heat content and conversion efficiency of all pilot charcoal kilns are reported in Table 5.9. The permanent kilns gave the best results. The nonpermanent kilns gave moderate charcoal yield and efficiency and the mobile kilns gave the poorest results. The charcoal heat contents showed no difference and ranged from 7200 to 7800 calories per gram.

The permanent kilns provided the best results, which suggests that these kilns had the best operating performance and energy conservation. The charcoaling methods of both mud and brick beehive kilns are dry distillation processes similar to a furnace or retort. Most of the hot air generated by combusting firewood in the fire port will be sucked naturally into the kilns. The amount of hot air which relates to kiln temperature is controlled by the chimney height. The average pyrolysis temperature was from 430 to 460°C for most mud and brick beehive kilns which is an optimum temperature range for high yield and conversion efficiency (Bailey and Blankenhorn, 1982). It was also observed that only a small amount of loaded wood near the fire port in the kiln was combusted. Therefore, it is not surprising that most mud and brick beehive kilns at the Charcoal Research Center provided the highest yields and efficiency. Only the MB 1 gave a poor result due to improper kiln design and wood quality, as previously discussed.

The charcoal yields and conversion efficiency of the BM, HT and MH were less than those from the mud and local brick beehive kilns. The reasons might be the kiln characteristics and charcoaling methods. The kiln walls were about one-third thinner than those of the mud and local brick models. The heat loss of the BM, HT and MH kilns was more than the other permanent kilns. This heat loss could lower their yields and efficiencies. The other characteristic that is responsible for yield and efficiency is the kiln volume. The HT and MH are several times smaller than other permanent kilns. Therefore, the kiln characteristics such as wall thickness and volume could be a factor of lowering the charcoal yield and conversion efficiency.

The charcoaling methods of the BM, HT and MH differed from the mud and brick beehive kilns. Enough firewood inside the exotic kilns must be combusted in order to start up the reaction. During this period the direct draft process takes place. The carbonization temperature by direct draft is higher than that of reversed draft. Therefore, the charcoaling method of the BM, HT and MH could be an important factor of lowering the charcoal yield and efficiency.

The charcoal yields and conversion efficiency of the nonpermanent kilns tested at the CRC are moderate. However, these results were obtained through extensive firing experience and tight controls on the operator at the CRC; otherwise the yield could have been as low as normally found in rural practice. Both draft and heat loss of these kilns were not as good as the mud beehive and brick beehive kilns but they were better than those of mobile kilns. The lump charcoal was dirty and the carbonization was not directly controllable. The nonpermanent kilns have greater tendency to overcombust during operation.

The charcoal yields and conversion efficiency of the mobile kilns were the least for the same reasons as those of the MB, HT and MH, as discussed in the previous paragraph. The most important factor is the heat lost through the thin metal wall. The calculated heat loss from the values of thermal conductivity coefficiency, the operation time and the wall thickness of the Mark V and brick beehive wall indicated that the heat loss of prior kilns was more than 700 times greater than that of the brick beehive kilns. The other important factor is the pyrolysis temperature. The maximum temperature on one experiment of MV 1 was as high as 800°C. Therefore, heat loss and carbonization temperature are important factors of lowering yield and conversion efficiency of the mobile kilns. It should be also noted that if a lower temperature is sought for a better yield, the time required for operation will have to be prolonged.

Table 5.9 Conversion efficiency in the production of charcoal

Kiln types	% yield	Heat content* cal/g	Efficiency, % **
RM	31.6	7,601	48.5
SM	32.8	7,592	46.3
EM	31.1	7,819	50.9
MV1	30.4	7,672	47.9
MV2	30.6	7,250	43.3
DD	23.9	7,780	38.7
SD	24.2	7,560	38.0
TG	22.7	7,760	36.0
MB1	32.0	7,316	44.8
MB1&4	37.8	7,545	59.7
MB3&5	37.2	7,452	57.8
K1-3*	31.5	7,213	49.8
BB1	39.6	7,284	60.6
BB2&3	37.5	7,519	62.5
BM	34.5	7,183	55.1
HT	33.3	7,562	47.6
MH	30.7	7,828	50.3

* Heat content of acacia wood = 4,770 cal/g
except for mixed hardwoods, K1-3 = 4,564 cal/g

$$\text{** Efficiency} = \frac{\%\ \text{yield} \times \text{heat content of charcoal}}{\text{heat content of drywood raw material}}$$

Most operating times of the SD, DD and TG kilns were performed by direct combustion and direct draft. These processes are less efficient. They can raise temperature higher than the normal carbonizing temperature range. The higher the carbonized temperature, the lower the charcoal yield and conversion efficiency (Bailey and Blankenhorn, 1982). Therefore, the low charcoal yields and conversion efficiency of SD, DD and TG are caused by the important factors of combustion and direct draft during the operation.

E. FIRING TECHNIQUES AND WOOD MOISTURE CONTENT

The investigation of firing techniques was to find optimum variations for the BB 2 & 3 and MB 3 & 5 by evaluation of lump charcoal yields and properties as well as charcoal production rates and ease of operation. The variations are moisture content of wood loaded and methods of operations. The numbers of combination from both variations were divided into seven treatments which were limited by the amount of wood, raw material and experimental time available. The average results of charcoal output and quality for all treatments are revealed in Table 5.10, 5.11, 5.12 and 5.13. The summary of charcoal yield, heat of combustion and conversion efficiency is listed in Table 5.14. The typical sustained and continuous firing techniques are generally operated by local charcoal makers to commercial large brick and small mud beehive kilns, respectively. There has been no research revealing which firing technique would be better or should be recommended. The average charcoal outputs from sustained and continuous firing techniques which appear in Table 5.15 were summarized from treatments A, B, E and F of the brick and mud beehive kilns from Table 5.10 - 5.14. The t-test of two sample means between both firing techniques, using the 95% confidence level indicated that the charcoal yield and production rate as well as most charcoal quality are independent of firing techniques mentioned. The parameters of charcoal quality used in the test were moisture content, apparent density, ash content, fixed carbon content, heat of combustion and conversion efficiency.

Few works have been done on the effect of wood moisture content upon the lump charcoal yield. A few efforts reported that wood moisture content could affect the lump charcoal yields (U.S. Forest Products Laboratory, 1961; Earl, 1975; and Florestal Acesita S.A., 1982). These works investigated the charcoal yield on large scale commercial kilns. Most experiments estimated the charcoal yield by volume and used mixed wood species. The methods of carbonization differed from our system. Because of this, we decided to repeat the investigation of the role of wood moisture content to charcoal output using both brick and mud beehive kilns.

The wood moisture content in Table 5.10 and 5.11 could be divided into three conditions: dry (treatments A, B and C), semidry (treatment D) and green (treatments E, F and G) which are similar to the U.S. Forest Products Laboratory (1961). The average charcoal outputs of dry and green wood are

Table 5.10 Average test results of charcoal output of 2 m^3 brick beehive kilns using different firing techniques

Items	Firing techniques*						
	A	B	C	D	E	F	G
Number of tests	7	4	4	6	4	4	4
Wood weight, kg	756	766	848	928	967	922	944
Moisture content, %	20.4	18.0	22.1	32.3	46.4	43.2	41.6
Calculated ovendry weight, kg	628	648	695	701	660	644	668
Firewood used, kg	60	37.8	40.7	105	128	65.1	75.6
Operating time, hr	49.4	42.8	33.5	57	64.3	58.3	40.3
Max. kiln temp., °C	430	473	493	452	435	443	466
Max smoke temp., °C	190	163	212	194	179	176	188
Charcoal output							
- lump, kg	227	245	294	286	282	243	281
- %	35.1	37.5	40.2	37.2	37.5	57.0	40.9
- max - min	37.6-32.9	39.9-36.8	43.6-37.9	39.3-35.3	38.6-35.3	39.3-34.6	42.8-37.1
- CV, %	5.43	4.00	6.62	4.74	4.01	5.22	6.33
- fine & ash, %	0.7	1.0	0.7	0.5	0.5	0.5	0.8
- brand, %	6.00	5.0	0.4	4.5	4.4	7.6	7.5
Lump charcoal production							
- rate, kg/hr	4.7	5.7	8.8	5.0	4.4	4.2	7.0
- max - min	5.9-3.0	6.0-5.3	9.2-8.4	5.3-4.1	5.0-3.6	4.5-3.8	8.2-6.1
- CV, %	20.93	5.41	3.77	4.95	13.91	7.15	12.59

* See Table 5.7.

Table 5.11 Average test results of charcoal output of 2 m^3 mud beehive kilns using different firing techniques

Items	Firing techniques						
	A	B	C	D	E	F	G
Number of tests	6	5	-	6	4	4	2
Wood weight, kg	864	775	-	1017	1068	1059	1047
Moisture content, %	20.7	19.9	-	32.5	46.1	44.2	37.7
Calculated ovendry weight, kg	716	647	-	768	731	734	759
Firewood used, kg	59.5	26.2	-	108	110	65.7	87.3
Operating time, hr	49.6	47.0	-	57	65.1	63.8	52.3
Max. kiln temp, °C	468	-	-	486	479	471	532
Max. smoke temp., °C	154	-	-	186	142	166	180
Charcoal output							
- lump, kg	280	208	-	313	296	277	288
- %	39.3	32.4	-	37.0	39.8	37.2	36.7
- max - min	42.6-35.6	34.1-28.4	-	41.7-33.6	45.9-34.9	39.5-36.2	39.2-34.6
- CV, %	6.44	7.33	-	8.45	12.18	4.21	-
- fine & ash, %	0.5	0.6	-	0.6	0.8	0.6	0.8
- brand, %	8.14	4.5	-	3.3	10.7	7.0	7.2
Lump charcoal production							
- rate, kg/hr	5.7	4.4	-	5.5	4.6	4.3	6.3
- max - min	6.6-5.0	6.6-3.2	-	6.8-5.1	5.8-4.0	4.9-4.0	6.5-6.1
- CV, %	9.42	26.79	-	11.69	17.07	8.90	-

Table 5.12 Average results of charcoal quality of 2 m³ mud beehive kiln for different firing techniques

Items	Firing techniques					
	A	B	D	E	F	G
Chemical & physical properties:						
lump moisture content, %	3.81	5.65	3.21	4.04	4.23	4.86
lump density, g/cc	0.39	0.40	0.47	0.51	0.51	0.54
ash, %	2.36	2.20	2.49	1.29	2.93	3.16
volatile matter, %	17.96	26.58	18.04	18.52	22.58	22.48
fixed carbon, %	79.68	71.22	79.47	80.19	74.49	74.36
heat content, cal/g	7,012	7,396	7,258	7,273	7,326	7,447
Water boiling test:						
fine, %	9.78	7.91	10.90	9.58	9.17	10.16
fire cracking	9.4	3.0	9.4	6.2	3.6	8.7
time to boil, min	15.9	13.8	15.1	14.2	17.0	16.2
boiling time, min	21.2	26.5	20.7	22.6	26.4	23.4
last temp., °C	94.0	93.7	94.4	93.6	96.0	94.8
burning rate, g/min	8.69	8.19	8.89	9.12	8.66	8.17
fuel used, g	350	359	348	361	333	348
fuel remaining, g	50.5	36.3	52.5	39	67	52
water evaporated, g	731	848	744	700	618	640
work done, g.H_2O/g.fuel	2.08	2.37	2.15	1.94	1.86	1.84
heat utilization, %	28.30	-	28.77	26.77	26.93	26.10

Table 5.13 Average results of charcoal quality of 2 m^3 brick beehive kilns for different firing techniques

Items	Firing techniques						
	A	B	C	D	E	F	G
Chemical & physical properties:							
lump moisture content, %	5.05	2.58	3.78	4.05	3.20	4.24	5.17
lump density, g/cc	0.40	0.42	0.47	0.49	0.54	0.49	0.49
ash, %	2.12	2.32	2.35	4.01	2.29	3.04	3.68
volatile matter, %	24.69	21.27	14.70	20.80	22.36	17.05	19.87
fixed carbon, %	73.20	76.41	82.95	75.19	75.35	79.91	76.45
heat content, cal/g	7,437	7,471	7,775	7,237	7,269	7,789	7,653
Water boiling test:							
fina, %	7.52	12.47	10.74	10.42	-	9.09	8.94
fire cracking	3.2	9.6	6.5	9.2	-	6.8	6.5
time to boil, min	14.2	15.2	16.8	15.4	-	16.2	18.2
boiling time, min	25.99	26.6	24.7	23.4	-	28.4	25.8
last temp., °C	89.8	95.8	95.6	95.6	-	96.4	95.2
burning rate, g/min	7.97	7.76	7.31	8.0	-	7.0	7.05
fuel used, g	351	354	326	336	-	333	334
fuel remaining, g	49.2	46.0	74.0	64.0	-	67.0	66.0
water evaporated, g	805	792	738	736	-	692	582
work done, g.H_2O/g. fuel	2.29	2.24	2.00	2.19	-	2.07	1.74
heat utilization, %	25.98	29.32	-	29.52	-	28.74	25.88

Table 5.14 Conversion efficiency in the production of charcoal for various firing techniques

Firing techniques	% yield	Heat content cal/g	Efficiency, %
Mud beehive			
A	39.3	7,012	57.6
B*	32.5	7,396	49.8
D	37.0	7,258	62.0
E	39.8	7,273	61.7
F	37.2	7,326	58.0
G	36.7	7,447	59.2
Brick beehive			
A	35.1	7,437	56.4
B	37.5	7,471	59.2
C	40.2	7,775	69.0
D	37.2	7,237	61.9
E	37.5	7,269	65.1
F	37.0	7,789	61.6
G	40.9	7,653	67.5

* The data included the preliminary experiments.

Table 5.15 Average charcoal output from initial and continuous firing techniques

Items	Firing Technique	
	Continuous[1]	Initial [2]
Wood moisture content, %	33.4	31.3
Charcoal yield, %	37.9	36.0
Production rate, kg/hr	5.0	4.7
Charcoal quality		
Moisture content, %	4.0	4.2
Apparent density, g/cc	.46	.46
Ash content, %	2.02	2.62
Fixed carbon content, %	77.1	75.5
Heat of combustion, cal/g	7,248	7,496
Conversion efficiency, %	60.2	57.2

1 Average from treatments A and E.

2 Average from treatments B and F.

summarized in Table 5.16. The t-test at 95% confidence level between dry and green woods using treatments A, B, E and F of the mud beehive kilns and all treatments except G of the brick beehive kilns indicated that only the charcoal apparent density depended on wood moisture content. The green wood provided more dense charcoal than the dry wood. (The other factor affecting the charcoal density is the plantation site and tree age as mentioned earlier. Only dry wood for treatments A and B were taken from Chaibadal). The other charcoal output such as yield, production rate and quality were not significantly different.

The extension of the chimney height on mud beehive kilns has been made by several local charcoal makers. The advantages of chimney extension were to help the start-up and reduce the operating time. The effect of chimney extension on charcoal yield and properties was not observed. The charcoal output from treatments C and G was obtained by chimney extension prior to the carbonization temperature reaching 400°C, as mentioned previously. The average charcoal yield, production rate and conversion efficiency are greater than the normal operation such as treatments B and F. The charcoal quality from chimney extension is no different from other treatments.

F. EFFECT OF HEATING RATE

The extension of the chimneys resulted in an increase in the heating rate. The effect of the heating rate on the production of charcoal from 2 m^3 brick beehive kilns was studied. It was found that the increase in the heating rate within the temperature range of 30-400°C enhanced the charcoal output yield and production rate. This observation agreed with Beall, 1977 and Slocum, McGinnes and Beall, 1978.

Fig. 5.1 shows the rates of increases in the temperatures (measured at the center of the kiln) during carbonization process of dry wood and green wood. The heating rates measured in the temperature range of 30-400°C are tabulated in Table 5.17 together with their corresponding charcoal yield and production rate. For green wood (moisture content > 35%), the increase in the heating rate of 2.3 increased the percent yield and production rate by a factor of 1.1 and 1.6, respectively. For dry wood (moisture content < 25%), the increase in the heating rate of 1.8 increased the percent yield and production rate by a factor of 1.1 and 1.5, respectively.

This enhancement is probably due to the fact that at a higher heating rate, the kiln temperature reached optimum carbonization temperature faster ($\sim$400°C), thus reduced operating time and amount of firewood used. Furthermore, as the carbonization time is extended in normal firing, there might be some loss due to overburn of carbonized wood in some part of the kiln.

Table 5.16 Average charcoal output from drywood and greenwood

Items	Drywood[1]	Greenwood[2]
Wood moisture content, %	20.2	44.3
Charcoal yield, %	36.9	38.5
Production rate, kg/hr	5.9	4.9
Charcoal quality:		
Moisture content, %	4.2	4.2
Apparent density, g/cc	0.42	0.51
Ash content, %	2.27	2.65
Fixed carbon content, %	76.7	77.3
Heat of combustion, cal/g	7,418	7,462
Conversion efficiency, %	58.4	62.8

1 Average from treatments A, B and C of BB 2 & 3 and treatments A and B of MB 3 & 5.

2 Average from treatments E, F and G of BB 2 & 3 and treatments E and F MB 3 & 5.

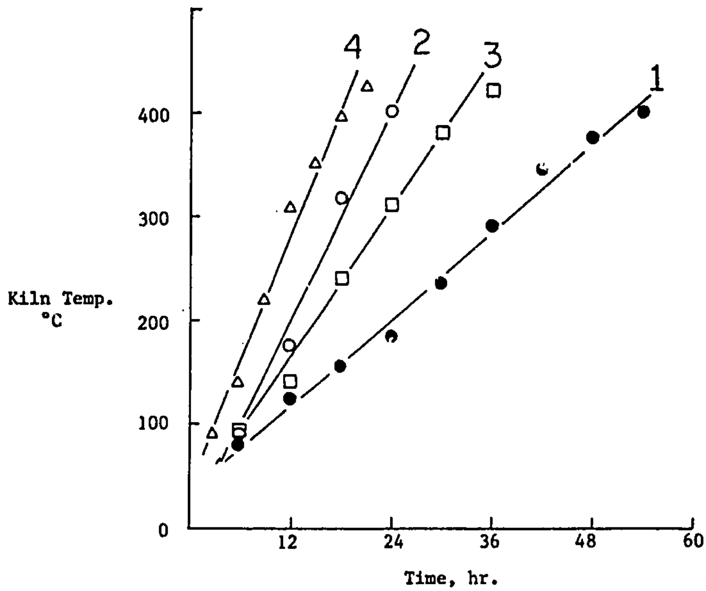


Figure 5.1 Average rates of increase in temper -- e during carbonization of *Acacia Catechu*, Willd wood from 2 m^3 brick beehive kiln.

1. Green wood
2. Green wood, chimney extended
3. Dry wood
4. Dry .ood, chimney extended

Table 5.17 Effects of heating rate on charcoal yield and production rate.

Heating rate, °C/hr	Charcoal yield, %	Production rate, kg/hr
Green wood		
1)* 6.9	37.3	4.3
2) 16.1	40.9	7.0
Dry wood		
3) 12.0	37.5	5.7
4) 21.4	40.2	8.8

*Identification numbers correspond to numbers in Figure 5.1

G. RELATIONSHIP BETWEEN KILN TEMPERATURE AND SMOKE TEMPERATURE

A typical plot of temperature profiles during the carbonization of wood from brick beehive and mud beehive kilns is shown in Fig. 5.2. The positions of the arrows indicate that the changes in smoke colors are only approximate.

In an attempt to correlate kiln temperature to smoke temperature in order to establish an inexpensive way to monitor/control the production of charcoal from a single glass rod thermometer, it was found that such a relationship is nonlinear. Fig. 5.3 shows the smoke-kiln temperatures' relation to the carbonization of *Acacia catchu Willd* wood from 2 m^3 brick beehive and mud beehive kilns. As in Fig. 5.3, the smoke temperature increases initially with the increase in the kiln temperature. As the kiln temperature reaches 200°C, the smoke temperature becomes steady around 80-90°C until the kiln temperature reaches ∿ 350°C, then the smoke temperature increases rapidly as the kiln temperature increases. The change in the smoke color was also observed around these transition temperatures, as indicated in Fig. 5.3. The constancy in the smoke temperature and the change in the smoke color can be explained in terms of the chemical constituents of the smoke.

Tillman (1981) reported that, during the carbonization of wood in the temperature range of 200-350°C, the major constituent of smoke is pyroligneous acid which is composed of acetic acid, formic acid, methanol, and water. This pyroligneous acid is responsible for the white color of the smoke. When the kiln temperature is higher than 350°C, tars start to come out, which result in the gray color of the smoke. Finally, when the kiln temperature is higher than 400°C, and all of the wood has turned into charcoal, the smoke will be composed of various gases such as CO, CO_2, CH_4 and C_2H_6, which is a bluish color and/or is transparent.

At kiln temperatures below 200°C, the relationship between smoke temperature and kiln temperature is almost linear. In this temperature range, only moisture from wood is driven off and the smoke is heating up. Later on, in the temperature range of 200-350°C, pyroligneous acid will stabilize smoke temperature. Then, above 400°C, the smoke is dried and free from both acids and moisture; as a result, the smoke temperature rises rapidly. At this smoke sharp-rise state (smoke temperature over 120°C) care must be taken to avoid the combustion of charcoal being produced inside the kiln.

H. PROPERTIES OF THE ACACIA SPECIMEN IN CARBONIZATION

The observation of physical properties of acacia wood specimens was made from both the 2 m^3 brick and mud beehive kilns. The result of wood and charcoal physical properties are reported in Table 5.18. Each test

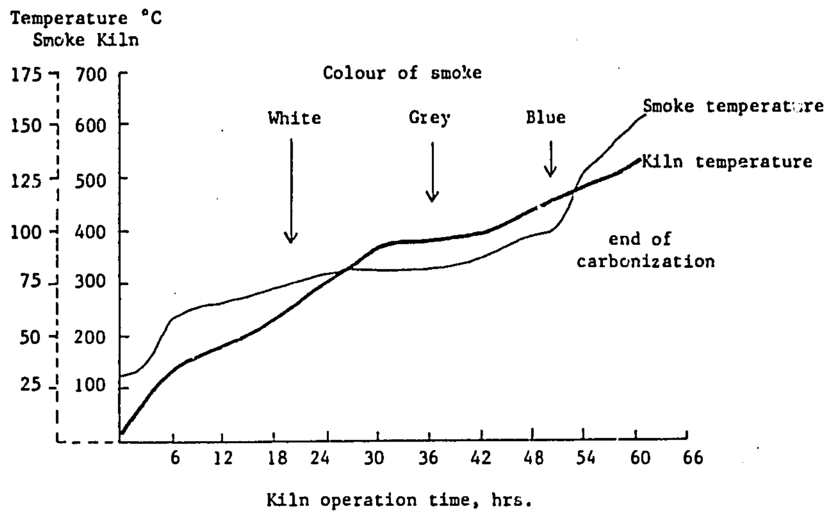


Figure 5.2 (A) Development of temperature in the mud beehive kiln (MB3)

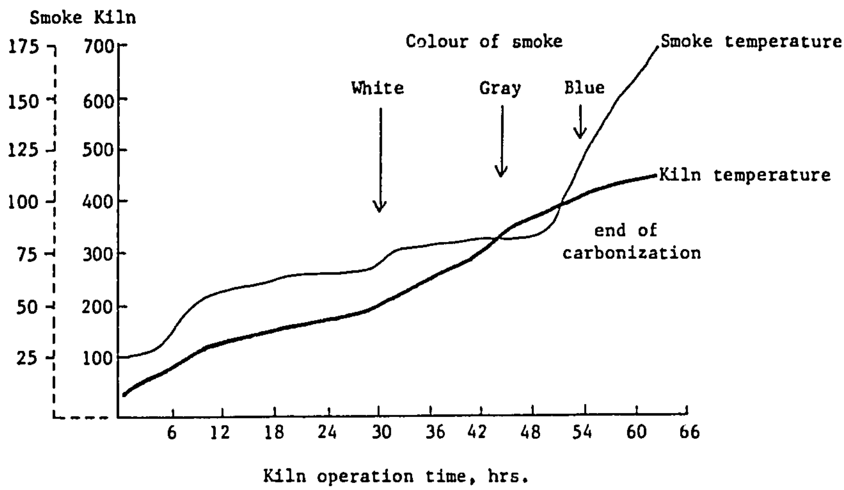


Figure 5.2 (B) Development of temperature in the brick beehive kiln (BB2)

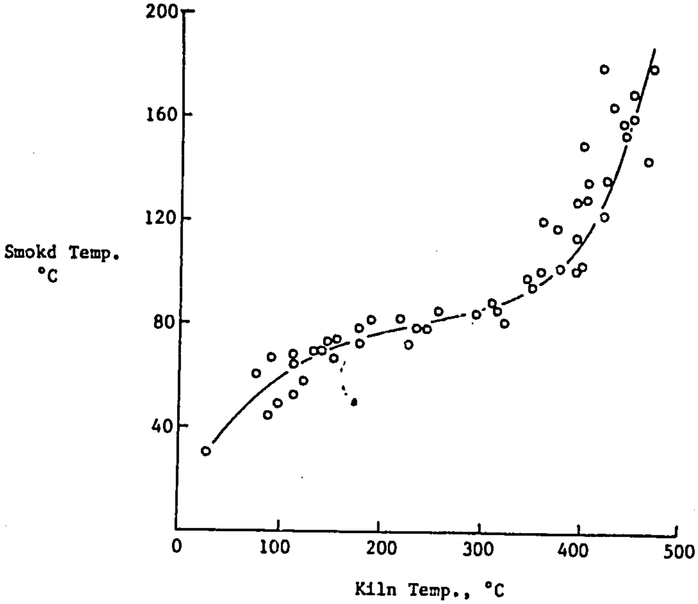


Figure 5.3 Smoke-kiln temperature relationship

Table 5.18 Average physical properties of acacia samples (no bark) in transformations of wood into charcoal by 2 m^3 brick and mud beehive kilns at three wood moisture content conditions

Items	Wood Moisture Contents (%)		
	<25	28-35	>35
No. of tests*	10	8	23
Average Wood Properties:			
Moisture content, %	18.5	30.8	46.0
Diameter, cm	10.6	10.7	11.7
Length, cm	88.6	96.3	97.5
Apparent densities, g/cm^3:			
Average	0.68	0.72	0.71
Max-Min	0.71-0.55	0.80-0.66	0.81-0.63
CV, %	13.0	9.9	6.6
Charcoal properties:			
Yield, %:			
Average	44.7	44.4	43.3
Max-Min	50-44	47-43	49-35
CV, %	7.3	2.6	6.9
Sectional shrinkages, %:			
Cross-section : Average	14.9	17.4	19.1
Max-Min	48-12	23-14	24-10
CV, %	13.5	18.1	18.4
Longitudinal-section : Average	10.1	9.90	9.81
Max-Min	14-7	1.2-6	13-7
CV	9.9	18.1	15.8
Apparent Density, g/cc: Average	0.45	0.48	0.51
Max-Min	.48-.44	.52-.43	.59-.40
CV, %	3.4	7.1	8.7
Average Heat content, cal/g	7,520	7,250	7,460

* Each test consisted of six samples that were vertically piled from the kiln floor.

consisted of 6 specimens for brick beehive kilns and 5 specimens for mud beehive kilns. All specimens were vertically piled from the kiln floor at even distribution but away from the firing port. In Table 5.18 the number of tests includes combined specimens from both kiln types. The number of tests of the brick beehive kilns were 7, 6 and 13 for wood moisture content of <25, 25-35, and >35%, respectively.

The wood moisture content, diameter and length were determined by the conventional method. The moisture content was obtained on a 5 cm thick sample of oven dried wood. The average diameter was taken from two measurements at the middle of the same sample. The apparent density was calculated based on the oven dried weight of the wood sample and its green dimension.

The apparent density of the acacia wood samples ranged from 0.55 to 0.81 g/cc. The averages were 0.68, 0.72 and 0.71 g/cc for the wood samples containing moisture contents of <25, 25-35, and >35%, respectively. The coefficients of variation of the apparent density were 15.0, 9.9 and 6.6%, respectively.

The averages, maximum-minimum and coefficients of variation of charcoal yield, shrinkages along cross-section and longitudinal sections from green wood to charcoal, charcoal apparent density and heat content are reported in Table 5.18. These properties were obtained by the following method:

$$\text{Charcoal yield} = \frac{\text{Charcoal weight}}{\text{Oven dried wood weight - Brands weight}}$$

$$\text{Shrinkages} = \frac{\text{Green wood dimension - charcoal dimension}}{\text{Charcoal dimension}}$$

Charcoal apparent density was measured by water immersion method

Charcoal heat content was measured by a bomb calorimeter

The comparison of two sample means using t-test method at 95% confidence level indicated that the wood moisture condition could not affect charcoal yield and longitudinal shrinkage but it does affect the cross sectional shrinkage. The dry wood was significantly less shrunk on a cross section than the semidry and green wood. The shrinkage of acacia wood sample from greenwood at several moisture contents to oven dried wood are reported in Table 5.19.

I. CHARCOAL FROM DIFFERENT WOOD SPECIES

The average results of charcoal output and properties from specimens of eleven wood species are reported in Table 5.20. Most of these species were tested at 6 specimens per kiln except *Peltophorum dasyrachis*. There

Table 5.19 Shrinkage along diameter of four Acacia catechu wood samples for green to oven dry wood*

% Moisture Content		% Shrinkage	
Average	Max-Min	Average	Max-Min
101	105-97	3.90	4.31-3.45
67	70-65	3.18	3.70-2.78
30	33-25	2.71	2.81-2.49

* Average diameter of green wood sample is 11.4 cm with the range from 10.2 to 13.0 cm

Table 5.20 Average results of charcoal output from samples of different wood species

Wood species	Yield (%)	Density g/cc	Fixed Carbon (%)	Volatile Matter (%)	Ash Content (%)	Heat of Combustion (Kcal/g)	Conversion Efficiency (%)
Acacia catechu	45.2	.48	75.2	20.8	4.0	7.24	63.8
Acacia auriculiformis	46.4	.41	71.1	24.0	4.9	7.47	61.6
Casuarina equisetifolia	40.6	.70	83.3	13.8	2.9	7.89	69.8
Casuarina junghuniana	38.4	.45	77.8	18.9	3.3	7.59	58.3
Combretum quadrangulare	46.5	.40	79.9	16.2	3.9	6.90	61.2
Eucalyptus camaldulensis	43.6	.42	79.8	16.7	3.5	7.35	59.1
Leuceana leucocephala	43.2	.44	78.3	18.9	2.7	7.43	65.9
Melia azedarach	43.3	.34	73.2	24.1	2.8	7.43	64.2
Peltophorum dasyrachis	52.5	.33	75.8	20.5	3.7	7.03	66.5
Rhizophora apiculata	43.8	.49	79.9	17.2	2.9	7.50	66.4
Spondias pinnata	41.5	.30	73.8	21.6	4.6	7.19	61.6

were only 4 specimens per kiln. The acacia wood sample was averaged from several experiments. The *Melia azedarach, Leuceana leucocephala, Rhizophora apiculata* and *Eucalyptus comaldulensis* wood samples were averaged from several kilns but the remaining wood species were taken from one or two kilns. Most of wood samples were pyrolyzed in the BB 2 & 3 except the samples from *Peltophorum dasyrachis* and *Acacia auriculiformis* which were obtained from the BB 1. Most species gave 40 to 45% charcoal sample yield except the samples of *Casuarina junghuniana* and *peltophorum dasyrachis*. The casuarina wood provided less charcoal yield because it was taken from juvenile wood of 3.5 years old which might not be fully mature. The peltophorum wood gave greater charcoal yield because the sample length was shorter. The normal sample length was about 80 to 110 cm but the length of the peltophorum samples were 40 to 50 cm. The shorter samples were closer to the kiln floor. This means that the peltophorum samples were pyrolyzed at lower temperature and could give higher charcoal yields, as discussed previously.

The average charcoal yield of wood samples was greater than the total charcoal yield in the same kiln, because of two reasons: a) all wood samples were stacked at the lower half of the kiln which relate to low carbonization temperatures, and b) the calculated charcoal yields from the sample did not account for the firewood used at the firing port, if any.

J PRODUCTION COST

The overall cost of charcoal production from various kilns was calculated from the weight of charcoal output, not the quality. Three parameters were considered in the analysis of production cost: raw material, depreciation and operating time. These three parameters added up to the total production cost, which was expressed in terms of baht per kilogram of charcoal produced.

Cost of Raw Material

The cost of raw material in the production of charcoal is calculated from the stacked wood volume converted into charcoal. The stacked wood volume was calculated from the following relations:

$$\text{Wood volume (in stere)} = \frac{\text{(Oven dried wt. wood input - Brands wt.) in kg}}{\text{400 kg/stere}}$$

Table 5.21 tabulates such volumes for each kiln together with the weight of charcoal output. The cost of raw materials per burn, then, can be calculated from a price at 200 Baht per stere.

Table 5.21 Quantity and characteristics of wood input and charcoal output used in the calculation of cost of raw material.

Kiln type	Wood input* kg	Brands kg	Net wood volume stere	charcoal output, kg
5-8 m^3				
BB1	2,629	216	6.0	976
MB1	2,041	181	4.7	596
BM	2,655	158	6.2	914
MV1	1,594	75	3.8	452
2-4 m^3				
BB2 & 3	738	37	1.8	263
MB3 & 5	801	53	1.9	277
MB2 & 4	1,149	169	2.5	370
MV2	817	57	1.9	233
$<$ 1 m^3				
TG	425	1	0.1	9.4
SD	85	0.7	0.2	20.9
DD	211	1.7	0.5	50.1
HT	186	15.4	0.4	55.7
HM	196	0.6	0.5	60.1
SM	174	19.8	0.4	50.6
EM	173	2.6	0.4	52.9
RM	174	6.1	0.4	52.9

*Wood input base on oven dry weight and include firewood

Cost of Investment

The cost of investment in terms of depreciation for various kilns is tabulated in Table 5.22. The life expectancy of the kilns was estimated according to Earl, 1975 and the Royal Forest Department. The life expectancy of the nonpermanent kilns (SM, EM, RM) was not considered.

The number of burns during the life expectancy of the kiln were calculated from the following relationship based on 300 working days per year:

$$\text{Number of burns} = \frac{300 \times \text{kiln life}}{\text{Operation cycle (days)}}$$

The cost of depreciation per burn was calculated from the relationship:

$$\text{Depreciation per burn} = \frac{\text{Cost of construction}}{\text{number of burns}}$$

The costs of construction of various kilns were tabulated in Table 4.1.

The interest rate used was 15% per annum. The cost of interest per burn was calculated from the relation:

$$\text{Interest per burn} = \frac{\text{Cost of construction} \times 0.15 \times \text{kiln life}}{\text{number of burns}}$$

The cost of maintenance and repair per burn was estimated and shown in Table 5.22. This can be applied only to brick and mud types of kilns. The maintenance of such kilns during each operation is to seal the loading port and the cracks on the wall of the kiln.

The total cost of investment per burn was the summation of depreciation per burn, interest per burn, and maintenance and repair per burn. From Table 5.22, it can be seen that the cost of investment per burn of the Mark V kilns is the highest, followed by the brick beehive kilns and the mud beehive kilns.

Cost of Operation

The cost of operation of each kiln in terms of labor is tabulated in Table 5.23. The labor used in the operation started from wood loading and ended with charcoal unloading. The cost of operation was based on 9 baht per man-hour. The total man-hour in the operation of each kiln indicates the ease of operation.

Table 5.22 Details in calculation of cost of investment

Kiln types	Days/Cycle	Kiln life/# burns	Depreciation per burn	Interest per burn	Maintenance & repair per burn	Total cost per burn *
5-8 m^3						
BB1	8	8/300	16.73	20.78	1.00	38.5
MB1	7	7/300	2.94	3.09	1.00	7.03
BM	8	8/300	10.51	14.43	1.00	25.94
MV1	3	3/300	50.00	22.50	-	72.50
2-4 m^3						
BB2 & 3	5	5/300	8.01	6.23	1.00	15.24
MB3 & 5	5	5/300	1.68	1.26	1.00	3.9
MB2 & 4	6	6/300	1.80	1.62	1.00	4.42
MV2	2	2/300	40.00	12.00	-	52.0
$<$ 1 m^3						
TG	1	0.3/100	3.00	0.14	-	3.14
SD	1	0.3/100	4.00	0.18	-	4.18
DD	1	0.3/100	7.00	0.32	-	7.32
HT	1	1/300	1.69	0.32	1.00	3.01
MH	7	2/300	1.69	0.63	1.00	3.32
SM		N/A	-	-	-	-
EM		N/A	-	-	-	-
RM		N/A	-	-	-	-

* in Baht

Table 5.23 Labor used in various kilns operation

Kiln types	Man-hour				Total man-hour
	Wood loading	Initial caring	Intermittant caring until closing	Charcoal unloading	
@ 5-8 m^3					
BB1 *	6	1	7	6	20
**	6	1	10	6	23
MB1 *	5	1	7	5	18
**	5	1	10	5	21
BM	6	7	6	6	25
MV1	4	1	3	4	12
@ 2-4 m^3					
BB2&3 *	3	1	2	3	9
**	3	1	3	3	10
MB3&5 *	3	1	3	3	10
**	3	1	4	3	11
MB2&4 *	4	1	4	4	13
**	4	1	6	4	15
MV2	2	1	2	2	7
@ 1 m^3					
TG,SD,DD	1	3	3	1	5
HT	1	3	2	1	7
MH	1	3	2	1	7
SM&EM	1	1	2	2	6
RM	1	1	2	2	6

* initial firing
** continuous firing

Local labor cost = 9 Baht /man-hour

Total Cost

The overall costs of charcoal production for various kilns are tabulated in Table 5.24. The cost of production per kilogram of charcoal produced indicates that the brick beehive and mud beehive kilns are lower than other types of kilns. These low production costs resulted from the high charcoal output (high yield) of such kilns.

K. RECOVERY OF CHARCOAL BY-PRODUCTS

Material Balance

The average gross composition of products in making charcoal using a 2 m^3 brick and mud beehive kiln is listed below:

Early water	=	27.2	wt.%
Early gas	=	7.3	"
Pyrolysis liquor condensed after 68°C stack temperature	=	28.2	"
Pyrolysis liquor not condensed	=	7.3	"
Visible tar	=	0.5	"
Charcoal	=	37.9	"
Total	=	108.4	wt.%

The total weight percentage of over 100% could be due to the air that was used in the process and over estimation of early gas and noncondensed fractions pyrolysis liquor.

Composition and Properties of Pyrolysis Liquor

The liquor was composed of 88.5% water, 6% acetic acid, 1.1% methanol and 4.4% other organic materials. The pH of the liquor was 3.6. The overall amount of organic chemicals was about 11.5% of the total liquor. This amount of organic chemicals in their crude and complex form might not be of commercial value at present, particularly for a small scale rural operation that would have to invest in the equipment for a recovery system and separation. Table 5.25 shows the composition of each fractionated pyrolysis liquor of 12 liters total using method described in Fig. 4.11.

Table 5.24 Overall cost of charcoal production

Kiln types	Baht/Burn			Total Cost	
	Raw material	Investment	Operation	Baht/burn	Baht/kg. charcoal
5-8 m^3					
BB1	1,206.90	38.51	207	1,452.41	1.49
MB1	930.00	7.03	162	1,099.03	1.84
BM	1,248.50	25.94	225	1,499.44	1.64
MV1	759.60	72.50	108	940.10	2.08
2-4 m^3					
BB2&3	350.65	15.24	85.5	451.39	1.72
MB3&5	374.05	3.94	94.5	472.49	1.71
MB2&4	490.05	4.42	126	620.47	1.68
MV2	379.75	52.00	63	494.75	2.13
< 1 m^3					
TG	20.75	3.14	45	68.89	7.33
SD	42.15	4.18	45	91.33	4.48
DD	104.80	7.32	45	157.12	3.14
HT	85.15	3.01	63	151.16	2.71
MH	97.75	3.32	63	164.07	2.73
SM	82.05	-	54	136.05	2.69
EM	85.10	-	54	139.1	2.63
RM	88.80	-	54	142.8	2.70

Table 5.25 Composition of fractionated pyrolysis liquor

Fraction No. **	Compositions (%)				
	Water	Methyl alcohol	Formic + butylic acid	Acetic anhydride	Unidentified
GC_1 (12 ml)	30	35	-	-	34
GC_2 (263 ml)	95	2.5	-	-	2.5
GC_3 (8.9 ml)	-	89.4	-	-	9.0
GC_4 (67 ml)	-	93.5	-	-	6.5
GC_5 (232 ml)	8.5	24.6*	-	-	70.2
GC_6 (5.1 ml)	9.0	-	-	-	89
GC_7 (323 ml)	99.5	0.1	-	-	0.3
GC_8 (62 ml)*	-	-	98.3	-	0.2
GC_9 (18 ml)	100	←----	----Trace---	-------→	-
GC_{10} (170 ml)	-	-	87.8	11.5	0.7
GC_{11} (840 ml)	-	-	88.4	6.0	3.7
Fraction C(650 ml)	95.6	-	-	-	4.4

*Unidentified peak may be composed of methyl acetone, light solvent

**See Fig. 4.11

Chapter 6

Promotion and Training

PROMOTION AND TRAINING

This Chapter reports the main activities during the last period of the project. The aim of these activities was to transfer appropriate small-scale charcoal production technology to the rural people.

A. TRAINING

Two types of training programs have been carried out:

1. A two-week intensive training courses held at the Charcoal Research Center for government rural development officials, and

2. A one-week training courses held in rural areas for village leaders, rural charcoal makers and prospective producers.

The schedule for these training programs is shown in Table 6.1. The intensive training courses consisted of lectures and experiments. The lectures covered the theory behind the process of charcoal making, the steps in constructing brick and mud beehive kilns, the steps in producing charcoal. Fast-growing tree plantation production, and forest regulation for charcoal production was also presented. The experimental parts of the training were conducted in the field to ensure that each trainee would be able to construct, operate, and maintain charcoal brick beehive and mud beehive kilns.

The one-week training courses were conducted at the village level in several parts of Thailand as shown in Table 6.1. These short course training experiences also consisted of lectures and experiments. However, these lectures covered only the basic principles of charcoal production. Emphasis was placed upon practical knowledge and the skills of construction and production of charcoal in the brick beehive and mud beehive kilns that have been found to be most suitable for rural Thailand.

At the conclusion of training, questionnaires were given to trainees. Evaluation of the training was drawn from the responses to these questionnaires (summarized in Table 6.2 and 6.3). Only 2 m^3 brick beehive and mud beehive kilns were used for training. Their responses revealed that the trainees preferred the brick beehive kiln over the mud beehive kiln (52% : 48%). The evaluation also indicated that improved charcoal production technology could be transferred with a certain degree of success.

Table 6.1 Training schedule

Date	Place	Trainee *	Number of Trainee
12-16 Dec 1983	Regional Energy Center, Maha Sarakharm	GO, VL, T	35
9-20 Jan 1984	Charcoal Research Center, Saraburi	GO, S	16
2-11 Feb 1984	Mobile Development Units of the National Security High Command, Sakon Nakhorn	GO, VL, VP, T	45
5-9 Mar 1984	Regional Energy Center, Phitsanuloke	GO, VL, VP, T	33
13-23 Mar 1984	Charcoal Research Center, Saraburi	GO	11
16-20 Apr 1984	Kho Hin Sorn Development Center, Chachengsao	GO, VL, S	36
30 Apr - 4 May 84	Ban Tha Toom School, Maha Sarakharm	GO, VL, VP, T	58
14-25 May 1984	Charcoal Research Center, Saraburi	GO	19
4-8 Jun 1984	Mobile Development Units of the National Security High Command, Nan	GO, VL, VP	54
Total			307

* GO : Government officials
VL : Village leaders
VP : Village people
T : Teachers
S : Vocational school students

Table 6.2 Experiences before training

Items	% Response	
	Average	Min - Max
Knowledge about charcoal kiln		
Brick beehive	6.2	0 - 16
Mud beehive	30.6	8 - 46
Ricehusk mound	36.6	11 - 60
None	26.6	6 - 46
Experience in kiln construction		
Yes	30.7	9 - 61
No, but have seen others	53.0	32 - 67
Not at all	16.3	5 - 27
Experience in making charcoal		
Yes	35.3	9 - 64
No, but have seen others	60.7	36 - 82
No, but have read from books	4.0	0 - 12

Table 6.3 After training evaluation

Items	% Response (average)		
	Maximum	Moderate	Minimum
Knowledge in kiln construction			
Brick beehive	46.0	50.3	3.7
Mud beehive	60.9	37.7	1.4
Knowledge in charcoal production			
Brick beehive	62.0	35.7	2.3
Mud beehive	61.7	37.3	1.0
Possibility to transfer the acquired knowledge to others	36.0	58.4	5.6

B. PUBLICATIONS

During the course of the project several documents were published. These publications included public relations documents as well as scientific reports on improved charcoal production technology.

Promotion Brochure

Two brochures were produced -- one in Thai and the other in English. These brochures contain a general introduction to the Charcoal Production Project and discuss its potential.

Training Manual

Two training manuals were prepared in Thai. The first one was used for training. This manual consists of a general introduction to the process of carbonization, kiln specification, kiln construction, and step-by-step procedures in the charcoaling process (which start at wood preparation and loading and go through charcoal unloading). The evaluation of charcoal output is also included. The second manual is more thorough -- both in its technical details and step-by-step illustrations. This second manual will be distributed to prospective charcoal-making trainees and to the public at large (through primary and secondary school systems, village councils).

Other Publications

Other publications that were produced as result of this project include:

1. *A Survey on Charcoal Production, Distribution and Consumption in Thailand,* final report was earlier submitted to NEA and USAID in 1983.

2. *Country Status Report on Charcoal Production and Technology in Thailand,* presented at FAO/ESCAP regional workshop and study tour, June 1983, Bangkok.

3. *Fuel Wood or Charcoal?* the proceedings prepared for a regional ILO/Denmark workshop and seminar on *Fuel Wood and Charcoal Preparation,* 1983, Thailand.

4. *Development and Promotion of Technology for Small-Scale Charcoal Production in Thailand,* the proceedings prepared for regional ILO/Denmark workshop and seminar on *Fuel Wood and Charcoal Preparation,* 1983, Thailand.

Lecture session during training

Field work session during training

Construction of a 2 m^3 brick beehive kiln during training

Preparation of fuel wood for loading the kiln

5. *Effect of Charcoal Kilns and Firing Techniques on the Yield and Density of Charcoal made from Acacia Wood*, the proceedings prepared for regional ILO/Denmark workshop and seminar on *Fuel Wood and Charcoal Preparation*, 1983, Thailand.

6. *Technological Improvement of Charcoal Making from Mud and Brick Beehive Kilns for Rural Areas*, paper presented at seminar on *Energy from Plants and Agricultural Waste*, August 1983, Bangkok.

7. *Charcoal Kilns for Thai Rural Areas*, paper presented at seminar on *Nonconventional Energy and its Applications*, March 1983, Thonburi.

8. *Energy from Wood: Theory of Charcoal Making*, Technical Paper No. 4, November 1983, Department of Forest Product, Kasetsart University and Forest Products Research Division, Royal Forest Department (In Thai).

9. *Relationship between Kiln Temperature and Smoke Temperature during the Carbonization Process*, presented at the 10th Meeting of the Science Society of Thailand, October, Khon Kaen.

10. *Effect of Heating Rate in The Production of Charcoal from Brick Beehive Kiln*, presented at the 10th Meeting of the Science Society of Thailand, October, Khon Kaen.

Chapter 7

Conclusions

CONCLUSIONS

The implementation of the charcoal improvement component was actually carried out for 26 months between April 1982 - June 1984. The operation can be considered highly successful in terms of the objectives and the scope of work. Conclusions concerning activities and findings can be drawn as follows:

1. The Charcoal Research Center has been successfully established to deal with charcoal improvement for rural development. The Center and the RFD Central Laboratory were well provided with scientific equipment to cope with present and future research, development and promotional training.

2. The nationwide charcoal survey (to determine the status of charcoal production, distribution, and consumption) was completed. A full, separate report was published. This survey revealed that Thailand's charcoal consumption is as high as 3 million metric tons annually with an estimated minimum market value of 4,500 million Baht per year.

3. 18 kilns of various sizes and 13 models (both local and exotic designs) were built and tested to determine their appropriateness for conditions in rural Thailand.

4. Research on various types and sizes of kilns has shown that permanent charcoal kilns provide the highest charcoal yield and conversion efficiency, especially the mud and brick beehive kilns.

5. The 2 to 8 m^3 capacities of both types of beehive kilns are more suitable for rural families and/or communal village practices when such factors as charcoal quality and quantity, ease of operation, firing duration, and capital investment are considered.

6. The moisture content of the wood had very little influence on charcoal yield and conversion efficiency, but the moisture content prolonged the operating time significantly.

7. Continuous firing "until the kiln is closed" versus "until white thick smoke appears" showed that both firing methods did not significantly affect charcoal quality or quantity.

8. Increasing of heating rate of the kiln within the temperature range of 30 - 400° C. significantly enhanced the charcoal output.

9. The extension of chimneys reduced the operating time significantly under carefully controlled conditions; i.e., the chimney should be extended until white thick smoke appears or until carbonization begins.

10. The average charcoal output of wood specimens from eleven species revealed a difference in charcoal quality and quantity. The range of both charcoal yield and conversion efficiency differences was about ten percent. However, a few species provided charcoal yields that deviated from the average.

11. The charcoal outputs within the nonpermanent kilns -- earth mound, rice husk mound and sawdust mound -- were slightly different. The operation must be done carefully to avoid overcombustion. The average charcoal yield and conversion efficiency were better than the mobile kilns.

12. Although the capital investment of the nonpermanent kilns is negligible, the cost of operation was rather high.

13. The mobile kilns such as the Mark V, Tonga, Single Drum and Double Drum are less suitable charcoal kilns for Thailand's rural people because of the high capital investment required and the poor quality of charcoal that was produced.

14. Although the production rate of the mobile kilns was the fastest, the average charcoal yield was the lowest and mobile kilns produced more fine and ash.

15. The promotion training of improved charcoal production technology (employing mostly mud and brick beehive kilns) was launched from January to June 1984. So far, three two-week intensive training courses for government rural development and NGO officials were conducted at the Center and six one-week training courses for village leaders, rural charcoal makers and prospects were conducted at the village level around the country with very close cooperation from the NEA, the Regional Energy Center and Mobile Development Units of the National Security High Command. So far, as many as 34 mud and brick beehive kilns have been built at various places during the promotion campaigns.

16. The results of training (including actual field practices as viewed by most charcoal trainees at the end of the course) indicate that the chance of acceptance of these improved technologies among rural charcoal makers is high, if wood is available. In addition, the introduction of the improved charcoal cooking stove has greatly helped them focus on production, conservation and use of charcoal.

Chapter 8

Recommendations

RECOMMENDATIONS

In implementing the Charcoal Improvement Project, a considerable investment was made both in financial and technical support. Even though the operation has attained its objectives and targets of the overall project, there still remains a great deal of future work that should be carried out within a certain time frame. The charcoal technology developed under this Project would be deemed meaningless unless it has found its place in rural areas and becomes widely practiced. In order to achieve this goal, therefore, the following recommendations are proposed:

1. Since the consumption of charcoal for cooking in Thailand is very high and effective replacement by other fuels cannot be foreseen within the next 10-15 years, government efforts should concentrate on a strategy to implement an integrated program on fuel wood production and improved charcoal making technology in rural areas. This program not only will help alleviate the future shortage of charcoal and retard the rate of importation of cooking LPG but will also create more woodlots, a better environment, and more jobs for rural people without having to rely heavily on the natural forest.

2. Information and vital data gathered during charcoal promotional training of village people, even though limited, have indicated that establishing small tree farms to make charcoal for sale can be a very good alternative for those depressed cash crop growers (who are suffering from both low product price and rapid soil depletion). However, the problem still lies with educating farmers to believe in this technology through demonstration and proof. The government, therefore, should not be reluctant to carry out trials. If proven, rural farmers can have another choice for making a living in the immediate future.

3. While keeping the production of more fuel wood from tree farming in mind, the diffusion of improved charcoal technology can be spread throughout the country through:

   a. Training of selected village leaders and rural charcoal makers in methods of making better charcoal (using locally available kilns and/or introducing kilns) with improved firing techniques as well as better fuel wood preparation prior to kilning.

   b. Charcoal Research Center initiated training of officials responsible for rural development and private interest groups on appropriate methods of charcoal making.

c. Exhibition and demonstration of efficient charcoal kilns as a follow-up program in selected villages and at the newly-established Thailand Regional Energy Centers.

d. Public compaigns for improved charcoal production methods, through manuals, pamphlets etc., to be distributed to schools, village libraries, universities and institutions responsible for rural development.

e. Creation of public awareness, particularly among charcoal consumers, on criteria for the selection of good quality charcoal and its more efficient use with better stoves.

4. Research and development activities directed toward even better technology for charcoal conversion from wood should be continued -- particularly with the popular fast growing species. In addition, the recovery of charcoal fines in large-scale commercial mangrove charcoal production and the improvement of inferior physical properties of light-weight charcoal (from rubber wood and from low-medium density fast-growing species) briquetting techniques should be pursued.

5. Charcoal is an important carbon source for numerous industrial applications such as steel smelting, calcium carbide, activated charcoal, carbon black, etc. At present, its use has been limited because of uncertainty in constant supply, difficulty in procuring charcoal in large quantities, variability in charcoal quality, and lack of appreciation or support to develop such an indigeneous renewable product. To encourage these potential applications, future charcoal research and development should be promoted -- both on various charcoal end-use specifications and standards and on charcoal derived end-products development.

ANNEX

List of Staff and Personnel for Charcoal Improvement Component

1.	Dr. Aroon Chomcharn	Component Leader, RFD
2.	Mr. Winai Punyathunya	Assistant Comp. Leader, RFD
3.	Mr. Pramook Thichakorn	Project Officer, RFD
4.	Ms. Malee Rungsrisawadh	" " RFD
5.	Mr. Chawalit Urpeepatanapong	Principal Charcoal Surveyor, RFD
6.	Mr. Songsak Vitaya-udom	" " " , RFD
7.	Mr. Somchai Pienstaporn	" " " , RFD
8.	Mr. Jerdpong Makaramanee	" " " , RFD
9.	Mr. Niwat Champathong	" " " , RFD
10.	Mr. Thawatchai Sinna	Surveyor, RFD
11.	Mr. Manoch Wong-ngern	"
12.	Mr. Rangsan Pumthongchareon	"
13.	Dr. Amnuey Korvanich	Senior Consultant, Kasetsart Univ.
14.	Dr. Preecha Kiatgrajai	Consultant, Kasetsart Univ.
15.	Dr. Somrat Yindepit	" , " "
16.	Dr. Thavorn Prakongjit	" , " "
17.	Dr. Sompetch Mongkorndin	" , " "
18.	Mr. Watcharin Nuankao	Project Researcher, Temp. Employee
19.	Ms. Natthakorn Semsantud	" " , " "
20.	Mr. Pramook Jungraksereechai	" " , " "
21.	Ms. Kevalee Musikapong	Project Coordinator, Temp. Employee

22.	Mr. Maitree Soisuwan	Skilled Worker, RFD
23.	Mr. Thongpoon Hin-gled	Worker, RFD
24.	Mr. Thongchai Jittavarangkoon	Driver, RFD
25.	Mr. Chumlaung Wanwong	Principal Charcoal Kiln Builder and Operator, Temp. Employee
26.	Mr. Jam Nomkun	Assistant Charcoal Kiln Builder and Operator, Temp. Employee
27.	Mr. Sombat Meka	" " "
28.	Ms. Silom Meka	Food Service and Cleaning

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